Education Research Highlights in Mathematics, Science and Technology 2019

Editors

Dr. Mack SHELLEY

Dr. S. Ahmet KIRAY

ISRES Publishing

Education Research Highlights in Mathematics, Science and Technology 2019

Editors

Dr. Mack SHELLEY
Dr. S. Ahmet KIRAY

ISRES
Publishing

Education Research Highlights in Mathematics, Science and Technology 2019

Editors

Dr. Mack Shelley & Dr. S.Ahmet Kiray

Cover Design and Layout

Davut Alan

This book was typeset in 10/12 pt. Calibri, Italic, Bold and Bold Italic.

Education Research Highlights in Mathematics, Science and Technology 2019
Published by ISRES Publishing, International Society for Research in Education and Science (ISRES).

Includes bibliographical references and index.

ISBN
978-605-69854-0-9

Date of Issue
December, 2019

Address
Iowa State University, 509 Ross Hall, Ames, IA 50011-1204, U.S.A.

E-mail
isresoffice@gmail.com

www.isres.org

SECTION 1: MATHEMATICS EDUCATION

2 - 16 The Secondary–Tertiary Transition in Mathematics: A Multifaceted Issue
Devon Lee Gunter

17 - 35 Conceptual Understanding and Procedural Knowledge of Fractions: How to Learn and How to Teach
Vyomesh Pant

36 - 62 Dynamic Math Teaching and Learning: Zones of Math Knowledge Creation Framework
Steven Reid

63 - 78 Mathematics Learning and Teaching in an Interdisciplinary Framework Simulating Ancient Academy
Maria Giuseppina Adesso, Roberto Capone, Oriana Fiore, Francesco Saverio Tortoriello

79 - 89 Using GeoGebra for Correction of Incorrect Premises in Geometric Proofs
Jan Frank, Lukáš Honzík

90 - 105 Enhancing Calculus in Undergraduate STEM Education with Bloom's Taxonomy
Martene L. Stanberry, Wanda R. Payne

SECTION 2: SCIENCE & ENVIRONMENTAL EDUCATION

107 - 126 Cognitive Theories of Learning on Virtual Science Laboratories
Hasan Ozgur Kapici, Hakan Akcay

127 - 143 Chemical Laboratory Safety: A Neglected Topic in Science Curriculum Design
B.H.S. Thimmappa

144 - 162 Argument Based Inquiry Approach Accompanied by Models in Primary Science Teaching
Serpil Kara, Sevgi Kingir

163- 194 Environmental Education in India: Constructing Environmental Citizens through Narratives of Optimism
Rebecca A. Johns, Rachelle Pontes

195 - 210 10 Challenges for a Future Environmental Education
Fernando Echarri, Víctor Echarri

211 - 221 An Analysis of the Impact of Forest School Provision on Early Years Foundation Stage Outcomes Using CASEY
Graham Arnold, Sara Knight

SECTION 3: EDUCATIONAL TECHNOLOGY

223 - 242 The Functions of each Discipline in STEM Practices
Rabia Nur Ondes, Engin Kursun, Alper Ciltas

243 - 253 Good Practices Using Digital Technologies in STEM Education with a Focus on Mathematics
Jenny Sendova

254 - 270 Distance Learners Expactations and Concerns about Educational Social Software
Adem Akbiyik

271 - 285 Incorporating Assistive Technology for Students with Disabilities
Muhammad Zayyad

286 - 297 Augmented Reality and Education
Fatih Serdar Yildirim

298 - 309 From TPaCK to DPaCK – Digitalization in Education Requires more than Technical Knowledge
Johannes Huwer, Thomas Irion, Sebastian Kuntze, Steffen Schaal, Christoph Thyssen

SECTION 1
MATHEMATICS EDUCATION

The Secondary–Tertiary Transition in Mathematics: A Multifaceted Issue

Devon Lee Gunter
University of Oklahoma, United States

Introduction

The discontinuities between school and university are plentiful, which is a major concern due to the growing need for a college education without regard for student preparation in secondary schools. As B. R. Clark (1960) wrote:

In American higher education the aspirations of the multitude are encouraged by "open-door" admission to public-supported colleges. The means of moving upward in status and maintaining high status now include some years in college, and a college education is a prerequisite of the better positions in business and the professions. The trend is toward an even tighter connection between higher education and higher occupations, as increased specialization and professionalization insure that more persons will need more preparations. The high-school graduate, seeing college as essential to success, will seek to enter some college, regardless of his record in high school. (p.570)

Despite the words of B. R. Clark being over fifty years old, they still ring true today. This concern is further exacerbated by the dismal 6-year U.S. four-year college and university graduation rates—around 59% for first-time, full-time students starting in 2007 and graduating by 2013 (National Center for Education Statistics, 2015).

The transition from secondary to post-secondary education is certainly a contributing factor to these issues. Beach defines transition as "a developmental change in the relation between an individual and one or more social activities. ... Transitions are consequential when ... the eventual outcome changes one's sense of self and social positioning" (2003, p. 114), and there exists a relative glut of recent research on the general issue of the transition from secondary school to university. That said, this transition is not considered a new problem; DeGuzmán, Hodgson, Robert, and Villani identify reports on this topic as far back as 1967 (1998). As might be expected, there is a great diversity in perspectives as to the cause and necessity of the gap that currently exists. In this examination of the literature, I focus on the causes and categories of problems associated with this transition, the two dominant frameworks that guide analysis of this transition (especially as they apply to the study of mathematics) as well as discuss ways in which these analyses are limited, and potential ways to mitigate the identified transition problems.

Method of Selecting Articles

Articles were first identified by searching relevant databases, namely ERIC, JSTOR, MathSciNet, EBSCOhost, and Google Scholar. A combination of descriptors and descriptor roots were used (alphabetically: gap, high school, higher ed*, math*, secondary*, school, tertiary, transition*, university) to collect articles. Each item was then subjected to an abstract analysis and, subsequently, a thorough reading with key points coded.

Studies were selected for inclusion if they met the following criteria:

1. Studies were published in peer-reviewed journals, proceedings of peer-reviewed conferences, or in any medium so long as it has been cited no fewer than 10 times, as identified in Google Scholar (so as to imply significance to the field of study despite its origins).

2. Studies were published in English or translated into English.

3. The primary focus of the studies was the transition to mathematics at the post-secondary level. Studies were considered, although none were eventually included in this review, if their focus was on the phenomenology of the transition to university, irrespective of subject.

4. Given the pace of changing policy regarding secondary education, studies were published after the year 2006, unless there was significant evidence supporting inclusion of the study (i.e.: a seminal work).

This process reduced the collection of articles to a total of 12 items.

In the spirit of completeness, additional articles were identified from discussions with other researchers. From each of these articles, a citation analysis was conducted, moving both forward and backward in time (i.e.: works cited in the identified articles as well as works citing the identified articles), with the assistance of Google Scholar. The items selected by this method were subjected to the same rigor for selection that the database-identified items were, which produced an additional 18 items, for a total of 30 items to be used in this literature review.

These articles were then subjected to a close read and open coding. The resulting codes form structure of this review.

Types of Difficulties in the Transition to Tertiary Mathematics

In the discussion of the secondary–tertiary transition, it would be remiss to not enter into a discussion of the difficulties that the transition presents to students. The work of DeGuzmán et al. (1998) is widely accepted as foundational in establishing broad, yet distinct, categories for these difficulties. As such, I have adopted their category names verbatim for the subsections and discussion presented below.

Epistemological and Cognitive Difficulties

These difficulties originate from the conceptual leap that corresponds with the transition to university mathematics (DeGuzmán et al., 1998). It is important to note that these difficulties are often misrepresented by students as the content at university being merely "more difficult" than in school (DeGuzmán et al., 1998; Hernandez-Martinez et al., 2011). Other student misconceptions that are possibly indicative of epistemological and cognitive difficulties are: the nature of mathematics ("[m]athematics is figuring out problems involving numbers"), learning approaches ("...it's only worth studying the mathematics that I know will be examined"), and instructor and course criticisms ("[t]he workload...is too heavy") (Crawford, Gordon, Nicholas, & Prosser, 1998, p. 460). In reality, the topics in post-secondary mathematics are often different and, even when they are not, they are explored with increased depth (both procedural and conceptual). High-achieving secondary students are often quite adept at performing algorithms despite lacking understanding of the concepts that govern them. These students may experience substantial difficulty in transition due to their systemically validated belief that their surface learning constitutes mathematical talent or ability (Crawford et al., 1998; DeGuzmán et al., 1998; Kajander & Lovric, 2005). Since they have been trained to reproduce mathematical information, these students often have difficulty becoming autonomous mathematical learners (Crawford et al., 1998; DeGuzmán et al., 1998). Students are encouraged to adopt these rote, surface-learning practices by the typical assessment given in secondary school, which emphasizes the ability to accurately reproduce mathematical information over the ability to reason mathematically (Taylor, 2008; Thomas & Klymchuk, 2012; Wood, 2001).

Sociological and Cultural Difficulties

While classes in secondary schools are typically modest in size, by comparison, they are often dwarfed by the size of an introductory-subject being taught at the tertiary level. This shift from being able to know most of the individuals in one's class to being an anonymous face in a sea of students can be quite the culture-shock for students in transition (Taylor, 2008). Exacerbating the stresses of the change in peer group size is the fact that peer groups at university are often poorly defined and often in flux, with students at different points in their academic progression and students with different academic interests are often thrust into the same course. This fact alone makes forming a sense of community within the classroom an elephantine challenge (DeGuzmán et al., 1998). Further, communication becomes an ever-present issue. Since lecturers, often professional researchers, may have more responsibilities outside of their classrooms than their teacher counterparts which creates an artificial barrier between the lecturer and the students. Teaching assistants are helpful, but students may not have unfettered access to them since most teaching assistants are graduate students with limited numbers of hours and myriad demands outside of their work assignment as well. Even when the directions and requests of the instructor are made explicit, they are often misinterpreted by students who are less likely to request clarification or to even participate due to the unfamiliar anonymity of the tertiary class (Kouvela, 2015).

Didactic Difficulties

Many students arrive at university not knowing "how to take notes during a lecture, how to read a textbook, how to plan for the study of a topic, which questions to ask themselves before they get asked by the teacher" (DeGuzmán et al., 1998, pp. 756–757). That is, the students enter into tertiary mathematics, unable to teach themselves. Further, a number of attitudes and beliefs affect teacher efficacy in universities. DeGuzmán et al. provide the following list of some such attitudes and beliefs:

- A lack in pedagogical and didactical abilities—the belief that all one needs in order to teach mathematics is to know and understand the subject.
- A lack of positive role models—new instructors often identify role models who are gifted researchers, but rarely does one find (or is directed to) one that is a gifted educator.
- A disregard for the importance of methodology—not sharing with students how mathematics is really done by mathematicians.
- A lack of innovation—university classrooms are still predominantly delivered exclusively via 'chalk-and-talk' lectures.
- Haphazard course design—university instructors may not give much, if any, thought to the preparation and pace of their curriculum, and even when such consideration is given, it is rarely shared with students.
- A lack of feedback procedures—lectures often operate as monologues with little to no feedback on teaching and learning from the students to the instructor.
- A lack of assessment skills—there exists a prevalence of the written exam as assessment (most distressing of which is any form that requires no human grader) with little to no consideration for possibly stronger alternate assessment strategies. (1998)

Approaches in the Literature

There are a number of beliefs about the nature of transition from school to university mathematics. The vast majority of the research acknowledges that the transition from secondary to tertiary school involves a number of changes associated with the difficulties described above. These changes include the mathematical content, the learning environment, the cognition required, and social adjustments (Hong et al., 2009; Wood, 2001). The way that the literature approaches and ranks, by importance, these changes, by-and-large, fall into one of two frameworks: the transition is qualitatively dependent on coursework and preparation (content specific transition) and the transition is a culturally constructed phenomenon (transition as a rite of passage).

Content Specific Transition Perspective

This is the belief that the secondary–tertiary transition is primarily an issue of academic preparedness and looks at the cognition required in specific courses and discusses, in-depth, the transition, as Tall (1997) puts it, as one from elementary to formal mathematics. The literature that adopts this framework, either explicitly or implicitly, attests that the one of the primary problems that students face in transition is epistemological and cognitive difficulties (DeGuzmán et al., 1998).

At school the accent is on computations and manipulation of symbols to "get an answer", using graphs to provide imagery to suggest properties. At university there is a bifurcation between technical mathematics that follows with style (with increasingly sophisticated techniques) and formal mathematics. (Tall 1997, p.1)

It is precisely this avenue of exploration of the problems students face when transitioning to formal mathematics that would eventually lead Tall to develop his theory of the Three Worlds of Advanced Mathematical Thinking (see Tall (2004)). This perspective often considers the secondary–tertiary transition as occurring starting in the last two years of secondary school and ending only when students successfully manage to move to advanced mathematical thinking; typically, this is arbitrarily set at the end of the second year of post-secondary training (see Dreyfus (1991) for a good description of what is meant here by advanced mathematical thinking as well as the chain of processes that develop it) (Tall, 1997, 2008).

There exist a great many pieces of research that turn an analytical eye toward the teaching and learning of many subjects found in lower-level undergraduate mathematics. As such, it is not appropriate to try to treat these subjects as in isolation in this review–doing so would be quite long-winded and away from the intended focus of this paper.

It is, however, important to notice that there is commonality between many of these subjects. In Analysis, "in secondary schools the focus is on the practical-theoretical blocks of concrete analysis, while at university level the focus is more on complex praxeologies of concrete analysis and on abstract analysis" (Thomas et al., 2012, p. 95). In Abstract Algebra, "students' overall problematic experience of the transition... is characterised by the strong interplay between strictly conceptual matters,... affective issues and those that are germane to the wider study skills and coping strategies that students are at university with" (Thomas et al., 2012, p. 101). In Linear Algebra, "one of the challenges of the transition from secondary algebra to university linear algebra is that the formalism obstacle appears when students work with expressions losing sight of the mathematical object that the symbols represent" (Thomas et al., 2012, p. 102). On the nature of equations, "[i]t has been recognised that many student perspectives on equations and their use of the equals sign have not mirrored those that mathematicians would like to see in tertiary students" (Godfrey & Thomas, 2008, p. 71). Each of these quotes discusses the same problem: secondary schools are not producing graduates that have the prerequisite skills in order to mitigate the epistemological and cognitive difficulties associated with transition.

Perhaps it is because of the working nature between students and university lecturers but when asked about the difficulties that their students were experiencing, most lecturers cited epistemological and cognitive difficulties, which may explain the proliferation of publications written from this perspective (Gruenwald, Klymchuk, & Jovanoski, 2004; Hong et al., 2009).

Rite of Passage Perspective

M. Clark and Lovric (2008, 2009) posit that the secondary–tertiary transition can and perhaps should be viewed from the anthropological lens as a Rite of Passage. Rites of passage are events that move an individual from a state of crisis to a return to normalcy and are separated into three distinct phases: separation, liminal, and incorporation. In the context of the secondary–tertiary mathematics transition for traditional first-year undergraduates, the separation phase occurs in that they are often physically separated from their home, family, and friends. They must also learn to shed their previous roles, thought processes, and expectations as they learn to function in their new, post-secondary setting (M. Clark & Lovric, 2008). The separation phase begins while students are still in their high school and have begun anticipating the life change ahead of them. (M. Clark & Lovric, 2009). It is at this point that the verbiage of the articles begin to differ than the explicit framework that M. Clark and Lovric have put forth. In M. Clark and Lovric (2009), it is asserted that the liminal phase occurs between the end of high school and the start of the first year at university and the incorporation phase includes roughly the first year of university. Although few authors openly invoke this framework, contextually most agree that the liminal phase does not end at the beginning of life as a university student. Rather, a more appropriate timeline, in relation to mathematics, might list the separation phase as the final year of secondary school, liminal as the time between graduation and the first several experiences with formal mathematics, and the incorporation phase may only occur by the end of undergraduate study. Of course, these timelines are of little value without agreement on the milestones of each phase. I contend that if the goal of mathematics training is, in the words of Dreyfus, to “bring our students’ mathematical thinking as close as possible to that of a working mathematician’s” (1991, p. 41), then we must consider transition the process affecting our students until they achieve Tall’s advanced mathematical thinking. This clearly makes the transition much more difficult to study as it removes the clear temporal boundaries from the rite and forces us to consider much more profoundly the cognition, metacognition, and self-efficacy our students–which are not transitioning all at the same rates. Ironically, M. Clark and Lovric (2009), which describes their timeline for transition, is the source that most openly disputes the existence of a potential set timeline:

Thus, a success in transition can tentatively be defined as accomplishing most of: individual is comfortable in her/his new role as a university student, she/he is able to achieve and work towards their goals, she/he shows good academic progress, she/he has support (both academic and otherwise), and can access it when needed, she/he enjoys mathematics courses, etc. However, students’ individual goals and expectations of tertiary education are so broad that, by itself, would render futile any attempt at defining what success in transition really is. (p.759)

The most notable difference between this perspective and the content-specific perspective presented above is that when viewed as a rite of passage, attempts to remove the difficulties of transition from secondary to tertiary mathematics are likely to be more harmful to the overall development of the students.

Due to the complications in determining which phase students may be in during their transition, I have broadly considered all publications that consider such sociological and cultural difficulties as the primary source of transition distress. The literature that adopts this framework, either explicitly or implicitly, attests that the one of the primary problems that students face in transition is sociological and cultural difficulties (DeGuzmán et al., 1998). Even with this broad inclusion, there are notably fewer articles that attempt to make use of the framework of M. Clark and Lovric (2008, 2009), which is perhaps expected given the novelty of the framework, but the framework is interesting enough to warrant close inspection, especially given its sharp contrast to the content-specific framework.

There are numerous culture differences between school and university, which is part of the reason why some researchers are suggesting that any further refining of the cut-scores in mathematics required for entry into certain classes or even certain majors are likely to not improve student outcomes (Barton, Goos, Wood, & Miskovich, 2012). That is, there must be something more to the transition than merely readiness, and that other thing must have sufficient weight to overcome unlimited academic preparation.

Hernandez-Martinez et al. (2011) found that despite the abundance of anecdotal evidence and research suggesting that transition is a problem to be overcome, students often view the change with a sense of excited optimism and are quite excited to take on the challenges that the new situation, expectations, and environment bring with them. Further, “the more severe the troubles, the more life-affirming the transition is as a record of successful growing up, in the students’ narratives” (Hernandez-Martinez et al., 2011, pp. 127–128).

A Complicated Issue

Content-specific framework views the transition as being inherently married to the course in which the student is engaged, thus the secondary–tertiary transition for a high achieving student that is taking linear algebra their first or second year is significantly different than a student taking calculus, whereas the rite of passage framework suggests that although variances occur between students, the essence of the transition transcends coursework distinctions and is influenced more by the differences in cultures (student and professional) at school and at university. Further, the content-specific framework often seeks to ‘narrow the gap’ between secondary and tertiary mathematics, while the rite of passage framework suggests that these attempts are inherently detrimental to student transition and that the pain of transition is necessary to the rite of passage itself. Of course, it is much more comfortable for mathematicians to focus on content and leave sociological and cultural difficulties to other academics to study, but doing so only reveals to us part of the story. Important lessons can be gleaned from careful examination of both the cultures on either end of the secondary–tertiary transition as well as from the content-specific skills that students have or lack entering into higher education. It is shortsighted to assume that narrowing the gap between school and university can, by itself, adequately mitigate or even remove the transition problems that many students face when entering the tertiary environment. On the other hand, the evidence is too substantial to pretend as though preparation (in school) and reasonable expectations (at university) do not have very significant impacts on this transition, as measured in performance, retention, and eventual graduation rates with respect to mathematics (see: Barnett, Sonnert, and Sadler (2014), James, Monelle, and Williams (2008), Jennings (2009), Rylands and Coady (2009)). As such, the reasonable perspective that it is a combination of both coursework (in choice, preparedness, and nature) and culture (of school, university, society, and the academy) that governs the transition process.

Recommendations

A great many of the readings used to compose this review end their work with suggestions for improving the current system. Some are in direct opposition to each other, such as the implication of Wood (2001) that universities should emulate things that work in secondary education, which goes against the suggestions put forth by M. Clark and Lovric (2008) who propose that by being different that secondary classrooms, universities are promoting changes in students that will help them be successful in formal mathematics. There are a number of areas, however, that there is general agreement between the two perspectives. Several recommendations are provided below, in no particular order.

Bridging Courses

Bridging courses in this context refers to those courses that occur after the formal end of high school but before the formal course of study at university. These courses may take the role of non-credit refresher or even remediation classes or may be for-credit (as elective) courses that serve as prerequisites to the first mathematics course required by a degree program. These courses should have targeted goals to match targeted populations. For instance, bridging courses that cater to fields that use mathematics as a service course should have emphasis on deep problem solving and procedural competence, while bridging courses that cater to fields that require formal mathematics should introduce the vocabulary, structure, and presentation of such formal mathematics–to include deductive reasoning. By separating these cohorts, universities will be better able to provide meaningful experiences for students while promoting those skills necessary for advancement in their chosen academic paths. These bridging courses should be required very early in students' course of study since "skills and attitudes [developed] in the first year can lead to more effective learning in later years" (Wood, 2001, p. 91). These courses should use non-traditional and non-contrived tasks, as such tasks may promote a transition from surface learning to deep conceptual learning (Breen, O'Shea, & Pfeiffer, 2013).

Student Support Systems

It is clear that strong student support systems are needed to assist in transition. These supports may come as individualized assistance, group tutorial sessions, workshops, reviews, self-study guides, etc. (Wood, 2001). Student help centers are highly visible outlets to provide such support (DeGuzmán et al., 1998). It is important for not just paid tutors and graduate students to provide this assistance–faculty must as well. By requiring faculty to offer regular assistance, outside and beyond "office hours," opens up communication channels with students and can begin to alleviate some of the stress caused by the change in social environments.

Open and Candid Discourse

The most common suggestion found in the literature is an increase in communication.

Typically this is described as coordination between secondary school teachers and post-secondary lecturers, but occasionally also between professionals and students. I believe whole-heartedly that the latter of these two is perhaps the more beneficial of the two.

Between Educators and Students

"Rites of passage involve situations that are clearly defined and transparent to everyone involved, so, while still in high school, students should be told (directly and in detail) about their future life as university students" (M. Clark & Lovric, 2008, p. 30). Even if one does not believe that transition should be viewed as a rite of passage, with all of the implications implicit to that perspective, it is hard to believe that being candid with students about the ways in which their lives and their study will change could be detrimental.

Between Professionals

Barton, Clark, and Sheryn (2010) describes the outcomes of a meeting between university lecturers and secondary teachers. Among the outcomes are an agreed upon need for "the means and opportunity to continue the conversation about mathematics between teachers and university lecturers" and "better information about mathematics requirements at university to people who help students make choices within school" (2010, p. 25). Di Martino and Maracci (2009) describes the results of two university preparatory courses that allowed lecturers and teachers to collaborate. Their intervention in secondary school allowed them to share materials and ideas with teachers, providing a rich dialogue between the educators. Further, lecturers often lack knowledge of what is going in in secondary schools (Gruenwald et al., 2004). This must be rectified if there is any hope of coordinating efforts to ease transition for students. One convenient place to begin these discussions is between mathematicians and pre-service secondary mathematics teacher educators within individual institutions. In this way lecturers may gain a better understanding of the realities of secondary mathematics classes as well as obtain some pedagogical training for them to exercise in their own classes.

Rigor and Expectations

Schoenfeld (1994) provides a telling vignette about when he created a problem-solving course, but his department chair did not want to allow mathematics students to receive credit for the course because it lacked what he perceived to be "content." We must rethink the desired outcomes of especially our bridging and introductory courses. It is well established that lecturers perceive that their students are entering tertiary mathematics with little more than a poorly organized catalog of procedures and a disturbing lack of conceptual understanding. Should our idea of content be fixated on large lists of reproducible procedures of little developmental value or on smaller lists of concepts of which our students have deep, meaningful, and flexible understandings? “The danger in this kind of ‘content inventory’ point of view comes from what it leaves out: the critically important point that mathematical thinking consists of a lot more than knowing facts, theorems, techniques, etc.” (Schoenfeld, 1994, p. 57). Our courses need to reflect this reality as well.

Community

Lacking in the majority of the literature is the need to establish a sense of community in transition. Rites of passage occur with cohorts of uninitiated moving through together. Although the realities of university make this difficult, it would be beneficial to encourage this behavior in tertiary mathematics, especially in first year and bridging courses. Beyond this, since rites of passage affect the whole community (M. Clark & Lovric, 2008), the reasonable analog in academia would be more mentorship by faculty members, graduate students, and more advanced peer students. Students should feel not just welcome but also involved.

Conclusion

In this review we have explored the nature of transition problems through the categorization of DeGuzmán et al. (1998), very briefly explored two dominant perspectives in the research and discussion of the secondary–tertiary transition, and offered suggestions to mitigate transition difficulties that accommodate both perspectives. Through the reading of the current literature a few questions are answered, although a great many more are made apparent. The one thing that the research does clearly illustrate is that the transition from high school to university is multifaceted and that atomistic approaches to minimize the gap between secondary and tertiary mathematics are likely to produce inadequate results–a holistic approach is required.

Although it is apparent that the study of the secondary–tertiary transition is one that has experienced tremendous research interest in the past decade, there is still much work to be done. Of the articles consulted for this review, the overwhelming majority of the research has come from Australasia, and a significant number of recent publications have been reviews of existing literature themselves. Other countries such as Ireland, the United Kingdom, the United States of America, and Canada are represented in the reading by no more than two articles each. This constitutes a glaring hole in the literature. Without in-depth comparisons of the secondary and tertiary mathematics standards and norms (not to mention the cultural norms surrounding education itself), one must be very cautious to accept that the findings in, for instance, Auckland, New Zealand have parallels in Boston, USA. I cannot strongly enough recommend such a study as a course for future research.

Also, the frameworks with which the epistemological and cognitive difficulties have been analyzed are quite robust and frameworks for examination of the sociological and cultural difficulties are being refined. However, there is currently little effort to build frameworks with which the didactical difficulties can be studied. Such work is far from trivial, and is necessary to develop the rich body of research needed to establish any semblance of 'best teaching practices' in university mathematics. It is unclear how much, or even if any, of the results from similar examinations in secondary mathematics education can be applied to the tertiary mathematics classroom. Further research is also needed to address these issues.

Lastly, there is little research as to the interplay of the three categories of transition difficulty. Can excellent university lecturers help students overcome their epistemological difficulties? Do social and cultural difficulties mediate didactical difficulties? Questions such as these are entirely unanswered and provide yet more avenues for future research. Research into the secondary–tertiary transition is an exciting new field of research that marries together the interests of stakeholders in both secondary and tertiary mathematics education. As such, it would be imprudent to categorize the field as a secondary mathematics education or mathematics (specifically research in undergraduate mathematics education) topic for the sake of research–it is indeed a hybrid of the two. As such, research in this field carries the opportunity to bring together professional mathematicians and pre-service teacher educators and begin the process of implementing the recommendations provided above.

References

Barnett, M., Sonnert, G., & Sadler, P. (2014). Productive and ineffective efforts: how student effort in high school mathematics relates to college calculus success. International Journal of Mathematical Education in Science and Technology, 45 (7), 996–1020.

Barton, B., Clark, M., & Sheryn, L. (2010). Collective Dreaming: A school-University Interface. New Zealand Journal of Mathematics, 40, 15–31.

Barton, B., Goos, M., Wood, L., & Miskovich, A. (2012). Growth and new directions? Research in tertiary mathematical science education. In B. Perry, T. Lowrie, T. Logan, A. MacDonald, & J. Greenlees (Eds.), Research in mathematics education in australasia 2008-2011 (pp. 245–265). Rotterdam, The Netherlands: Sense Publishers.

Beach, K. (2003). Consequential transitions: a developmental view of knowledge propagation through social organizations. Between school and work: New perspectives on transfer and boundary-crossing, 39–62.

Breen, S., O'Shea, A., & Pfeiffer, K. (2013). The use of unfamiliar tasks in first year calculus courses to aid the transition from school to university mathematics. In Proceedings of the eight congress of the european society for research in mathematics education (pp. 2316–2325). Middle East Technical University, Ankara, Turkey.

Clark, B. R. (1960). The "cooling-out" function in higher education. American Journal of Sociology, 65 (6), 569–576.

Clark, M. & Lovric, M. (2008). Suggestion for a Theoretical Model for Secondary-Tertiary Transition in Mathematics. Mathematics Education Research Journal, 20 (2), 25–37.

Clark, M. & Lovric, M. (2009). Understanding secondary-tertiary transition in mathematics. International Journal of Mathematical Education in Science and Technology, 40 (6), 755–776.

Crawford, K., Gordon, S., Nicholas, J., & Prosser, M. (1998). Qualitatively Different Experiences of Learning Mathematics at University. Learning and instruction, 8 (5), 455–468.

DeGuzmán, M., Hodgson, B. R., Robert, A., & Villani, V. (1998). Difficulties in the Passage from Secondary to Tertiary Education. Documenta Mathematica, 747–762.

Di Martino, P. & Maracci, M. (2009). The secondary–tertiary transition: beyond the purely cognitive. In M. Tzekaki, M. Kaldrimidou, & C. Sakonidis (Eds.), Proceedings of the 33rd conference of the international group for the psychology of mathematics education (Vol. 2, pp. 401–408). Thessalonkiki, Greece.

Dreyfus, T. (1991). Advanced mathematical thinking. In D. Tall (Ed.), (Chap. Advanced Mathematical Thinking Processes, pp. 25–41). Dordrecht: Springer Netherlands.

Godfrey, D. & Thomas, M. O. J. (2008). Student Perspectives on Equation: The transition from school to university. Mathematics Education Research Journal, 20 (2), 71–92.

Gruenwald, N., Klymchuk, S., & Jovanoski, Z. (2004). Reducing the Gap between the school and university mathematics: university lecturers' perspective.

Hernandez-Martinez, P., Williams, J., Black, L., Davis, P., Pampaka, M., & Wake, G. (2011). Students' views on their transition from school to college mathematics: rethinking transition as an issue of identity. Research in Mathematics Education, 13 (2), 119–130.

Hong, Y. Y., Kerr, S., Klymchuk, S., McHardy, J., Murphy, P., Spencer, S., . . . Watson, P. (2009). A Comparison of teacher an lecturer perspectives on the transition from secondary to tertiary mathematics education. International Journal of Mathematical Education in Science and Technology, 40 (7), 877–889.

James, A., Monelle, C., & Williams, P. (2008). From lessons to lectures: NCEA mathematics results and first year mathematics performance. International Journal of Mathematical Education in Science and Technology, 39 (8), 1037–1050.

Jennings, M. (2009). Issues in bridging between senior secondary and first year university mathematics. In R. Hunter, B. Bicknell, & T. Burgess (Eds.), Crossing divides: proceedings of the 32nd annual conference of the mathematics education research group of australasia (Vol. 1, pp. 273–280). Palmerston North, New Zealand.

Kajander, A. & Lovric, M. (2005). Transition from secondary to tertiary mathematics: McMaster University experience. International Journal of Mathematical Education in Science and Technology, 36 (2-3), 149–160.

Kouvela, E. (2015). The transition from high school to university mathematics: messages interpreted by first year mathematics students. In G. Adams (Ed.), Proceedings of the British society for research into learning mathematics (Vol. 35, 2, pp. 31–36). Durham, England.

National Center for Education Statistics. (2015). The condition of education 2015. U.S. Department of Education.

Rylands, L. J. & Coady, C. (2009). Performance of students with weak mathematics in first-year mathematics and science. International Journal of Mathematical Education in Science and Technology, 40 (6), 741–753.

Schoenfeld, A. H. (1994). What do we know about mathematics curricula? Journal of mathematical behavior, 13 (1), 55–80.

Tall, D. (1997). From school to university: the transition from elementary to advanced mathematical thinking. In Proceedings of the 7th conference of the Australasian bridging mathematics network (pp. 1–20). Auckland, New Zealand.

Tall, D. (2004). Building theories: the three worlds of mathematics. For the Learning of Mathematics, 24 (1), 29–32.

Tall, D. (2008). The Transition to Formal Thinking in Mathematics. Mathematics Education Research Journal, 20 (2), 5–24.

Taylor, J. A. (2008). Assessment in First Year University: A Model to Manage Transition. Journal of University Teaching & Learning Practice, 5 (1), 19–33.

Thomas, M. O. J., de Freitas Druck, I., Huillet, D., Ju, M.-K., Nardi, E., Rasmussen, C., & Xie, J. (2012). Survey Team 4: Key Mathematical Concepts in the Transition from Secondary to University. In The proceedings of the 12th international congress on mathematical education (pp. 90–136). Seoul, Korea.

Thomas, M. O. J. & Klymchuk, S. (2012). The school-tertiary interface in mathematics: teaching style and assessment practice. Mathematics Education Research Journal, 24 (3), 283–300.

Wood, L. (2001). The secondary-tertiary interface. In D. Holton (Ed.), The teaching and learning of mathematics at university level: an ICMI study (pp. 87–98). The Netherlands: Springer Netherlands.

Citation:
Gunter, D.L. (2019). The secondary–tertiary transition in mathematics: A multifaceted Issue. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 2-16). ISRES Publishing, ISBN:978-605-698540-9.

Conceptual Understanding and Procedural Knowledge of Fractions: How to Learn and How to Teach

Vyomesh Pant
Ministry of Finance, India

Mathematics is commonly considered as one of the most difficult subjects to study. 'Math Phobia' or 'Math Anxiety' is very common among the people, especially among the children. Due to intricacies involved in Mathematics, most of the children are either not interested or least interested to learn it. Inside mathematics, there are certain topics wherein the students, for a variety of reasons, often face difficulty in understanding and in conceptualizing them. Decimal, Fractions and Percentage are among these topics, where not only the students struggle to understand the concepts but the teachers also find it very tedious to teach these phenomena to their students. Researchers have corroborated the aspect that the students face difficulties in developing conceptual understanding of fractions and decimals (see Condon & Hilton, 1999). Many tests and research studies have documented that understanding of fractions is week among the students of every grade ranging from Primary to Secondary and even to higher grades also (see Armstrong & Larson, 1995; Erlwanger, 1973; Empson & Levi, 2011; Kamii & Clark, 1995; Mack, 1990; Moss & Case, 1999; Orpwood, Schollen, Leek, Marinelli-Henriques & Assiri, 2011; Post, Cramer, Lesh, Harel, & Behr, 1993; Perle, Moran & Lutkus, 2005; Stigler, Givvin & Thompson, 2010). Various suggestions have been made by the researchers to improve the learning of fractions. However, the teaching and understanding of fraction still poses significant challenge.

The paper is intended to find out the reasons which make the aspect of 'fraction' more difficult for the teachers to teach and for the students to understand. The paper also suggests the teaching methodology which may be adopted to make easy the understanding and conceptualization of fractions. A model has been presented to introduce the term 'fraction' and preliminary mathematics associated with it to the beginners in a way so that the children can understand and conceptualize fractions easily in a natural way. This model may help to overcome the difficulties which come while teaching and learning fractions. We also provide answers to the problems posed by Siegler et al (see Siegler, Fazio, Bailey & Zhou, 2013). We start with analysing the problems which come during the teaching of fractions and associated reasons. The present study may be seen as interdisciplinary work which associates the studies in Mathematics Education with that in Psychology, Medical Science and Cognitive Science.

Difficulties in Teaching and Learning Fractions

The main reasons which create difficulty in learning and teaching of fractions have been discussed in this Section.

Multiple forms of fractions

Fractions can be expressed in multiple forms. Accordingly, these can be introduced to the children in different ways, which are as follows:

1. A fraction in bipartite form, i.e., in the form of x/y, where x and y are whole numbers and y ≠ 0.
2. x/y can be expressed as 'x divided by y' or x ÷y,.
3. x/y also denotes the ratio of two numbers x and y and can also be represented as x:y.
4. x/y can be expressed as 'x out of y', more precisely, x/y can be expressed as 'x number of parts out of total y number of equal parts of the whole.
5. x/y is also used as an operator. For e.g., when we say 3/4 of 100, it means (3/4) x 100 = 75. In that case 3/4 is an operator, which when multiplied by a number, reduces to the said number to its 'three fourth' value.

Kieren had identified five different interpretations (or sub-constructs) of rational numbers (see Kieren, 1980). These are often summarized as part-whole, measure, quotient or division, operator and ratio. Due to variety of forms, it is a challenge for a teacher to choose the appropriate form to introduce fractions to the kids and subsequently expose them to all the forms one by one without creating any doubt or confusion in their minds. The basic difficulty before a teacher is that how to introduce fraction – in bipartite form or as a ratio or as division of two numbers or as an operator. On the other hand, the children get confused due to the abstract nature of the 'fractions' and with various forms it is used in. While learning fractions, much of the confusion among the students occurs because they are either not familiar with a variety of representations or they cannot synthesize different interpretations or sub constructs (see, Clarke, Roche & Mitchell, 2007). Most of the students are not able to develop understanding of fractions due to the multiple forms it is introduced in and as a result they start focusing on surface similarities of the representations rather than numerical meaning and understanding of fractions. (see Moseley & Okamoto, 2008; Clarke, Roche & Mitchell (2007; 2011)).

The students generally fail to perceive the fractions like numbers (Park, Flores & Hohensee, 2016; Hannula, 2003; Post, et al, 1993). Instead they visualize fractions as some separate entity (in form of or) made up from numbers and perceivethe fractions as an object disconnected from the number system.

Absence of natural reference point

According to Wu (see Wu, 2014), the reasons which make difficult the learning of fraction are absence of a natural reference point and the inherent abstract nature of the concept of fraction. To deal with the learning of whole numbers in grades 1-4, children always have a natural reference point : their fingers. The modeling of whole numbers on one's finger is both powerful and accurate (see Wu, 2014). In case of fractions, it is normally introduced using a pizza or pie or bread and thus the pizza, pie or bread become the reference points. These may be good reference points to help the beginners for the purpose of the vocabulary learning aspect. However, these models become awkward in case of fractions bigger than 1 or in describing mathematical operations like addition, subtraction, multiplication etc. For e.g., one cannot multiply two pieces of a pie (Wu, 2014; Hart, 2000).

Presentation/ interpretation of fractions is complex for the beginners

A fraction comprises of three parts – a numerator, a denominator and a line which separates the numerator and denominator. Normally, it is taught that the numerator represents a counting number and signifies "how many", whereas the denominator is named as the ordinal number which signifies "what is being counted" (see Watanabe, 2002). Both the numerator and denominator are whole numbers (with a restriction that denominator is always non-zero), but their behavior in the operations related to fractions remain different. For e.g., while adding two fractions, LCM of the numbers in denominator is taken and equivalent fractions are formed. During the addition the denominator remains as it is (equal to LCM), whereas the numbers in numerator are simply added as whole numbers. Therefore, for the children, particularly for those who are in the early stage of learning, numerator and denominator become two separate entities and the bar separating them is a third one, which makes the things difficult. A considerable amount of attention of the kids gets utilized to understand these three entities and a less amount is left to understand the structure and operations related to fractions and its execution. The greater memory load of representing fractions reduces the cognitive resources available for thinking about the procedure needed to solve the problems related with fractions (see Lortie-Forgues, et al, 2015; Fuchs, et al, 2013; 2014; Hecht & Vagi, 2012; Jordan et al, 2013; Siegler & Pyke, 2013).

Fractions do not behave like whole numbers

One of the main difficulties while learning fractions is that often learners use the natural number properties to make inferences on rational numbers, which was termed as "whole number bias" by Ni & Zhou (2005). It is a general belief among the learners that the properties of fractions (rational numbers) would be same as that of the whole numbers (see Siegler et al, 2011). The rational numbers form a densely ordered set, whereas the whole numbers are part of a discrete set. As such the rational numbers (fractions) possess certain properties which are different from corresponding properties of the whole numbers. However, for the beginners it often becomes difficult to adapt these difference and they expect the rational numbers (fractions) to behave like whole numbers. For many people the fraction consists of two whole numbers a and b and with this understanding they process numerator and denominator as two separate whole numbers (see Vamvakoussi & Vosniadou, 2004). There are some questions related to the basic arithmetic operations on fractions, which creates doubts in the minds of the learners. For e.g., while adding or subtracting the fractions, it is necessary to form equivalent fractions in such a way that denominator of all the fractions become equal (equal to the LCM), whereas while multiplying or dividing the fractions, there is no such requirement of making equivalent fractions. Further, in case of addition or subtraction, after making the equivalent fractions, only numerators are added or subtracted but denominators are not added or subtracted. Contrary to the practice followed in fraction addition or subtraction, both numerator and denominator are multiplied in case of fraction multiplication. In case of fraction division, the denominator is reversed and then multiplied with numerator. Though all these queries can be answered mathematically, but these are not normal to understand, does not appear natural and are far from obvious. From the point of view of a beginner, such problems arising during the basic fraction arithmetic are away from realization, answers to these problems are not apparent and this is one of the important reasons which create difficulty in understanding fractions.

Conceptual understanding and procedural knowledge

Studies have shown that while learning fractions, students perform calculations without understanding mathematics behind it (see Kerslake, 1986, Gabriel et al, 2013). The thrust of the teachers generally remains in imparting procedural knowledge and, less, or, no emphasis is given to conceptual understanding of fractions. Children usually learn rote procedures, which lead to misunderstanding (see Byrnes & Wasik, 1991; Gabriel et al, 2013). Conceptual knowledge is a must to have explicit or implicit understanding of the principles, central concepts, their interrelations and further generalizations (Rittle-Johnson & Alibali, 1999; Schneider & Stern, 2005; Hiebert, 1986; Gabriel et al, 2013) whereas the procedural knowledge is about the sequences of actions useful to solve the problems (Rittle-Johnson & Alibali, 1999). The conceptual and procedural knowledge are complementary to each other and both of them must co-exist in an iterative and interactive way to make the learning thorough, interesting and purposive (Rittle-Johnson & Alibali, 1999).

Lortie-Forgues et al have presented a fine survey of the inherent and culturally contingent difficulties comes in the way of learning fractions and decimals (see Lortie-Forgues, et al, 2015). Magnitude plays an important role in arithmetic of whole numbers. When we talk of a whole number, say 7, it means that its magnitude is 7. While thinking of a number, it is the magnitude which gives us impression about its position or place in the number system. In case of whole numbers or integers, it is quite easy to find out the magnitude of any number and, as such, to imagine position of the number in the number system. Two whole numbers or integers can be compared to find out which one is greater. Same degree of comparative ease is available in addition, subtraction and multiplication of the whole numbers. The operation of division in whole numbers or integers creates more problem as compared to the others. The division is not always quick and this is the reason due to which it is not easy to compare two fractions having different denominators. It is not easy to find out the magnitude of a fraction, which creates problem for the learner to determine the position or place of a fraction. Comparing two whole numbers is easy task but comparing two fractions, particularly those having different denominators is not always easy. Unlike whole number magnitudes, fraction magnitudes have to be derived from the ratio of the two values, which reduces the accuracy, speed and automaticity of access to the magnitude representations (English & Halford, 1995). Accessing fraction magnitude also requires understanding whole number division, often considered the hardest of the four arithmetic operations (Foley & Cawley, 2003).

Other factors

In addition to this, there are some factors which are also responsible for difficulties faced by the learners. Quality of teaching and the knowledge of the teacher play pivotal role in minimizing the difficulties of the learners. The social, cultural, educational and financial background of the learners as well as of the teacher also make a great impact on the learning and understanding of the children.

How to Overcome the Problems

Throughout this paper, when we form fractions using integers, we talk of non-negative integers only. Thus the term rational number for expressing the fractions has been used in the sense of non-negative rational numbers only.

In the study of fractions, the most important part is introduction, i.e., the way the fractions are introduced to the beginners. The way how the fractions are introduced is very crucial for the beginners. As explained in the previous paragraphs, there are number of ways to introduce fraction and a child must get himself familiarised with all these expressions gradually in due course of learning. However, if all the forms are taught simultaneously, it may create confusion. Instead, we must go on one by one and initiate in such a way that the pupils may not feel the burden of being taught an entirely new concept.

Fractions may be introduced as a part of the number system

Numbers occupy an important place in mathematics. Infact, our primary exposure with mathematics starts with numbers and during initial few years of learning, mathematics is all about the numbers only. A child is initially exposed to numbers, counting, reverse counting, number line, comparison of numbers and basic algebraic operations on numbers. During initial phase of learning mathematics, numbers signify the whole numbers only. Gradually, with increase in the level of learning, natural numbers, integers, rational and irrational numbers are introduced as a part of the framework of the number system.

It may be better for the beginners if rational numbers are taught before introducing the term 'fraction'. The following steps represent one of the models of teaching to introduce fraction :

Step 1: After having understood the concept of number line, the students may be asked to imagine in the number line, "what will be there between 0 and 1?", "what is between 4 and 5?", or in general, "What is between any two consecutive whole numbers?". Simultaneously, sharing problems may also be given to the children. For e.g., they may be asked to share 20 candies among 4 students, in which each of them will get 5 candies. If the number of candies is increased to 21, 22 or 23, it is not possible for them to share whole number of candies equally. They will be able to share equally, if the number of candies is increased to 24.In that case each of them will get 6 candies. Such type of examples may help the children to understand the requirement of numbers which are different from the whole numbers and may fill up the gaps between the whole numbers or integers. This forms basis for introduction of rational numbers. Each point of the Number Line represents a number, as such, there exist infinite numbers in the number line, all of them are not whole numbers or integers. Initially, there may be no need to classify these numbers into rational and irrational numbers. Infact, the irrational numbers may be kept at abeyance for quite some time because it may create some difficulty for the children at the initial stage, but the numbers in the form a/b : a and b are non-negative integers and $b \neq 0$, may be taught and the children may visualize position of these numbers in the number line. Initially there is no need to use the term 'fraction', instead, the terminology of 'rational number' would be sufficient to understand the term and mathematics behind it. Further, the teacher must confine him to the non-negative integers only. In this way fractions may be introduced as rational numbers, as a part of number system, which will not only strengthen the concept number system but also familiarise childrenwith the essence of fractions, without burdening their minds with the load of the new terminology (fraction). The learners will be able to understand the rational numbers in a natural way as an extension of the number system. Further, having less memory load of introducing fractions will certainly increase the cognitive resources available for thinking about the structure and mathematical operations associated with fractions.

Step 2: Rational Numbers can be expressed as the numbers which are made of two integers a and b placed in the form a/b, b ≠ 0. Initially the students may be taught about positive rational numbers only. The integers and the whole numbers can also be expressed as rational numbers. For e.g., 2 can be expressed as 4/2 , 7 can be written as 7/1 or 14/2 and so on, which may help children in understanding that the rational numbers include the natural numbers, whole numbers and the integers. In the number line, the rational numbers can be represented by the dots of the whole numbers or integers and numerous other dots between these whole numbers or integers.

Step 3: The study of rational numbers is quite interesting and it can be made more interesting by highlighting the properties which are possessed by the rational numbers and not by the numbers the children are familiarise with, i.e., integers or whole numbers. The whole numbers as well as the integers form a discrete set, whereas the rational numbers form a densely ordered set. As such there are certain properties which differentiate the rational numbers from rest of the numbers. Some of these properties, which may be discussed to make the study of rational numbers more natural and purposeful, are as follows:

(i) Integers are not closed under the operation of division, but the rational numbers (excluding zero) are closed under the operation of division.

(ii) There are fixed or countable numbers of integers between any two integers. However, in case of rational numbers, there lies infinite number of rational numbers between any two integers or between any two rational numbers. For e.g., consider two rational numbers 3/10 and 7/10. There are 3 integers between 3 and 7, viz., 4, 5 and 6. Therefore, the corresponding rational numbers between 3/10 and 7/10 are 4/10 , 5/10 and 6/10. Now write 3/10 and 7/10 as 30/100 and 70/100 respectively and count the rational numbers between these two numbers, viz,31/100, 32/100, ...69/100. Again write 3/10 and 7/10 as 300/1000 and 700/1000 respectively and count the rational numbers between these two numbers. The process can go on and thus infinite numbers of rational numbers can be accommodated between any two rational numbers.

(iii) Between any two given numbers (integers or rational numbers), there may or may not exist an integer but it is for sure that there will always be a rational number between any two numbers. For e.g., there is no integer between 3 and 4 but there are infinite number of rational numbers between these numbers, such as, 7/2, 10/3, 13/4, ... etc.

(iv) In the set of integers, every integer can be represented by a unique symbol but a rational number can be represented by infinite number of expressions. For e.g., 1/2 = 2/4 = 3/6 = 4/8 = ... Though an integer can also be written in this manner, like 2 = 2/1, 4/2, 6/3 =..... , but we should not forget that for making such expressions we have to come out of the set of integers and use the set of rational numbers. Infact the integers are also rational numbers and, as such, hold the properties of rational numbers also. Inside the set of integers, it is not possible to write any rational number in multiple forms.

(v) In the set of integers, every integer has a unique predecessor and successor. However, in case of rational numbers, every rational number has infinite number of predecessors and successors.

(vi) Before learning rational numbers, the general perception of the children may be that the multiplication always increases the value of multiplicand as well as that of the multiplier. However, this is not true in case of integers. For e.g., 8 x (1/2) = 4 , which is less than 8.

(vii) Similarly, in case of division of rational number, the result may be greater than the dividend, which is contrary to the expectations of the learners because so far they are exposed to the division of integers only where the division always reduces the magnitude of the dividend. For e.g., (1⁄2)/(1⁄4)= 1/2 × 4/1=2 , which is greater than.

From the above, it is obvious that there are certain properties of rational numbers, which are entirely different from integers or whole numbers, due to which the rational numbers are required to be studied separately. The algebra of the rational numbers is also different from that of integers or whole numbers. Therefore, there is a need to study how the basic mathematical operations can be performed in case of rational numbers.

Step 4: Now the point to ponder is that despite so many differences, is there something which is common between the whole numbers and rational numbers. This insists the learners to identify the property which is common between the whole numbers and rational numbers. Obviously, the property that unites all the real numbers is that they possess magnitudes on the basis of which the numbers can be ordered in the number line. The magnitude of the fraction (rational numbers) plays crucial role in conceptual understanding and procedural knowledge of fractions. Once the children understand the magnitude of a rational number, they are able to visualize its position in the number line. The magnitude of a rational number and its position in the number line are the aspects which help the learner to understand that the rational numbers are part of the number system. Infact, these two aspects – magnitude and position in number line of rational number – form the basis for conceptualization of rational numbers or fractions.

Advantage of introducing fraction in form of rational numbers

The study of fractions as rational number as an extension of the existing number system comes in a natural way for the beginners. Other sub-constructs are not so natural or self-evident during the initial phase of learning. The part-whole concept does not work when it comes to the fractions which are greater than 1 or the negative fractions. ‘x out of y’ type explanation of fractions creates problems for the learners, when improper fractions like 5/3 are to be understood – ‘how can one take 5 parts out of total 3 parts?’ If the fractions are introduced as an operator or decimal numbers, there are several other constraints of these methods, particularly from the point of view of the beginners. Fraction as an operator can reduce the value of any integer on multiplication and increase its value on division. This behaviour is quite opposite to that of the whole numbers and creates confusion. However, if factions are introduced as non-negative rational numbers in a natural way, as described above, it will become easy for the learners to understand the requirement of introducing rational numbers and conceptualize their existence and position in the number line.

After understanding the rational numbers, the learners become able to recognize that the number system is not confined to the whole numbers and there exists other type of numbers also. Further, there are many properties of the whole numbers which are not true for all the numbers, in general. Some of these properties have been highlighted in Step 3 above. Simultaneously, Step 4 provides the properties which are common for both the whole numbers and the rational numbers. Such comparison will make the study interesting and will help in conceptualization and understanding as well.

Neuroscience corroborates that there is underlying commonality in the neural basis of whole number and fraction knowledge

Studies in Neuroscience have revealed that the intraparietal sulcus (IPS), which is located in human brain on the lateral surface of the parietal lobe, plays a role in processing of numerical information. It has been found in the study of brain that while solving arithmetic problems brain activity shows strong commonalities between whole numbers and fractions (Schmithorst & Brown, 2004). An independent components analysis of brain activity during addition and subtraction of fractions, as measured by functional Magnetic Resonance Imaging (fMRI), revealed task-related components with activation in bilateral inferior parietal, left perisylvian, and ventral occipitotemporal areas, a pattern closely similar to that observed with whole number arithmetic (Dehaene et al, 2003). These results suggest an underlying commonality in the neural basis of whole number and fraction knowledge (see Siegler, Fazio, Bailey & Zhou, 2013). Studies have shown that the behavioural and neural methods which have proved useful for understanding whole number representations and processes are also useful for understanding representations and processes involving fractions (Siegler, Thompson, & Schneider, 2011; Ischebeck, Schocke & Delazer, 2009; Jacob, Vallentin & Nieder, 2012; Schneider & Siegler, 2010). It has been found that understanding of fractions is centered around understanding the magnitude of the fraction in a similar manner like the understanding of whole numbers is centered around understanding of their magnitudes (see Siegler, Fazio, Bailey & Zhou, 2013; Dehaene, 2011; Opfer & Siegler, 2012). The problem in conceptualization of the fractions is due to the fact that the learners often cannot visualize the magnitude of the fraction, and, accordingly, its position in the number system. The problem can be overcome by introducing the fractions as rational numbers specifying their magnitude and position in the number line.

It has been found in the neuroimaging studies that like integers, the fraction comparisons also exhibit distance effect, however, the size and scale of the effect is entirely different from the corresponding outcome in case of the integers and it depends upon the holistic magnitudes of the numbers being compared. The response time and error rate for fraction comparison were found much higher than that in case of integers. (DeWolf, Chiang, Bassok, Holyoak, & Monti, 2016; DeWolf, Grounds, Bassok, & Holyoak, 2014). Neuroimaging results suggest that the brain represents proportional (fraction) magnitudes in the same way that it does absolute (integer) magnitudes (Ischebeck, Schocke & Delazer, 2009; Jacob & Nieder, 2009). In a subsequent study, it is found that the brain processes the fractions in different manner as it does in case of integers (see DeWolf, Grounds, Bassok, & Holyoak, 2014). However, the reason behind the difference in processing integers and rational numbers may be attributed to the procedural and conceptual competence of the person on which the experiment was performed. If the fractions are understood as rational numbers and are conceived in ordered mental continuum as per their magnitudes, there might be no considerable difference between the integers and fractions (rational numbers). The fact which cannot be ignored here is that it is always not very easy to get the magnitude of a rational number, therefore, the response time may vary. The fraction magnitudes are much more difficult than the whole-number or integer magnitudes. Hurst & Cordes have found that in the study of fractions carried out by them, the adults fixated significantly longer at the numerator of the fractions relative to the denominator. Individual differences in this measure of whole-number bias suggested that looking more at the numerator than at the denominator implies poorer understanding of fraction procedures (see Hurst & Cordes, 2016).

If the fractions are introduced as rational numbers, as an extension of the number system, the learner will be able to understand the magnitude of the rational numbers and on the basis of their magnitude, they will also be able to determine its position in the number line. Further, in this form the learner will recognize the fraction as one entity and instead of focusing more on numerator, the learner will look at the complete fraction (rational number). The clinical results support the assertion that the fractions as rational numbers are not difficult to understand if they are taught properly.

Number line acts as a reference point

Study of rational numbers using the number line provides the learner a reference point, i.e., the number line. They may visualize the position of the rational numbers on it, which may help them in understanding the number system in better way. Further, the number line becomes a reference point which may help the students to visualize the rational numbers, which may addresses the concern posed by Wu (see Wu, 2014) and Hart (see Hart, 2000) that the difficulty in teaching and learning fraction is due to absence of a reference point.

Optimal use of cognitive resources

It may be recalled that much of the confusion in teaching and learning fractions is because fractions are introduced in various forms and the students cannot synthesize the different interpretations or sub-constructs of fractions (see Clarke, et al, 2011). Therefore, instead of teaching fractions in different forms, it would be better if the rational numbers are introduced first as an extension of number system, without referring to the term fraction. Initially there is no need to use the terminology 'fraction' or any other sub-construct of it to name fraction. If fractions are introduced as rational numbers, without using the term fraction, this may allow the beginners to pay their whole attention towards learning of rational numbers. While learning fractions, the greater memory load of representing fractions reduces the cognitive resources available for thinking about the procedure needed to solve the problems related with fractions (see Lortie-Forgues, et al, 2015; Fuchs, et al, 2013; 2014; Hecht & Vagi, 2012; Jordan, et al, 2013; Siegler & Pyke, 2013). To address this problem, it would be better if fractions are introduced as rational numbers so that all the cognitive resources available for thinking may be utilized in learning intricacies of rational numbers.

The pupil understand the algebra of fractions before formal introduction of fractions

Having expressed the pupils the properties of the rational number with illustrative examples, we can show that the rational numbers behave in different manner and unlike the whole numbers or integers. After introduction of rational numbers, beginners may be told about the addition, subtraction, multiplication and division of rational numbers. Remember that the term fraction has not been introduced to the learners and we have to focus on the algebraic properties of the rational numbers. After explaining the children the properties of the rational numbers, it becomes natural for them to adapt that the operations of addition, subtraction, multiplication and division of rational numbers will be different from that of the whole numbers or integers.

How to make the learning easy for the beginners

Use of geometry and multimedia can make the things easy

The Cognitive Load Theory (CLT), developed by John Sweller, is considered as one of the most influential theories in instructional design. It states that the instructional design can be used to reduce cognitive load among learners. CLT has been designed to provide guidelines intended to assist in the presentation of information in a manner which encourages learner activities that optimize intellectual performance (see Sweller, 1988; Sweller, et al, 1998). As per the CLT, there are three types of cognitive loads – Intrinsic Cognitive Load, which refers to the effort associated with a specific topic, Extraneous Cognitive Load, which describes the mode or the way of presenting the topic before a learner and Germane Cognitive Load, which indicates the efforts done to create a permanent store of knowledge in the learner. The method of teaching fractions step by step must be designed keeping in view the CLT. Another important theory is the Cognitive Theory of Multimedia Learning (CTML), which was popularized by the work of Richard E. Mayer who argues that multimedia supports the way that the human brain learns (Mayor, 2010; 2010). As per the theory of Mayer, the people learn more deeply from words and pictures than from words alone. Such kind of learning is referred to as the multimedia principle. Multimedia researchers generally define multimedia as the combination of text and pictures and suggest that multimedia learning occurs when we build mental representations from these words and pictures. The words can be spoken or written, and the pictures can be any form of graphical imagery including illustrations, photos, animation, or video. Multimedia instructional design attempts to use cognitive research to combine words and pictures in ways to optimize the learning effectiveness. Following the CLT and CTML, efforts may be made by the teachers to provide geometrical interpretation of every concept so that the children may be able to understand it properly and memorize it in better way. Stepanek et al have emphasized on the need of teaching elementary mathematics by Design (see Stepanek, et al, 2011). The term design generally refers to the creation of a product in an artistic or highly skilled manner. Good design means that the product fits the needs of the people who will use it and the context in which it will be used. Teaching by Design is a way to describe teachers' work that focuses on planning deliberate and purposeful lessons that fit the needs of their students.

Fraction knowledge may be linked with real world applications

All too often learners think of 'fractions' as being a discrete (and often difficult) topic that has no real connection with any other area of mathematics (see McLeod & Newmarch, 2006). However, if meaningful connections are made, the learning becomes more powerful. While attempting such connections, the teacher should be extra cautious that in the endevour to make it understandable to the pupils, the basic structure of the mathematical phenomenon of fraction is not distorted. Mathematics is often considered as 'abstract' or 'dry' subject by a large section of society. To make it understandable and interesting for all, various examples are created by the teachers so that all the student can attach them and learn it without any fear. Being abstract is an underlying essence of mathematics and one enjoys this flavor of mathematics only after proper conceptualization of any mathematical phenomenon. It is also true that Mathematics is often connected with real world applications to make it interesting and purposeful. Therefore, work on fractions needs to be integrated with other topics of mathematics; number, shape, data handling, and particularly every sort of measure of weight, length, capacity, time, and simple probability. Learners encounter fractions throughout their work at all entry levels of the numeracy curriculum, e.g., solving money problems, sharing a bill, comparing prices, calculating journey times, cooking, interpreting data in pictograms and bar charts, using a meter rule, measuring a room, comparing each other's heights, and checking the weight of ingredients (see McLeod & Newmarch, 2006), which may be connected with the learning of fractions.

Discussion

This paper suggests method to teach fractions as extension of number system, i.e., in form of rational numbers. The technique suggested in this paper is very simple, natural and keeps the children connected with the number system so that they can understand and conceptualize it. During further study, they may be taught the rational numbers are also known as fractions.

We also provide answers to the problems posed by Siegler et al (see Siegler, Fazio, Bailey & Zhou, 2013). Some of the problems posed by Siegler et al are as follows:

> "What relations connect whole number and fractions knowledge? Are individual differences in representations of whole number and fraction magnitudes related, do earlier individual differences in whole number representations predict later differences in fraction representations, and do interventions that improve whole number magnitude representations improve fraction representations as well?"

> "How specific are the relations of neural processing of whole numbers and fractions? For example, are individual differences in brain activations on the two types of numbers related? Do interventions that improve whole number and fraction magnitude representations produce similar changes in brain activity?"

The present paper provides answers to the above problems. Clearly it is the magnitude that relates the whole numbers and fractions. Number line acts as a frame of reference for all the numbers and the numbers are positioned in it in order of their magnitudes. Two things are required to conceptualize a number – position of the number in the number line (to understand existence of the number) and ordering of the number with reference to other numbers. It's the magnitude of the whole number which determines the position of the number in the number line and also decides its order as to which numbers are superseded by it and which one are succeeded. As described in this paper, if the fractions are introduced as rational numbers and emphasis is given to find out and understand their magnitudes, it will help the learners to determine position of the rational numbers in the number line, which, in turn, will help them to understand the position of the rational numbers and their ordering in the number line. Clear understanding of the position and ordering of the rational numbers, which is based on their magnitudes, will help the learners to conceptualize the rational numbers (fractions).

It has been found in the study of brain that while solving arithmetic problems brain activity shows strong commonalities between whole numbers and fractions (Schmithorst & Brown, 2004). The fMRI analysis of brain activity during addition and subtraction of fractions exhibits a pattern closely similar to that observed with whole number arithmetic (Dehaene et al, 2003). The problem in conceptualization of the fractions is due to the fact that the learners often cannot visualize the magnitude of the fraction, and, accordingly, its position in the number system. The problem can be overcome by introducing the fractions as rational numbers specifying their magnitude and position in the number line.

Neuroimaging results suggest that the brain represents proportional (fraction) magnitudes in the same way that it does absolute (integer) magnitudes (Ischebeck, Schocke & Delazer, 2009; Jacob & Nieder, 2009). If the fractions are understood as rational numbers and are conceived in ordered mental continuum as per their magnitudes, there might be no considerable difference between the integers and fractions (rational numbers). The fact which cannot be ignored here is that it is always not very easy to get the magnitude of a rational number, therefore, the response time may vary. The fraction magnitudes are much more difficult than the whole-number magnitudes and this facts give slight edge to the whole numbers. The brain activation in case of fractions may be different due to two factors – poor understanding of fractions and difficulty in calculation of their magnitudes as compared to the whole numbers. The difficulty in calculation of the magnitude of fractions is inherent or structural and will persist but the poor understanding of the fractions can be rectified by introducing them as rational numbers emphasising focus on their magnitudes. If the fractions are taught in the manner as suggested in this paper, the neural results will certainly exhibit better results and the change in brain activity in case of the whole numbers vis-à-vis the rational numbers will reduce to the minimum level leaving the part aside which may persist due to inherent structure of the fractions.

References

Armstrong, B.E. & Larson, C.N. (1995). Students' use of part-whole & direct comparison strategies for comparing partitioned rectangles, *Journal of Research in Mathematics Education*, 26(1), 2–19.

Bruce, C., Chang, D., & Flynn, T. (2013). *Foundations to Learning and Teaching Fractions: Addition and Subtraction – Literature Review*, Report submitted to Curriculum and Assessment Branch, Ontario Ministry of Education, ON K9J 0G2, Canada.

Byrnes, J. P., & Wasik, B. A. (1991). Role of conceptual knowledge in mathematical procedural learning. *Dev. Psychol.* 27, 777–786. doi: 10.1037/0012-1649.27.5.777

Clarke, D., Roche, A. & Mitchell, A. (2007). Year six fraction understanding: A Part of the Whole Story. In J. Watson & K. Beswick (Eds), *Proceedings of the 30th Annual Conference of the Mathematics Education Group of Australasia*, pp. 207–216. Adelaide, Australia: MERGA Inc.

Clarke, D., Roche, A., & Mitchell, A. (2011). Year Six Fraction Understanding: A Part of Whole Story. In J. Watson & K. Beswick (Eds.), *Proceedings of the 30th Annual Conference of the Mathematics Education Research Group of Australia* (Vol. I, pp.207-216). Adelaide, Australia: MERGA Inc.

Condon, C., & Hilton, S. (1999). Decimal Dilemmas. *Australian Primary Mathematics Classroom*, 4(3), 26-31.

Dehaene, S. (2011). The Number Sense: How the Mind Creates Mathematics, In Revised and Updated Edition, Oxford University Press.

Dehaene, S., Piazza, M., Pinel. P., & Cohen L. (2003). Three parietal circuits for number processing. *Cogn. Neuropsychol*. 20, 487–506.

DeWolf, M., Chiang, J.N., Bassok, M., Holyoak, K.J & Monti, M.M. (2016). Neural Representations of Magnitude for Natural and Rational Numbers, *NeuroImage*, 141, 304-312. http://dx.doi.org/10.1016/j.neuroimage.2016.07.052

DeWolf, M., Grounds, M., Bassok, M. & Holyoak, K.J. (2014). Magnitude comparison with different types of rational numbers. *J. Exp. Psychol. Hum. Percept. Perform.* 40 (1), 71–82.

Empson, S. & Levi, L. (2011). Extending children's mathematics: Fractions and decimals: Innovations in cognitively guided instruction. Portsmouth, NH:Heinemann. pp. 178-216.

English, L., & Halford, G. (1995). Mathematics education: Models and processes. Mahwah, NJ: Lawrence Erlbaum. doi: 10.5860/choice.33-3963

Erlwanger, S. H. (1973). Benny's conception of rules and answers in IPI mathematics. *Journal of Children's Mathematical Behavior*, 1(**2**), 7-26. Reprinted in Carpenter, T. P., Dossey, J. A., & Koehler, J. L. (Eds.) (2004), Classics in mathematics education research (pp. 48-58). Reston, VA: National Council of Teachers of Mathematics.

Foley, T., & Cawley, J. (2003). About the mathematics of division: Implications for students with learning disabilities. Exceptionality, 11, 131-150. doi: 10.1207/s15327035ex1103_02

Fuchs, L. S., Schumacher, R. F., Long, J., Namkung, J., Hamlett, C. L., Cirino, P. T., . . . Changas, P. (2013). Improving At-Risk Learners' Understanding of Fractions. *Journal of Educational Psychology, 105*, 683-700. doi: 10.1037/a0032446

Fuchs, L. S., Schumacher, R. F., Sterba, S. K., Long, J., Namkung, J., Malone, A., . . . Changas, P. (2014). Does working memory moderate the effects of fraction intervention? An aptitude–treatment interaction. *Journal of Educational Psychology, 106*, 499-514. doi: 10.1037/a0034341

Gabriel, F., Coche, F., Szucs, D., Carette, V., Rey, B., & Content, A. (2013). A componential view of children's difficulties in learning fractions, *Frontiers in Psychology*, 4, 1-11. doi: 10.3389/fpsyg.2013.00715

Hannula, M. S. (2003). Locating fraction on a number line. In N. A. Paterman, B. J. Dougherty, & J. T Zilliox (Eds.), *Proceedings of the 27th conference of the International Group of the Psychology of Mathematics Education*, Vol. 3, 17-24. Honolulu, HI.

Hart, K, (2000). Mathematics Content and Learning Issues in the Middle Grades. In Mathematics Education in the Middle Grades: Teaching to Meet the Needs of Middle Grades Learners and to Maintain High Expectations, *Proceedings of a National Convocation and Action Conferences* (pp. 50-57). Washington, USA: National Academy Press.

Hecht, S. A., & Vagi, K. J. (2012). Patterns of strengths and weaknesses in children's knowledge about fractions. *Journal of Experimental Child Psychology, 111*, 212-229. doi: 10.1016/j.jecp.2011.08.012

Hiebert, J. (ed.). (1986). *Conceptual and Procedural Knowledge: the Case of Mathematics*. Hillsdale, NJ: Erlbaum.

Hurst, M. & Cordes, S. (2016). Rational-Number Comparison Across Notation: Fractions, Decimals and Whole Numbers, *Journal of Experimental Psychology: Human Perception and Performance*, 42(2), 281-293. http://dx.doi.org/10.1037/xhp0000140.

Ischebeck, A., Schocke, M., Delazer, M. (2009). The processing and representation of fractions within the brain: an fMRI investigation. *Neuroimage*. 47, 403–413. doi: 10.1016/j.neuroimage.2009.03.041. Epub 2009 Mar 25.

Jacob, S.N. & Nieder, A. (2009). Notation-independent representation of fractions in the human parietal cortex. *J. Neurosci.* 29, 4652–4657.

Jacob, S.N., Vallentin, D. & Nieder A. (2012) Relating magnitudes: the brain's code for proportions. *Trends Cogn. Sci.*, 16, 157–166. doi: 10.1016/j.tics.2012.02.002.

Jordan, N. C., Hansen, N., Fuchs, L. S., Siegler, R. S., Gersten, R., & Micklos, D. (2013). Developmental predictors of fraction concepts and procedures. *Journal of Experimental Child Psychology, 116*, 45-58. doi: 10.1016/j.jecp.2013.02.001

Kamii, C. & Clark, F.B. (1995). Equivalent fractions: Their difficulty and educational implications. *Journal of Mathematical Behaviour*, 14 (4), 365–378.

Kerslake, D. (1986). Fractions: Children's Strategies and Errors. *A Report of the Strategies and Errorsin Secondary Mathematics Project*. England: NFER-NELSON Publishing Company Ltd.

Kieren, T. E. (1980). The rational number construct: Its elements and mechanisms. In T. E. Kieren (Ed.). *Recent research on number learning*, (pp. 125–149). Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education.

Lamon, S.J.(2007). Rational number and proportional reasoning. In F.K. Lester, Jr. (Ed.), *Second handbook of research on mathematics teaching and learning*, pp.629-667. Charlotte, NC: Information Age Publishing.

Lortie-Forgues, H., Tian, J., & Siegler, R. S. (2015). Why is learning fraction and decimal arithmetic so difficult? *Developmental Review*, 38, 201-221. doi:10.1016/j.dr.2015.07.008.

Mack, N. K. (1990). Learning fractions with understanding: Building on informal knowledge. *Journal for Research in Mathematics Education*, 21(**1**), 16-32.

Mayer, R. E. (2010). Applying the science of learning to medical education. *Medical Education*, (44), 543–549. doi:10.1111/j.1365-2923.2010.03624.x.

Mayer, R. E. (2010). Seeking a science of instruction. *Instructional Science*, (38), 143–145. doi:10.1007/s11251-009-9113-x.

McLeod, R., & Newmarch, B. (2006). *Fractions, Math for Life*. National Research and Development Centre for Adult Literacy and Numeracy, London.

Moseley, B., & Okamoto, Y. (2008) Identifying fourth graders' understanding of rational number representations: A mixed methods approach. *School Science and Mathematics*. 108 (6), 238-250.

Moss, J. & Case, R. (1999). Developing children's understanding of the rational numbers: A new model and an experimental curriculum. *Journal for Research in Mathematics Education* 30(2), 122-147.

Ni, Y., & Zhou, Y. D. (2005). Teaching and learning fraction and rational numbers: the origins and implications of whole number bias. *Educ. Psychologist* 40, 27–52. doi:10.1207/ s15326985ep4001_3

Opfer, J.E. & Siegler, R.S. (2012). Development of quantitative thinking. In Holyoak, K.J. & Morrison, R., (Eds). *Oxford Handbook of Thinking and Reasoning*, pp. 585–605, Oxford University Press, Cambridge.

Orpwood, G., Schollen, L., Leek, G., Marinelli-Henriques, P., & Assiri, H. (2012). College mathematics project 2011: Final report. Retrieved from http://collegemathproject.senecac.on.ca/cmp/en/pdf/FinalReport/2011/CMP _2011_Final_Report%20 -%2002Apr12%20pmh.pdf

Park, J., Flores, A., & Hohensee, C. (2016) Fraction as Numbers and Extensions of Numbers and Extensions of the Number System: Developing Activities Bases on Research. *Ohio Journal of Mathematics*. 73, 13-21.

Perle, M., Moran, R., & Lutkus, A. D. (2005). *NAEP 2004, trends in academic progress: Three decades of student performance in reading and mathematics*. Washington, DC: National Center for Education Statistics.

Post, T. R., Cramer, K. A., Lesh, R., Harel, G., & Behr, M. (1993). Curriculum Implications of research on the learning, teaching and assessing of rational number concepts. In T. P. Carpenter, E. Fennema & T. A. Romberg (Eds.), Rational numbers: An integration of research (pp. 327-362). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Rittle-Johnson, B., & Alibali, M. W. (1999). Conceptual and procedural knowledge of mathematics: does one lead to the other? *J. Educ. Psychol*. 91, 175–189. doi: 10.1037/0022-0663.91.1.175

Schmithorst, V.J. & Brown, R.D. (2004). Empirical validation of the triple-code model of numerical processing for complex math operations using functional MRI and group Independent Component Analysis of the mental addition and subtraction of fractions. *Neuroimage*. 22, 1414–1420.

Schneider, M. and Siegler, R.S. (2010) Representations of the magnitudes of fractions. *J. Exp. Psychol. Hum. Percept. Perform*. 36, 1227–1238.

Schneider, M., & Stern, E. (2005). "Conceptual and procedural knowledge of a mathematics problem: their measurement and their causal interrelations," in *Paper Presented at the 27th Annual Meeting of the Cognitive Science Society (CSS)*, Stresa.

Siegler, R. S., & Pyke, A. A. (2013). Developmental and individual differences in understanding of fractions. *Developmental Psychology*, *49*, 1994–2004. doi:10.1037/a0031200.

Siegler, R. S., Fazio, L.K., Bailey, D. H., & Zhou, X. (2013). Fractions: The new frontier for theories of numerical development. *Trends in Cognitive Sciences*, 17, 13-19.

Siegler, R.S., Thompson, C.A., & Schneider, M. (2011). An integrated theory of whole number and fractions development. *Cogn. Psychol.* 62, 273–296. doi: 10.1016/j.cogpsych.2011.03.001

Stepanek, J., Leong, M., Griffin, L. & Lavelle, L. (2011). *Teaching by Design in Elementary Mathematics*. Corwin (In association with Education Northwest).

Stigler, J. W., Givvin, K. B., & Thompson, B. (2010). What community college developmental mathematics students understand about mathematics. *The MathAMATYC Educator*, *10*, 4–16.

Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science,* 12 (2), 257–285.

Sweller, J., Van M. J. & Paas, F. (1998). Cognitive Architecture and Instructional Design. *Educational Psychology Review*, 10 (3), 251–296.

Vamvakoussi, X., & Vosniadou, S. (2004). Understanding the structure of the set of rational numbers: a conceptual change approach, *Learn. Instr.* 14, 453–467. doi:10.1016/j. learninstruc.2004.06.013

Watanabe, T. (2002). Representations in Teaching and Learning Fractions. *Teaching Children Mathematics*, NCTM, 8(8), 457-463.

Wu, H. (2014). *Fractions, Decimals and Rational Numbers*, Report of the Learning Processes Task Group of the National mathematics Advisory Panel. Berkeley. doi: https://math.berkeley.edu/~wu/NMPfractions.pdf

Citation:
Pant, V. (2019). Conceptual understanding and procedural knowledge of fractions: How to learn and how to teach. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 17-35). ISRES Publishing, ISBN: 978-605-69854-0-9.

Dynamic Math Teaching and Learning: Zones of Math Knowledge Creation Framework

Steven Reid
University of Toronto, Canada

Introduction

Successful math teaching and learning is elusive to many educational systems around the world. Students' math achievement across various jurisdictions is trending downward regardless of the efforts to boost the love and learning of math. The debate that mathematicians, educators, curriculum developers, policy makers, and public are currently engaged in focuses primarily on the pedagogy of math, that is, how should math be taught? From the author's perspective, this debate is fundamentally steeped in a question that has been asked for centuries involving how individuals actually acquire knowledge. Without a doubt, this is an important debate that regularly polarizes the masses between reform and traditional methods of teaching math. The concept of reform math is associated with other terms, for example, discovery-based learning (Destrebecqz, 2004; Rittle-Johnson, 2006), inquiry-based learning (Maaß & Artigue, 2013), constructivist approach (Richardson, 2003) and new math (Kilpatrick, 2012).

Although there is no definitive definition for reform mathematics, consistent principles and beliefs in the literature are used by this author to define reform mathematics. For the purpose of this article, reform math is defined as a dynamic teaching and learning approach, which encompasses the belief that students learn by socially interacting with others to delve into complex and authentic mathematical tasks. Ultimately, this enables learners to build upon current knowledge, construct new knowledge, advance deep conceptual understandings about math ideas, and develop efficacy and interest in the field of math (NCTM, 2000, 2014; Ross, McDougall, & Hogaboam-Gray, 2002).

On the other side of the spectrum, one finds a traditional approach, that is, a transmissive style to teaching and learning math. This approach can be defined as a belief that teachers hold math knowledge and disseminate it to students. Subsequently, instruction is dominated by the teacher requiring students to memorize facts, practice procedures, and gradually learn different ways to solve problems. A typical lesson, based on a transmissive approach, involves whole group review of previous knowledge, teacher demonstration of new knowledge, and student practice to gain new knowledge. Based on these definitions alone, there is a wide divide between reform and traditional approaches to teaching and learning math. Not surprisingly, disparate groups have been formed based on their beliefs, each citing evidence to promote either approach (Ross et al., 2002).

For several decades, the National Council of Teachers of Mathematics (NCTM) has advocated for reform math (NCTM, 1989, 2000, 2014). Regardless of continued efforts to implement reform math, NCTM reports limited progress. The council identifies several challenges that still exist such as heavily relying on learning procedures at the expense of understanding the conceptual foundations of the procedures (NCTM, 2014). In addition to NCTM, other organizations also proclaim the importance of reform math (Ontario Association for Mathematics Education, 2017). For example, the Ontario Association for Mathematics Education (OAME) is a strong advocate of reform math pedagogy. As part of OAME's vision for teaching and learning math, it highlights the importance of building communities of math learners in which students are dynamic participants in inquiry. Students are not merely recipients of knowledge, but rather they actively create math knowledge in a social context by asking questions and exploring their understandings (OAME, 2017). The social construction of knowledge is foundational to a dynamic approach to teaching and learning math, as well as a tenet of reform principles. Without question, past, current, and future efforts to promote knowledge creation in math classrooms is at a contentious crossroad, which presents opportunities and pitfalls for policy makers and teachers.

As jurisdictions around the world continue to investigate opportunities to promote competencies in math, the *Zones of Math Knowledge Creation Framework* is presented in this paper for consideration and further research. The foundational underpinning of this framework offers a perspective of why many educational districts have not actualized the gains in math that were strategically planned. To promote growth in the areas of student understanding and appreciation of math, teachers' personal math identities (PMIs), as well as their teaching and learning approaches implemented in classrooms must be contemplated and analyzed. When teachers' PMI increases and their willingness to engage in dynamic teaching and learning approaches advances, an *Optimal Zone* of math knowledge creation can be attained by individuals and ultimately by educational systems.

Although the framework introduced in this paper is not jurisdictionally dependent, Ontario's efforts to support math instruction in classrooms over a decade and a half are explored to offer readers a context. The importance of math to policy makers was highlighted in 2004 by the introduction of Ontario's Literacy and Numeracy Secretariat (LNS). Although literacy and numeracy were espoused as being equal priorities provincially, teachers questioned the focus on math compared to literacy … "There is such a focus on literacy and such support for literacy, numeracy is on the back burner" (Canadian Language and Literacy Research Network, 2009, p. 63).

In 2016, math was again identified as a priority in the province through the Renewed Math Strategy (RMS), which included requirements such as sixty minutes of protected math learning time each day in elementary classrooms, as well as resources for both elementary and secondary systems, e.g., math lead teachers, professional learning opportunities for teachers and principals (Zegarac, 2016). Improving student achievement in the area of math was again identified as a priority by the Government of Ontario in 2017, as there was a commitment to review policies involving curriculum and assessment to ensure that students acquire the transferable skills necessary for the future workforce (Office of the Premier, 2017).

The focus on math became a priority when Ontario's provincial and international assessments demonstrated insignificant gains and actually declined over the years in some cases. Ontario assessments in math are administered through the Education Quality and Accountability Office (EQAO) at grades 3, 6, and 9. Over a span of a decade (2009–2018), results of Ontario students achieving the provincial standard dropped by 14 percentage points (63% to 49%) in grade 6 and 9 percentage points (70% to 61%) in grade 3 (Education, Quality and Accountability Office, 2018a).

At the secondary level, two assessments are provided in grade 9 based on the course of study, applied or academic. In general, students enrolled in applied courses are primarily destined for college, i.e., career-orientated institutions offering diplomas or certificates, whereas students in academic courses are most likely to have a university pathway, i.e., degree granting institutions (Reid & Reid, 2017; James & Turner, 2017). The provincial results for applied and academic assessments remained fairly static during this same time. The percentage of students achieving the provincial standard in the applied level courses is in the mid 40s, while percentage of students achieving the provincial standard in academic math courses is in the mid 80s (EQAO, 2018b). The significant achievement gap between the two courses is of concern for a variety of reasons. One major issue is the overrepresentation of students in applied courses whom are from equity-seeking groups, including: low socio-economic status communities (Hamlin & Cameron, 2015), Black students (James & Turner, 2017), and students with special education needs (EQAO, 2018b).

Ontario is currently in the midst of proclaiming a *back to the basics* approach to teaching and learning math. In Ontario's Plan for the People (Fedeli, 2018), the government claims a need to end discovery math (i.e., reform math) due to the decline in provincial large-scale assessment scores … "A discovery-based learning environment does not teach students the fundamentals of basic math" (p. 78). However, large-scale Ontario assessment results have clearly identified that grade 3 and 6 students demonstrate higher achievement in the area of basic math skills requiring simple recall of content knowledge. These same students have more difficulty with math that requires them to apply their knowledge or demonstrate critical thinking (EQAO, 2019). With forthcoming changes to Ontario's math curriculum, along with new teacher education certification requirements in the area of math proficiency (Ontario Ministry of Education, 2019), the landscape of math education in this province is poised to dramatically change for years to come.

Literature Review

Many teachers tend to equate some of the factual aspects of math with a need to engage students in repetitive practice without conceptual understanding of the computations themselves (Boaler, 2019). Bruce (2007) considered why a traditional model of teaching math that "focused on basic computational procedures" continues to be commonplace in classrooms (p. 2). She purports that the greatest challenge many teachers face when embracing reform practices is that most teachers never experienced this model of teaching as students themselves (Bruce, 2005). Researchers also suggest that the absence of reform math is resultant from teachers' lack of content knowledge within this subject area (Reid & Reid, 2017; Ponte & Chapman, 2008). "Teachers who do not themselves know a subject well are not likely to have the knowledge they need to help students learn this content" (Ball et al., 2008, p. 404). As any future state of math teaching and learning is envisioned, it is necessary to explore the following areas of theory and research: reform and traditional models of math instruction, math knowledge, math identity, and knowledge creation.

Reform and Traditional Models of Math Instruction

At the core of reform math is a focus on understanding math at a conceptual level through problem-solving opportunities that involve connections across math ideas. This constructivist approach to knowledge creation has led to changes in curriculum and textbooks, as well as fueled debate regarding how to best teach math (Baker et al., 2010). In fact, this debate is often referred to as the *Math Wars* (Ross et al., 2002; Schoenfeld, 2004). As with most debates, the positions are juxtaposed and identified as dialectics (White-Fredette, 2010). The counterpoint to reform math is a traditional approach to instruction. In this transmissive model, the learning of math is viewed as highly sequential and achieved when the teacher transmits knowledge to their students in order to be practiced and memorized. This rote learning approach does little in the way of allowing students to undertake problems in innovative ways, nor apply skills to unfamiliar problems (Baker et al., 2010; Mann, 2006). Regardless of the philosophical conceptions of how to teach math, any attempts to change instructional practice on a large-scale will necessitate professional learning that is collaborative and connected to teachers' classrooms (Bruce, Esmonde, Ross, Dookie, & Beatty, 2010).

Many researchers argue that, despite attempts to support change in math instruction over the years, envisioned transformation has been largely missing (Haeck, Lefebvre, & Merrigan, 2014; Hiebert et al., 2005; Marshall, 2006). Studies illustrate how reform recommendations are regularly executed superficially or abandoned altogether (Ross et al., 2002). Charalambous and Philippou (2010) suggest that teachers who are comfortable in teaching math through transmissive methods often have more concerns about reform math. Specifically, teachers may lack confidence in their abilities to successfully implement complex teaching practices, as well as fear the potential of creating complicated learning situations for students who often struggle in math.

Moreover, when implementing instructional practices that are unfamiliar, Spillane (2005) gives evidence that teachers are less likely to reach out to their peers for support in math than in literacy. Wide sweeping transformation is complex and demanding for any system. However, for reform math, the challenges are heightened due in part to teachers' lack of content knowledge, fears of the unknown impacts on students, as well as fears of being vulnerable to one's peers.

Math Knowledge

For teachers to effectively create dynamic math teaching and learning environments, it requires a robust knowledge of math. Researchers have classified different types of knowledge that teachers must possess to successfully teach math (Ball et al., 2008). These types of knowledge include math knowledge for teaching (MKT), as well as a subset called math content knowledge (MCK). MCK is defined as the basic math knowledge required for an individual to be regarded as mathematically literate in society (Reid & Reid, 2017). Without MCK, teachers are often unable to make informed instructional decisions based on the needs of students (Lui & Bonner, 2016).

Additionally, teachers require deep conceptual understandings to implement effective teaching and learning strategies in support of students' learning of math (Ball et al., 2008; Ma, 1999; Thames & Ball, 2010). For Ball et al. (2008), the conceptualization of MKT involves teachers' knowledge of basic math content, conceptual understanding of the content, understanding of their own students and the math curriculum, as well as a math pedagogy. Silverman and Thompson (2008) also propose a framework for envisioning MKT in which teachers must possess a deep understanding of math ideas. This conceptual knowledge enables them to anticipate how students might understand and think about the ideas and design learning opportunities for students to develop math ideas and make connections to other ideas.

Researchers have signalled the importance of conceptual understanding of math to help students make conceptually-based connections and support the understanding of algorithms (Reid & Reid, 2017; Boaler, 2019; Ponte & Chapman, 2008; Thames & Ball, 2010), as well as make instructional decisions in the moment based on student interactions with the concepts (Mason & Davis, 2013). Therefore, a strong foundation of MCK is essential for teachers to develop the necessary skillset to support students in developing conceptual understandings, facilitate math discourse, and promote problem solving (Reid & Reid, 2017; Reid, Reid, & Hewitt, 2018; Hill et al., 2016). Without a concerted effort to develop MCK, attempts to build the capacities of teacher's MKT are undoubtedly compromised.

The relationship between procedural and conceptual understanding plays a significant role as teachers work to develop their own MCK and MKT (Boaler, 2019; Hill & Ball, 2009). Procedural knowledge is defined as understanding how to employ an array of actions, rules, or algorithms to answer certain types of math questions (Hiebert, 1992; McCormick, 1997). All too often, teachers' personal experiences as math students involve an over reliance on algorithms (Reid & Reid, 2017; Bruce, 2005; Lui & Bonner, 2016). This dependency has been observed in preservice teachers with low levels of MCK (Thanheiser et al., 2014).

There is no doubt that algorithms offer efficiencies to quickly carry out computations, however, the algorithms are often not easily understood intuitively, and at times counterintuitive (Bartell, Webel, Bowen & Dyson, 2012; Philipp, 2008). Developing procedural proficiency alone, without a deeper understanding of why the procedures are followed, presents issues of retention over time (Bransford, Brown, & Cocking, 1999; Hiebert et al., 2003) and discourages students from seeking out the conceptual underpinnings of the math ideas (Hiebert, 1999; Hiebert et al., 1996). Additionally, NCTM (2014) promotes procedural fluency as advanced flexibility of math ideas to deeply understand the appropriate procedures to use to effectively solve problems. This type of fluency develops through problem-solving that fortifies abilities to reason, communicate, and justify, as well as build MCK. Ultimately, dynamic approaches to teaching and learning involves both conceptual understanding and procedural fluency.

Math Identity

The *math identity* of a teacher encompasses how one views their own mathematical abilities. A teacher's math identity is influenced by personal experiences with math learning, how others view their math skills, prior math achievement, content knowledge, levels of math anxiety and efficacy, as well as gender, race, and socioeconomic status. Researchers suggest that strong math identities are associated with higher levels of achievement (Cass, Hazari, Cribbs, & Sonnert, 2011; McGee & Martin, 2011). Regrettably, the divide between strong and weak math identities has long been associated with key sociocultural factors such as gender, race, and socioeconomic status.

Over the years, the field of math has been recognized for its part in sifting and sorting students with long lasting effects. Those who excel at math can access various careers including the science, technology, engineering, and mathematics (STEM) fields; while others find doors to post-secondary STEM pathways closed due to lack of access to senior high school math and science courses (Blickenstaff, 2005; Wang, 2013), or face pressure to enrol in less challenging courses (Smyth & McArdle, 2004). Researchers have highlighted systemic issues such as significant gender and race gaps in STEM fields (National Science Foundation, 2011), beginning with higher percentages of marginalized students dropping out of senior math courses in secondary school (Wei, Lenz, & Blackorby, 2013). Studies have also demonstrated that racialized women are threatened by negative stereotypes, which dissuade them from STEM trajectories, as well as coping with their own low self-efficacy in these fields (Duran, Lopex, & Hughes, 2015; Gunderson et al., 2013). If the field of STEM or even math alone was used as a litmus test for societal equity, results unfortunately suggest a long road ahead to close systemic gaps.

A teacher's math identity is not static as all identities continue to be socially constructed and negotiated (Azmitia, Sye, & Radmacher, 2008). The theory of intersectionality presents insights into the interrelationship of an individual's social identities (Crenshaw, 1989). This intersectionality allows researchers and educators to consider math through the identities of individuals and groups, as well as the ongoing challenges presented due to stereotypes based on race, gender, and socioeconomic status. For instance, females have long underperformed in various math fields, especially in societies where gender parity has not made gains (Else-Quest, Hyde, & Linn, 2010; Guiso, Monte, Sapienza, & Zingales, 2008). Of most importance is that people live through one or more intersecting stereotypes. These stereotypes exist in one's own beliefs or the beliefs of others.

The fear of confirming a negative stereotype through action or personal feature has been recognized as stereotype threat (Steele 1992, 1997). These stereotypes include beliefs that certain racial groups are not suited for the field of math (Steele & Aronson, 1995; Tine & Gotlieb, 2013); girls are not predisposed to be as good at math as boys (Tomasetto, Alparone, & Cadinu, 2011); or those from low-socioeconomic environments are not equipped to succeed in higher levels of math (Tine & Gotlieb, 2013). Adverse effects on math performance are further compounded when negative stereotypes intersect (Brown & Leaper, 2010; Tine & Gotlieb, 2013).

Another threat to one's math identity involves the model minority myth, that is, the belief that certain races are better positioned for success. As a group, Asians are commonly perceived as being proficient in math and science (Lee, 1996; Wong & Halgin, 2006). At first glance, this might appear to have positive ramifications, however, the model minority myth can result in fears of not living up to the myth and ultimately lowering math and science outcomes (Cheryan & Bodenhausen, 2000). It quickly becomes evident that the intersectionality of one's math identity is not only complex, it is consistently reinforced or challenged by societal beliefs and expectations.

The constructs of math efficacy and math anxiety influence how math is conceptualized, approached, and taught, each influencing one's math identity. Bandura's (1977, 1986, 1997) research on teacher efficacy is founded on the theory of social learning. As part of self-efficacy, teacher efficacy is essentially the personal conceptions of one's own teaching abilities (Enochs, Smith, & Huinker, 2000). Teacher efficacy in the area of math can influence teachers' efforts in the classroom, perceived impact on student learning, reactions to disappointment, and how stress is encountered (Swackhamer, Koellner, Basile, & Kimbrough, 2009). The promotion of teacher efficacy is correlated with instructional choices and readiness to attempt new strategies (Swars, Daane, & Giesen, 2006).

Positive influences on instructional practices in the classroom also attribute to decreases in math anxiety in teachers (Vinson, 2001), as well as math achievement (Beilock, Gunderson, Ramirez, & Levine, 2010). According to Vinson (2001), math anxiety is an emotional feeling of nervousness that individuals may possess about their limited understanding of math. High levels of math anxiety influence the instructional choices that teachers make in the classroom, most often emulating transmissive approaches such as high levels of lecture style teaching, reliance on textbooks, memorization of rules, practice of basic skills, and low-level worksheets instead of rich problem-solving activities (Finlayson, 2014). Moreover, teachers with anxiety connected to teaching math are correlated with lower math achievement in students (Hadley & Dorward, 2011). This interplay between math anxiety, efficacy, and instructional choices may further amplify a vicious cycle observed in math education, one in which dynamic teaching and learning practices are superseded by transmissive teaching approaches (Reid & Reid, 2017).

Knowledge Creation

Knowledge creation is defined as the process of interpreting information based on the context and understandings of individuals and groups for the action of mind or body (Nonaka & Takeuchi, 1995). This process of creating knowledge is a foundational component of the social experiences that occur in dynamic math teaching and learning environments. Social learning happens internally within the individual as well as by observing and interacting with others (Bandura, 1962). A conscious awareness can develop in an individual about how learning occurs (Derry & Murphy, 1986; White & Mitchell, 1994), a process called metacognition, which includes *learning how to learn* (Smith, 1982) or *cognition about cognition* (Flavel, 1985).

In Ontario, metacognition is generally defined as students being able to monitor their own learning and develop a capacity to reflect on classroom experiences to support continued learning. Metacognition via reflections on personal thought processes through problem solving and investigations is one of seven mathematical processes expected in every elementary and secondary math classroom (OME, 2005a, 2005b). Notably, a reform approach to teaching and learning is woven throughout the Ontario math curriculums, which promotes students to use their knowledge, think critically, and nurture an enjoyment in math. In alignment with NCTM's (2014) reform approach, the Ontario curriculum also prioritizes students' reflection on thinking, their own and that of others, in order to create math knowledge that is internalized and deeply conceptualized.

When examining learning in math classrooms, knowledge creation is realized when students embrace productive struggle in which they work on problems that are not easily solved (Hiebert & Grouws, 2007; Warshauer, 2014). Further, students engage in tasks that encourage varied and purposeful discourse (Hufferd-Ackles, Fuson, & Gamoran-Sherin, 2004; Lester, 2007) and problems with multiple entry points and solution strategies in order to develop flexibility in understanding of math ideas (Leikin, 2013; Rittle-Johnson & Star, 2009).

The role of the teacher involves decisions that are made continually, and these decisions rely on a knowledge base developed over years within and beyond the educational environment. Polanyi (1962) identifies these two forms of knowledge as tacit and explicit. Tacit knowledge includes knowledge that individuals rely on daily but have a difficult time explaining definitively. This internal knowledge allows an individual to perform many tasks without consciously thinking about the specific actions taken. Alternatively, explicit knowledge is identified as knowledge that is easily externalized and shared with others without difficulty. As teachers gain experience in facilitating the learning of math, teachers' minds are available for deeper thinking about misconceptions that students might encounter, how students might answer a particular problem, as well as making connections between math concepts, representations, and procedures. If teachers' tacit knowledge is based on limited MCK, including their own misconceptions or inaccurate understandings, these errors can negatively affect decision-making and instructional interactions with students. It therefore becomes critical for teachers to consistently reflect on their understandings and practices, exploring explicit knowledge and exposing tacit knowledge in order to create new knowledge for math teaching.

Zones of Math Knowledge Creation Framework

The *Zones of Math Knowledge Creation Framework* includes approaches to math teaching and learning while connecting to teachers' personal math identities (see Figure 1). Deconstruction of the framework unveils teachers' specific strengths and needs so professional learning opportunities can be tailored for improved MCK and MKT. The four zones take into account various constructs: reform and traditional math instruction, math knowledge, math identity, and knowledge creation. As such, the *Zones of Math Knowledge Creation Framework* illuminates how knowledge creation materializes in math classrooms. Teachers bring to class each day their unique personal experiences with math, beliefs about their math abilities, levels of efficacy, anxiety towards math, as well as sociocultural factors. These important elements influence one's personal math identity (PMI).

As teachers plan their instructional approaches for math teaching and learning, PMI must be considered. A "one size fits all" approach to professional learning in math teaching will not be effective due to the unique PMI experiences teachers bring to the classroom. Hence, it would be unreasonable to expect each and every teacher to implement uniform instructional strategies without understanding teachers' current PMI. In fact, one size fits all approaches can be counter-productive in which outcomes could involve increased levels of math anxiety and superficial implementation of instructional practices.

Dynamic teaching and learning instruction provide environments for students to socially learn with one another. Knowledge creation is actualized when students engage in challenging and authentic mathematical tasks in efforts to reinforce their knowledge base, construct new knowledge, advance deep conceptual understandings, and develop efficacy and interest in math. In attempts to promote the *Optimal Zone* of math knowledge creation, a strategic, differentiated, and long-term approach to supporting the professional learning of teachers is necessary. To broadly consolidate this zone, large- and small-scale knowledge mobilization strategies are necessary to foster cultures of inquiry, trust, risk-taking, and learning (Reid, 2015).

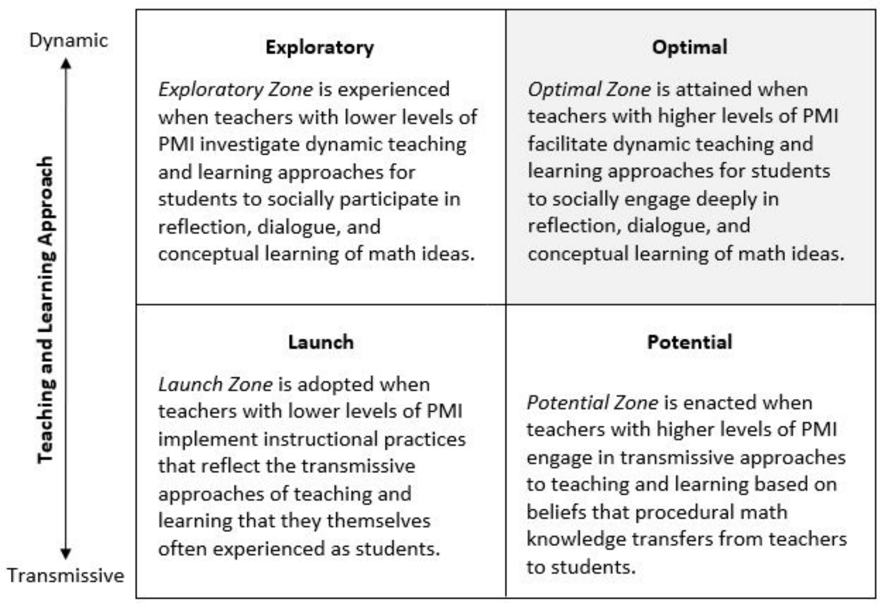


Figure 1. Zones of Math Knowledge Creation Framework

Figure 1. The Zones of Math Knowledge Creation Framework provides an opportunity to view teachers' current approach to teaching and learning math, along with their personal math identity (PMI). As teachers identify their location within the framework, plans can be developed to move toward higher PMI and more dynamic approaches to teaching and learning. In doing so, teachers can advance toward the Optimal Zone of math knowledge creation.

To conceptualize the *Zones of Math Knowledge Creation Framework*, the author envisioned two continuums: 1) teaching and learning approach situated on the vertical axis and 2) personal math identify (PMI) situated on the horizontal axis. The teaching and learning math continuum spans between two approaches: transmissive (i.e., traditional) and dynamic (i.e., reform). As emphasised previously, a highly transmissive style of instruction involves a focus on a lecture style of teaching, procedural learning, and rule memorization. Whereas a dynamic approach to instruction engages students in rich problem-solving activities, with a focus on conceptually understanding math ideas.

It is critical to note that dynamic approaches to teaching and learning math includes foci such as automaticity of basic facts, learning of procedures, as well as practice with algorithms. The essential difference between the approaches is the requirement of conceptual understanding in a dynamic environment. Therefore, how math activities are regularly facilitated differ based on the teaching and learning approach implemented in the classroom.

The horizontal continuum presents the construct of PMI, how a teacher views their mathematical abilities. Based on various factors that would influence their PMI (e.g., math experiences, personal beliefs about math ability, efficacy, anxiety, sociocultural), an individual would situate themselves on the PMI axis. For example, individuals with negative experiences in math as students, high levels of math anxiety, and exposed to stereotype threat, would likely place themselves near the far-left end of low PMI. Whereas individuals with high levels of efficacy and content knowledge in math look to the far-right end of the axis indicating high PMI. The placement on this axis can change based on teachers' contexts such as specific math concepts, grade levels, or external pressures to engage in targeted approaches to teaching and learning math. The goal for all teachers is to move into the *Optimal Zone*. To systemically support teachers to move toward this preferred zone as professionals, each of the four zones must be understood.

Optimal Zone

To further math knowledge creation, the *Optimal Zone* – situated in the upper right quadrant – is the proposed instructional goal for all individuals, classrooms, and learning organizations. When teachers identify higher levels of PMI due to confidence and knowledge of math as a student and teacher, combined with a willingness to explore dynamic approaches to teaching and learning, the highest levels of math knowledge creation for students and teachers occur. In this quadrant, teachers have the knowledge foundations in math required and they also work in a culture that affords them to continually engage their students in reflection, dialogue, and conceptual learning of math ideas.

In order for a teacher to move to this zone of the highest level of knowledge creation, professional learning and supportive networking environments are essential. Within these supportive cultures, teachers can access networks when questions arise or when learning activities do not evolve as planned. Then, teachers can collaboratively investigate students' capacities, understandings, and needs, all of which are drivers for teacher engagement (Little, Gearhart, Curry, & Kafka, 2003; Perry & Lewis, 2010). It is essential for teachers to encounter sustained opportunities to explore dynamic, creative, and innovative instructional approaches in efforts to deeply understand students' interactions and relationships with math. As teachers engage in more dynamic teaching and learning approaches, their PMI can also improve, thereby moving toward the upper right quadrant of the framework.

Launch Zone

Teachers with lower levels of PMI who implement instructional practices that reflect a more transmissive approach to teaching and learning are situated in the *Launch Zone* – found in the lower left quadrant of the framework. Here, teachers may find comfort in math practices that they encountered as students during elementary, secondary school and/or a teacher preparation degree. Through transmissive approaches to teaching, students are rarely engaged in developing their conceptual understandings of math ideas (NCTM, 2014). Furthermore, teachers may bring their own math anxiety to the classroom, which can negatively impact students learning.

Unfortunately, when teachers are anxious about math instruction, they are prone to avoidance behaviours by spending less time planning lessons and engaging in math instruction itself (Hembree, 1990; Trice & Ogden 1986). Researchers have also found that teachers with negative math attitudes or less efficacy toward teaching math are more likely to use transmissive approaches to instruction and avoid dynamic and innovative approaches (Karp, 1991). As teachers continue to evolve as professionals, they can move along both continuums toward higher levels of PMI and more dynamic approaches to teaching and learning. These positive shifts can occur by further developing MCK, efficacy, and MKT, as well as challenging sociocultural factors.

Exploratory Zone

The *Exploratory Zone* – situated in the upper left quadrant – incorporates teachers who are developing a higher level of comfort for increasing dynamic approaches to teaching and learning math, as well increasing their PMI. For this to occur, dynamic teaching and learning approaches are best explored within a supportive learning community. This professional assistance is essential as teachers' PMI is presently lower on the continuum. Through mentoring, professional learning, and collaborative inquiry, teachers could find themselves in positions in which they safely implement dynamic teaching and learning approaches without fears of isolation or reprimand. With successes in the classroom, teachers' PMI can also improve.

One of the risks for systems attempting to move teachers toward this quadrant occurs when innovative approaches to teaching math are implemented superficially. Initiatives to improve math become more about the activities themselves such as group work or using manipulatives instead of developing a deep understanding of math teaching and learning. Rather than merely going through the motions of what seemingly appears to be reform math, teachers should be engaged in investigating the broader understandings of how students effectively learn math concepts and integrating various strategies when most appropriate (Hiebert et al., 2005; Spillane, 2000).

Another risk associated with promoting a systemic move toward this quadrant is realized when teachers feel pressure to enact dynamic approaches in their math classrooms without receiving foundational assistance. In these situations, anxiety can ensue, resulting in a lowered PMI, thereby creating a greater gap to entering the *Optimal Zone*. Although it is important for teachers to explore dynamic instructional approaches, professional learning environments must be constructive and efficacious for knowledge creation to emerge.

Potential Zone

In the *Potential Zone* – situated in the lower right quadrant – teachers have strong MCK and efficacy in teaching math. The PMI of teachers may continue to strengthen through professional learning, gaining knowledge and efficacy, as well as lowering their anxiety. However, their beliefs toward teaching and learning math remain traditional. Despite strong math knowledge and confidence in one's teaching ability, a transmissive approach to math is firmly embraced. Choosing to implement this approach can stem from different pressures such as the demands of covering the curriculum (Darling-Hammond & Richardson, 2009), preparing for high-stakes tests (Boaler & Staples, 2008; Darling-Hammond & Richardson, 2009), or fear that the complexity of math is diluted through reform practices (Schoenfeld, 2004).

Furthermore, it is important to note that transmissive approaches to math instruction are often part of a school's culture, thereby perpetuating long-standing teaching practice (Hart, 2004). The instruction of teachers situated in this zone is dominated by algorithm dependency with a focus on procedures. This, in turn, does not promote a deep understanding of math ideas on a conceptual level. In attempts to engage teachers in the more dynamic approaches to teaching and learning, it is important to provide them with meaningful classroom examples and evidence-based research on how these pedagogies support their students' math achievement.

Discussion

The foundational concepts of the *Zones of Math Knowledge Creation Framework* takes into consideration the personal capacity and identity of teachers at any point in their career. Location within the framework is fluid, and will change as capacities and identities intersect differently with grade levels, students taught, curriculum content, and external pressures to implement specific pedagogical approaches. All teachers can increase their PMI as they evolve in their profession. As teachers increase knowledge, increase efficacy toward teaching and learning math, and lower levels of math anxiety, their readiness for engaging in dynamic approaches is more easily attainable.

Nevertheless, PMI does not automatically increase with expanded teaching experience as it is influenced by many factors. For example, veteran teachers may have taught in the primary grades for their entire careers, feeling very confident with the math knowledge they possess for the early grades. Yet, these same teachers may be asked to teach math at the middle school level thereby decreasing their teaching efficacy and increasing their anxiety due to the content knowledge that is required in the curriculum. In this situation, their PMI could be located on the left side of the continuum. Since math identities are fluid (Azmitia, Sye, & Radmacher, 2008) and confidence in math is dependent on so many variables, teachers will find themselves in different locations in the *Zones of Math Knowledge Creation* framework throughout their careers.

The future of math instruction is critical as society's demand for STEM roles increase (Ramsey & Baethe, 2013; Watt et al., 2017). Unfortunately, there will be a major gap in the workforce as potential positions outnumber the amount of people who possess the required math skills (Friedman, 2005; Lowell & Regets, 2006). So, how can school systems foster communities of mathematicians that include all students and teachers? Foundational to this work is transforming how students and teachers view this subject, as well as their relationship with this subject. Math must be regarded as interesting, challenging, and interactive, in which productive struggle to find solutions is the underpinning of learning itself. In fact, the ultimate goal should involve everyone seeing themselves as mathematicians, embracing challenging math problems and persevering until the problems are successfully unravelled, demystified, and conquered with excitement.

Within the *Zones of Math Knowledge Creation*, the *Launch Zone* is where many elementary teachers in Ontario might find themselves. Due to their math schooling experiences, transmissive approaches to teaching and learning have historically been the norm (Bruce, 2005; NCTM, 2014). Further, provincial data suggest that a majority have not encountered math in a significant way during undergraduate university. Based on EQAO questionnaires of grade three and six in-service teachers, approximately 80% possess a university major or minor that is unrelated to math (EQAO, 2018c; EQAO, 2018d). To support teachers situated in this zone, widespread professional learning and knowledge mobilization of math within and between classrooms, schools, districts, and beyond are necessary.

Researchers suggest that adult professional learning should occur as close to the classroom as possible, as well as being connected to the immediate learning needs of teachers (Reid, 2014; Merriam, 2001). In this zone, the learning needs of teachers are apparent, improved MCK, as well as MKT. For without solid knowledge base of content knowledge, teachers are challenged to engage appropriately with students who struggle with concepts and misconceptions (Ball et al., 2008), as well as making instructional decisions informed by student gaps in understanding (Lui & Bonner, 2016). Without a deeper understanding of the content knowledge, development of MKT and dynamic instructional approaches is threatened (Thames & Ball, 2010), resulting in a continued focus on procedural knowledge without conceptual understanding. Consequently, any attempts to achieve large-scale reform of instructional practice will necessitate sustained and systemic assistance.

Based on a continued prevalence of transmissive approaches to instruction (Banilower, Boyd, Pasley, & Weiss, 2006), it is probable that most secondary math teachers in Ontario would find themselves in the *Potential Zone*. Although they possess higher PMI due to stronger content knowledge and efficacy for teaching math, secondary math teachers may be reticent toward incorporating a dynamic approach to teaching and learning. In fact, providing procedures and algorithms can be viewed as a way to make math more accessible for students. However, without an understanding of the inner workings of the algorithm, math is prone to become a subject without reason (Nardi & Steward, 2003). Further, teachers can view activities such as the use of manipulatives as 'fun math', as compared to 'real math' involving transmissive approaches of textbooks and worksheets (Moyer, 2001). For a majority of math teachers, a transmissive approach worked for them in becoming a mathematician. Therefore, changes to their approach to teaching and learning can be perceived as detrimental to their own students (Charalambous & Philippou, 2010).

Teachers with lower levels of PMI may feel reticent to investigate deeper levels of dynamic teaching and learning. If guidance and support are afforded to teachers, the *Exploratory Zone* can be positively experienced. In this zone, teachers may gain confidence to challenge their own notions of instruction, as well as increase their PMI. Most importantly, when teachers are strategically assisted by others through learning networks, knowledge gained can be shared broadly across teams, schools, and systems (Katz, Earl, & Ben Jaafar, 2009). Conversely, teachers' learning that is unsupported most often results in experiences of isolation with an absence of occasions to engage with professionals or share new knowledge (Kim, 1993).

Additionally, teachers may feel an external pressure to implement dynamic approaches to teaching and learning without a supportive network in reach. For instance, teachers might present open-ended math problems to their students based on suggestions from superiors in their organizations. At the same time, teachers' math anxiety may increase as students develop unique responses to the problems in which teachers are unfamiliar with and cannot determine whether the students' strategies are accurate, applicable, or even valid. Without other teachers to confer with and exchange ideas, the pull toward providing traditional approaches may be strong. Unfortunately, teachers in this zone may feel ill prepared to experiment with more dynamic methods, perhaps sensing isolation in their practice due to a lack of formal or informal learning networks.

The *Optimal Zone* of math knowledge creation offers the most advantage for the teaching profession to be situated. Educational systems can support teachers in moving toward this zone by providing personalized and mobilized professional learning opportunities. This learning can contribute to concept attainment, collective sharing, knowledge creation, collaborative inquiry, and guided experimentation based on the math needs of their students. These conditions allow teachers to further develop both their MCK and MKT, bringing new learnings to the classroom for further exploration and reflection. Within this zone, teachers can feel confident to explore new concepts and pedagogical methods as they build their math competencies.

Historically, educational jurisdictions introduce instructional practices or new initiatives by providing significant funding for resources such as time for collaboration (Phillips, 2003). Regrettably, these vital start-up resources are almost always withdrawn as initiatives are expanded more broadly in organizations (Bulkley, Christman, Goertz, & Lawrence, 2010). It is not lost on the author of this paper that large-scale professional learning opportunities would be a costly endeavour, however, without a dedicated commitment toward sustained jurisdictional learning communities, the cycle of transmissive approaches to math instruction will remain unbroken.

Conclusion

Through the literature review, various supporting factors for this paper were established. The *Zones of Math Knowledge Creation* provides researchers with a framework to base future empirical studies upon. Overall, this paper advocates for extensive, sustained, and systemic professional learning to support transformative math environments. However, professional learning in and of itself will not support teachers if the concept of dynamic teaching and learning is not widely understood. This requires teachers of math, as well as curriculum designers, policy makers, and educational leaders to understand that dynamic approaches to math includes an attention to conceptual understanding, constructivist learning, along with procedural fluency. For instance, rules, procedures, and algorithms are not avoided in dynamic math classrooms. Instead, deep conceptual understanding and advanced flexibility with math ideas offer students opportunities to confidently apply algorithms when appropriate.

The author of this paper strongly believes that teachers desperately want their students to achieve in math, but may not know how to move forward based on their own history with math. Further, teachers may feel numerous pressures that impede their focus on math such as changing district or provincial initiatives, shifting demographics in the classroom, or lack of resources to engage students in deep learning of math. Therefore, organizations responsible for policy, curriculum, and professional learning must be clear with the ultimate approach to instruction and they must also open pathways for all teachers to move toward the preferred *Optimal Zone*.

Without the provision of growth pathways based on the strengths and needs of teachers, anxiety and guilt may be the unfortunate outcome thereby negatively influencing PMI. Just as teachers are charged with the responsibility to understand their students and plan accordingly, it is vital that educational systems consider the starting points and learning pathways of their teachers. For math instruction to transform, personal math identities and approaches to teaching and learning must move in a north-easterly direction in this framework. To occur systemically, it is necessary to immerse teachers in sustained environments of collaborative professional learning. Then and only then, effective instructional practices will be mobilized, networks of support and learning will be nurtured, and generations of mathematicians will be cultivated.

References

Azmitia, M., Syed, M., & Radmacher, K. (2008). On the intersection of personal and social identities: Introduction and evidence from a longitudinal study of emerging adults. In M. Azmitia, M. Syed, & K. Radmacher (Eds.), *The intersections of personal and social identities.* (pp. 1-16). San Francisco, CA: Jossey-Bass.

Baker, D., Knipe, H., Collins, J., Leon, J., Cummings, E., Blair, C., & Gamson, D. (2010). One hundred years of elementary school mathematics in the United States: A content analysis and cognitive assessment of textbooks from 1900 to 2000. *Journal for Research in Mathematics Education*, *41*(4), 383-423.

Bandura, A. (1962). Social learning through imitation. In M. R. Jones (Ed.), *Nebraska symposium on motivation*. (pp. 211-269). Lincoln, NE: University of Nebraska Press.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191-215.

Bandura, A. (1986). The explanatory and predictive scope of self-efficacy theory. *Journal of Social and Clinical Psychology*, *4*(3), 359-373.

Banilower, E. R., Boyd, S. E., Pasley, J. D., & Weiss, I. R. (2006). *Lessons from a Decade of Mathematics and Science Reform: A Capstone Report for the Local Systemic Change through Teacher Enhancement Initiative*. Horizon Research, Inc. Retrieved from http://www.horizon-research.com/pdmathsci/htdocs/reports/capstone.pdf

Bartell, T. G., Webel, C., Bowen, B., & Dyson, N. (2013). Prospective teacher learning: recognizing evidence of conceptual understanding. *Journal of Mathematics Teacher Education, 16*(1), 57-79.

Beilock, S. L., Gunderson, E. A., Ramirez, G., & Levine, S. C. (2010). Female teachers' math anxiety affects girls' math achievement. *Proceedings of the National Academy of Sciences*, *107*(5), 1860-1863. doi:10.1073/pnas.0910967107

Boaler, J. (2019). Developing mathematical mindsets: The need to interact with numbers flexibly and conceptually. *American Educator, 42*(4), 28-33.

Boaler, J., & Staples, M. (2008). Creating mathematical futures through an equitable teaching approach: The case of Railside School. *Teachers College Record, 110*(3), 608-645.

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline or gender filter. *Gender and Education, 17*(4), 369–386. doi:10.1080/09540250500145072

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Brown, C. S., & Leaper, C. (2010). Latina and European American girls' experiences with academic sexism and their self-concepts in mathematics and science during adolescence. *Sex roles, 63*(11-12), 860-870. doi:10.1007/s11199-010-9856-5

Bruce, C. (2005). Teacher candidate efficacy in mathematics: Factors that facilitate increased efficacy. In Lloyd, G.A., Wilson, S., Wilkins, J.L.M. & Behm, S.L (Eds.), Proceedings of the twenty-seventh Psychology of Mathematics Association-North America.

Bruce, C. (2007). *Student interaction in the math classroom: Stealing ideas or building understanding? What works? Research into Practice, Monograph #1.* Toronto, ON: The Literacy and Numeracy Secretariat, Ontario Ministry of Education. Retrieved from http://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/Bruce.pdf

Bruce, C. D., Esmonde, I., Ross, J., Dookie, L., & Beatty, R. (2010). The effects of sustained classroom-embedded teacher professional learning on teacher efficacy and related student achievement. *Teaching and Teacher Education, 26*(8), 1598-1608. doi:10.1016/j.tate.2010.06.011

Bulkley, K. E., Christman, J. B., Goertz, M. E., & Lawrence, N. R. (2010). Building with benchmarks: The role of the district in Philadelphia's benchmark assessment system. *Peabody Journal of Education, 85*(2), 186-204. doi:10.1080/01619561003685346

Canadian Language and Literacy Research Network. (2009). The impact of the Literacy and Numeracy Secretariat: Changes in Ontario's education system. London, UK: Author.

Cass, C. A. P., Hazari, Z., Sadler, P. M., & Sonnert, G. (2011, October). *Engineering persisters and non-persisters: Understanding inflow and outflow trends between middle school and college*. Paper presented at the ASEE Annual Conference, Vancouver BC, Canada. https://peer.asee.org/17881

Charalambous, C. Y., & Philippou, G. N. (2010). Teachers' concerns and efficacy beliefs about implementing a mathematics curriculum reform: Integrating two lines of inquiry. *Educational Studies in Mathematics*, *75*(1), 1-21.

Cheryan, S., & Bodenhausen, G. V. (2000). When positive stereotypes threaten intellectual performance: The psychological hazards of "model minority" status. *Psychological Science, 11*(5), 399-402. doi:10.1111/1467-9280.00277

Crenshaw, K. (1989). Demarginalizing the intersection of race and sex: A black feminist critique of antidiscrimination doctrine, feminist theory, and antiracist politics. *The University of Chicago Legal Forum, 1989*(1), 139-167.

Darling-Hammond, L., & Richardson, N. (2009). Research review/teacher learning: What matters. *Educational Leadership, 66*(5), 46-53.

Derry, S. J., & Murphy, D. A. (1986). Designing systems that train learning ability: From theory to practice. *Review of Educational Research, 56*(1), 1-39.

Destrebecqz, A. (2004). The effect of explicit knowledge on sequence learning: A graded account. Psychologica Belgica, *44*(4), 217-247. doi:10.5334/pb-44-4-217

Duran, A., Lopez, D., & Hughes, C. (2015). Women from diverse backgrounds in the science technology engineering and math (STEM) professions: Retention and career development. In C. Hughes (Ed.), *Impact of Diversity on Organization and Career Development* (pp. 214-242). Hershey, PA: Business Science Reference, IGI Global.

Education Quality and Accountability Office. (2018a). *Ontario Student Achievement: English Language Students: EQAO's Provincial Elementary Report: Results of the Reading, Writing and Mathematics, Primary Division (Grades 1-3) and Junior Division (Grades 4-6)*. Toronto, ON: Author.

Education Quality and Accountability Office. (2018b). *Ontario Student Achievement: English Language Students: EQAO's Provincial Secondary Report: Results of the Grade 9 Assessment of Mathematics and the Ontario Secondary School Literacy Test, 2016-17*. Toronto, ON: Author.

Education Quality and Accountability Office. (2018c). *Teacher Questionnaire – Grade 3: Provincial Results*. Toronto, ON: Author.

Education Quality and Accountability Office. (2018d). *Teacher Questionnaire – Grade 6: Provincial Results*. Toronto, ON: Author.

Education Quality and Accountability Office. (2019). *Lessons from EQAO Data on Fundamental Math Skills: How Are Ontario Students Doing?* Toronto, ON: Author.

Else-Quest, N. M., Hyde, J. S., & Linn, M. C. (2010). Cross-national patterns of gender differences in mathematics: a meta-analysis. *Psychological bulletin, 136*(1), 103-127. doi:10.1037/a0018053

Enochs, L. G., Smith, P. L., & Huinker, D. (2000). Establishing factorial validity of the mathematics teaching efficacy beliefs instrument. *School Science and Mathematics, 100*(4), 194-203. doi:10.1111/j.1949-8594.2000.tb17256

Fedeli, V. (2018). *A Plan for the People: Ontario Economic Outlook and Fiscal Review*. Toronto, ON: Queen's Printer for Ontario. Retrieved from https://www.fin.gov.on.ca/fallstatement/2018/fes2018-en.pdf

Finlayson, M. (2014). Addressing math anxiety in the classroom. *Improving Schools*, *17*(1), 99-115. doi:10.1177/1365480214521457

Flavel, J. H., (1985). *Cognitive development* (Second Edition). Englewood Cliffs, NJ: Prentice-Hall.

Friedman, T. (2005). *The world is flat: A brief history of the twenty-first century*. New York, NY: Farrar, Straus, and Giroux.

Guiso, L., Monte, F., Sapienza, P., & Zingales, L. (2008). Culture, gender, and math. *Science, 320*(5880), 1164-1165.

Gunderson, E. A., Gripshover, S. A., Romero, C., Dweck, C. S., Goldin-Meadow, S., & Levine, S. C. (2013). Parent praise to 1- to 3-year-olds predicts children's motivational frameworks 5 years later. *Child Development, 84*(5), 1526–1541. doi:10.1111/cdev.12064

Hadley, K. M., & Dorward, J. (2011). Investigating the relationship between elementary teacher mathematics anxiety, mathematics instructional practices, and student mathematics achievement. *Journal of Curriculum and Instruction*, *5*(2), 27-44. doi:10.3776/joci.2011.v5n2p27-44

Haeck, C., Lefebvre, P., & Merrigan, P. (2014). *The Distributional Impacts of a Universal School Reform on Mathematical Achievements: A Natural Experiment from Canada (revised)*, 41, 137-160.

Hamlin, D., & Cameron, D. (2015). *Applied or Academic: High Impact Decisions for Ontario Students.* People for Education. Toronto: ON. Retrieved from http://peopleforeducation.ca/wp-content/uploads/2017/07/Applied-or-Academic-Report-2015.pdf

Hart, L. C. (2004). Beliefs and perspectives of first-year, alternative preparation, elementary teachers in urban classrooms. *School Science and Mathematics, 104*(2), 79-88.

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal of Research in Mathematics Education, 21*, 33–46. doi:10.2307/749455

Hiebert, J. (1992). Learning and teaching with understanding. In D. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 65-97). New York, NY: Macmillan.

Hiebert, J. (1999). Relationships between research and the NCTM standards. *Journal for Research in Mathematics Education, 30*(1), 3-19.

Hiebert, J., Carpenter, T. P., Fennema, E., Fuson, K., Human, P., Murray, H., ... & Wearne, D. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. *Educational Researcher, 25*(4), 12-21.

Hiebert, J., Gallimore, R., Garnier, H., Givvin, K. B., Hollingsworth, H., Jacobs, J., … Stigler, J. W. (2003). Understanding and improving mathematics teaching: Highlights from the TIMSS 1999 Video Study. *Phi Delta Kappan, 84*(10), 768-775.

Hiebert, J., Stigler, J. W., Jacobs, J. K., Givvin, K. B., Garnier, H., Smith, M., … Gallimore, R. (2005). Mathematics teaching in the United States today (and tomorrow): Results from the TIMSS 1999 video study. *Educational Evaluation and Policy Analysis,* *27*(2), 111-132. doi:10.3102/01623737027002111

Hiebert, J., & Grouws, D. A. (2007). The effects of classroom mathematics teaching on students' learning. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 371–404). Charlotte, NC: Information Age Publishing.

Hill, H., & Ball, D. L. (2009). The curious—and crucial—case of mathematical knowledge for teaching. *Phi Delta Kappan, 91*(2), 68-71.

Hill, H. C., Blunk, M. L., Charalambous, C. Y., Lewis, J. M., Phelps, G. C., Sleep, L., & Ball, D. L. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition and Instruction, 26*(4), 430-511. doi:10.1080/07370000802177235

Hufferd-Ackles, K., Fuson, K. C., & Sherin, M. G. (2004). Describing levels and components of a math-talk learning community. *Journal for Research in Mathematics Education, 35*(2), 81-116.

James, C.E. & Turner, T. (2017). *Towards Race Equity In Education: The Schooling of Black Students in the Greater Toronto Area.* Toronto, Ontario, Canada: York University.

Karp, K. S. (1991). Elementary school teachers' attitudes toward mathematics: The impact on students' autonomous learning skills. *School Science and Mathematics, 91*(1), 265-270.

Katz, S., Earl, L. M., & Ben Jaafar, S. (2009). *Building and connecting learning communities: The power of networks for school improvement.* Thousand Oaks, CA: Sage.

Kilpatrick, J. (2012). The new math as an international phenomenon. *ZDM*, *44* (4), 563–571. doi:10.1007/s11858-012-0393-2

Kim, D. H. (1993). The link between individual and organizational learning. *The Strategic Management of Intellectual Capital, 24*(3), 41-62.

Lee, S. J. (1996). *Unraveling the "model minority" stereotype: Listening to Asian American youth*. New York, NY: Teachers College Press.

Leikin, R. (2013). Evaluating mathematical creativity: The interplay between multiplicity and insight1. *Psychological Test and Assessment Modeling, 55*(4), 385-400.

Lester, F. K., Jr. (Ed.). (2007). *Second handbook of research on mathematics teaching and learning*. Charlotte, NC: Information Age.

Little, J. W., Gearhart, M., Curry, M., & Kafka, J. (2003). Looking at student work for teacher learning, teacher community, and school reform. *Phi Delta Kappan, 85*(3), 184-192.

Lowell, B. L., & Regets, M. (2006). A half-century snapshot of the STEM workforce, 1950-

2000. Washington, D.C.: Commission on Professionals in Science and Technology.

Lui, A. M., & Bonner, S. M. (2016). Preservice and inservice teachers' knowledge, beliefs, and instructional planning in primary school mathematics. *Teaching and Teacher Education, 56*, 1-13. doi.org/10.1016/j.tate.2016.01.015

Ma, L. (1999). *Knowing and teaching elementary mathematics: Teachers' Understanding of fundamental mathematics in China and the United States.* Mahwah, NJ: Lawrence Erlbaum Associates.

Maaß, K., & Artigue, M. (2013). Implementation of inquiry-based learning in day-to-day teaching: A synthesis. *ZDM*, *45*(6), 779-795.

Mann, E. L. (2006). Creativity: The essence of mathematics. *Journal for the Education of the Gifted, 30*(2), 236-260.

Mason, J., & Davis, B. (2013). The Importance of Teachers' Mathematical Awareness for In-the-Moment Pedagogy. *Canadian Journal of Science, Mathematics and Technology Education, 13*(2), 182-197. doi:10.1080/14926156.2013.784830

Marshall, J. (2006). Math wars 2: It's the teaching, stupid!. *Phi Delta Kappan*, *87*(5), 356-363. doi:10.1177/003172170608700506

McCormick, R. (1997). Conceptual and procedural knowledge. *International Journal of Technology and Design Education, 7*(1-2), 141-159.

McGee, E. O., & Martin, D. B. (2011). "You would not believe what I have to go through to prove my intellectual value!" Stereotype management among academically successful Black mathematics and engineering students. *American Educational Research Journal, 48*(6), 1347-1389. doi:10.3102/0002831211423972

Merriam, S. B. (2001). Andragogy and self-directed learning: Pillars of adult learning theory. In S. B. Merriam (Ed.), *The new update on adult learning theory. New directions for continuing education, no. 89* (pp. 3-13). San Francisco, CA: Jossey-Bass.

Moyer, P. S. (2001). Are we having fun yet? How teachers use manipulatives to teach mathematics. *Educational Studies in Mathematics, 47*(2), 175-197. doi:10.1023/A:1014596316942

Nardi, E., & Steward, S. (2003). Is mathematics TIRED? A profile of quiet disaffection in the secondary mathematics classroom. *British Educational Research Journal, 29*(3), 345-366. doi:10.1080/01411920301852

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all.* Reston, VA: Author.

National Science Foundation. (2011). *Women, Minorities, and Persons with Disabilities in Science and Engineering*. Arlington, VA: Author.

Nonaka, I. A., & Takeuchi, H. A. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation.* Oxford, NY: Oxford University Press.

Office of the Premier. (2017). *Updated curriculum, new report cards coming to Ontario schools: Province modernizing school system to unleash full potential of every student* [News Release]. Retrieved from https://news.ontario.ca/opo/en/2017/09/updated-curriculum-new-report-cards-coming-to-ontario-schools.html

Ontario Association for Mathematics Education. (2017). A vision for learning mathematics. Retrieved from http://www.oame.on.ca/main/index1.php?lang=en&code=principles.

Ontario Ministry of Education. (2005a). *The Ontario Curriculum - Grades 1-8: Mathematics*. Toronto, ON: Author.

Ontario Ministry of Education. (2005b). *The Ontario Curriculum - Grades 9 and 10: Mathematics*. Toronto, ON: Author.

Ontario Ministry of Education. (2019). *Bill 48, Safe and Supportive Classrooms Act*. Toronto, ON: Author. Retrieved from https://www.ola.org/en/legislative-business/bills/parliament-42/session-1/bill-48

Perry, R., & Lewis, C. (2010). Building demand for research through lesson study. In C. E. Coburn & M. K. Stein (Eds.), *Research and practice in education: Building alliances, bridging the divide* (pp. 131-145). Lanham, MD: Rowman & Littlefield.

Phillips, J. (2003). Powerful learning: Creating learning communities in urban school reform. *Journal of Curriculum and Supervision, 18*(3), 240-258.

Philipp, R. A. (2008). Motivating Prospective Elementary School Teachers to Learn Mathematics by Focusing upon Children's Mathematical Thinking. *Issues in Teacher Education, 17*(2), 7-26.

Polanyi, M. (1962). Tacit knowing: Its bearing on some problems of philosophy. *Reviews of Modern Physics, 34*(4), 601-616.

Ponte, J. P. & Chapman, O. (2008). Preservice mathematics teachers' knowledge and development. In L. D. English (Ed.), *Handbook of international research in mathematics education: Directions for the 21st century* (2nd Edition, pp. 225 - 263). New York: Routledge.

Ramsey, K., & Baethe, B. (2013). The keys to future STEM careers: Basic skills, critical thinking, and ethics. *Delta Kappa Gamma Bulletin, 80*(1), 26-33.

Reid, S. (2014). Knowledge influencers: Leaders influencing knowledge creation and mobilization. Journal of Educational Administration, 52(3), 332-357. DOI: http://dx.doi.org/10.1108/JEA-01-2013-0013

Reid, S. (2015). Designing a knowledge mobilization strategy: Leading through influence. Journal of Leadership Education, 14(3), 159-167. DOI:1012806/V14/I3/A2.

Reid, M., & Reid, S. (2017). Learning to be a math teacher: What knowledge is essential? International Electronic Journal of Elementary Education, 9(4), 851-872.

Reid, M., Reid, S., & Hewitt, J. (2018). Nervous about numbers: Math content knowledge and math anxiety of teacher candidates. Master of Teaching Research Journal, (Inaugural Issue), 1-18.

Richardson, V. (2003). Constructivist pedagogy. *Teachers College Record, 105*(9), 1623–1640. doi:http://dx.doi.org/10.1046/j.1467-9620.2003.00303.x.

Rittle-Johnson, B. (2006). Promoting transfer: Effects of self-explanation and direct instruction. *Child Development, 77*(1), 1-15.

Rittle-Johnson, B., & Star, J. R. (2009). Compared with what? The effects of different comparisons on conceptual knowledge and procedural flexibility for equation solving. *Journal of Educational Psychology, 101*(3), 529-544. doi:10.1037/a0014224

Ross, J. A., McDougall, D., & Hogaboam-Gray, A. (2002). Research on reform in mathematics education, 1993-2000. *Alberta Journal of Educational Research, 48*(2), 122-138.

Schoenfeld, A. H. (2004). The math wars. *Educational Policy*, *18*(1), 253-286. doi:10.1177/0895904803260042

Silverman, J., & Thompson, P. W. (2008). Toward a framework for the development of mathematical knowledge for teaching. *Journal of Mathematics Teacher Education, 11*(6), 499-511. doi:10.1007/s10857-008-9089-5

Smith, R. M. (1982). *Learning how to learn: Applied theory for adults*. New York, NY: Cambridge University Press.

Smyth, F. L., & McArdle, J. J. (2004). Ethnic and gender differences in science graduation at selective colleges with implications for admission policy and college choice. *Research in Higher Education, 45*(4), 353-381. doi:10.1023/B:RIHE.0000027391.05986.79

Spillane, J. P. (2000). Cognition and policy implementation: District policymakers and the reform of mathematics education. *Cognition and Instruction, 18*(2), 141-179.

doi:10.1207/S1532690XCI1802_01

Spillane, J. P. (2005). Primary school leadership practice: How the subject matters. *School Leadership and Management*, *25*(4), 383-397. doi:10.1080/13634230500197231

Steele, C. M. (1992). Race and the schooling of Black Americans. *The Atlantic Monthly, 269*(4), 68-78.

Steele, C. M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist, 52*(6), 613-629. doi:10.1037/0003-066X.52.6.613

Steele, C. M., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology, 69*(5), 797-811. doi:10.1037/0022-3514.69.5.797

Swars, S.L., Daane, C.J., & Giesen, J. (2006). Mathematics anxiety and mathematics teacher efficacy: What is the relationship in elementary pre-service teachers? *School Science and Mathematics*, *106*(7), 306-315. doi:10.1111/j.1949-8594.2006.tb17921.x

Swackhamer, L. E., Koellner, K., Basile, C., & Kimbrough, D. (2009). Increasing the self-efficacy of inservice teachers through content knowledge. *Teacher Education Quarterly, 36*(2), 63-78.

Thanheiser, E., Browning, C., Edson, A. J., Lo, J. J., Whitacre, I., Olanoff, D., & Morton, C. (2014). Prospective elementary mathematics teacher content knowledge: What do we know, what do we not know, and where do we go? *The Mathematics Enthusiast, 11*(2), 433-448.

Thames, M., & Ball, D. L. (2010). What math knowledge does teaching require? *Teaching Children Mathematics, 17*(4), 220-229.

Tine, M., & Gotlieb, R. (2013). Gender-, race-, and income-based stereotype threat: the effects of multiple stigmatized aspects of identity on math performance and working memory function. *Social Psychology of Education, 16*(3), 353-376. doi:10.1007/s11218-013-9224-8

Tomasetto, C., Alparone, F. R., & Cadinu, M. (2011). Girls' math performance under stereotype threat: The moderating role of mothers' gender stereotypes. *Developmental Psychology, 47*(4), 943-949. doi:10.1037/a0024047

Trice, A. D., & Ogden, E. D. (1986). Correlates of mathematics anxiety in first-year elementary school teachers. *Educational Research Quarterly, 11*(3), 2-4.

Vinson, B. M. (2001). A comparison of preservice teachers' mathematics anxiety before and after a methods class emphasizing manipulatives. *Early Childhood Education Journal*, *29*(2), 89-94.

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms. *Journal of Mathematics Teacher Education, 18*(4), 375-400. doi:10.1007/s10857-014-9286-3

Watt, H. M., Hyde, J. S., Petersen, J., Morris, Z. A., Rozek, C. S., & Harackiewicz, J. M. (2017). Mathematics—A critical filter for STEM-related career choices? A longitudinal examination among Australian and US adolescents. *Sex Roles, 77*(3-4), 254-271.

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal, 50*(5), 1081-1121. doi:10.3102/0002831213488622

Wei, X., Lenz, K. B., & Blackorby, J. (2013). Math growth trajectories of students with disabilities: Disability category, gender, racial, and socioeconomic status differences from ages 7 to 17. *Remedial and Special Education, 34*(3), 154-165. doi:10.1177/0741932512448253

White, R. T., & Mitchell, I. J. (1994). Metacognition and the quality of learning. *Studies in Science Education, 23*(1), 21-37. doi:10.1080/03057269408560028

White-Fredette, K. (2010). Why not philosophy? Problematizing the philosophy of mathematics in a time of curriculum reform. *The Mathematics Educator*, *19*(2), 21-31.

Wong, F., & Halgin, R. (2006). The "model minority": Bane or blessing for Asian Americans?. *Journal of Multicultural Counseling and Development, 34*(1), 38-49.

Zegarac, G. (2016). *Ontario's renewed mathematics strategy* [Memorandum]. Retrieved from http://www.edu.gov.on.ca/eng/policyfunding/memos/april2016/dm_math_strategy.pdf

Citation:
Reid, S. (2019). Dynamic math teaching and learning: Zones of math knowledge creation framework. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 36-62). ISRES Publishing, ISBN: 978-605-69854-0-9.

Mathematics Learning and Teaching in an Interdisciplinary Framework Simulating Ancient Academy

Maria Giuseppina Adesso
University of Salerno, Italy

Roberto Capone
University of Salerno, Italy

Oriana Fiore
University of Salerno, Italy

Francesco Saverio Tortoriello
University of Salerno, Italy

Introduction

A scientific revolution arose during the seventeenth centuries, also thanks to the development of new institutions for the acquisition and dissemination of knowledge. The most important of these new institutions were the Academies (Ruscelli et al., 1984). Over 800 Academies flourished in Italy in the period 1525-1700, forming a significant and influential aspect of social and intellectual culture. Interdisciplinary in their interests, bridging literature, arts, medicine, and sciences, the Academies operated outside, but were often interconnected with official institutions like universities, courts, political and religious bodies, and offered a more flexible, apparently free and equal form of association. Members or affiliates could sometimes include socially marginal figures like women and artisans. Academies attracted also foreign intellectuals and their networks extended across Europe.

In the present work, a new learning/teaching approach has been introduced, authors named "Academic Education", to learn Mathematics and Science in an interdisciplinary framework, as in an ancient Academy, but with innovative and effective instruments. Role playing, and drama mediators (Damiani, 1993) have been preferred, to better live the Academic atmosphere.

An interdisciplinary educational path has been planned, in which "hidden" (i.e. absent on the schoolbooks) synthetic Geometry theorems have been re-discovered by simulating scientific Academies. This unit has been experimented with about ninety students, attending second year of a Secondary School.

Information and Communication Technology (ITC) has been used, in particular social networks and dynamical Geometry software GeoGebra.

Main interest in Geometry is because emerging data about study of this branch in literature. In particular, researchers have long reported the difficulties encountered by students of Geometry, referring to such basic geometric concepts as the angle, triangle and quadrilateral (Gal, 2010). Nevertheless, Özerem (2012) revealed that 7th grade secondary school students have a number of misconceptions, lack of background knowledge, reasoning and basic operation mistakes at the topics: measures, angles and shapes, transformations and construction and 3-D shapes. Moreover, EIA TIMSS2015 data (Jones et al., 2015), show that Italian 8th grade students don't attribute to Maths study an operational value, they think that Maths is not fundamental for their future and their pleasure in the studying Mathematics is very poor.

Main idea is increasing pleasure and motivation in studying Mathematics and Science, creating a social, free scheme environment, starting from free discussions and investigations, not necessarily connected to textbooks, starting from the particular Italian historical background.

Our research starts from these questions:

May a methodological approach based on a social comparison between students improve their motivation in studying Mathematics?

May a methodological approach based on an historical, students self-managed, research intrigue and arouse interest in Mathematics, and especially in Geometry?

May the use of an informal language encourage the students to discuss about Mathematics?

Italian Academies

The idea of "Academy" goes back to ancient Greece: the first Academy was founded by Plato in 387 B.C. in Athens. Aristotle studied there for twenty years before founding his school, Lyceum. Two women are known to have studied with Plato at the Academy, Axiothea of Phlius and Lasthenia of Mantinea. The subjects of study almost certainly included Mathematics as well as the Philosophical topics, but there is little reliable evidence about it.

Traditionally, an Academy has been defined as being composed of a group of individuals interested in intellectual or cultural matters, which held regular meetings to discuss topics of intellectual, cultural or current interest and to promote lectures, dramatic performances, scientific enquiry and experimentation, and to produce publications arising out of these.

In Italy, in the fifteenth century, this idea was revived and was used to refer to groups of humanists who gathered together informally to discuss matters of literature and philosophy arising out of the continuing revival of classical culture, to which the terms Humanism and Renaissance were later applied.

The birth of the Italian Academies in the full sense, as places to disseminate interdisciplinary learning, can be dated to the formation in 1525 of “Intronati Academy” in Siena. The Italian Academies of the sixteenth and seventeenth centuries, thus formally constituted, were the earliest of such institutions, which were subsequently found throughout Europe, as other countries sought to emulate this model. D’Alembert, in his l’Én-cyclopédie, wrote about the word.

An innovative collaborative project (since 2009 up to now) involving Royal Holloway, British Library, and University of Reading about Italian Academies 1525-1700 has been developed and a database has been realized (Italian Academy Database, IAD), which mapped the Italian world of Academies as a global phenomenon, http://www.bl.uk/catalogues/ItalianAcademies/, connecting Academies, books, and people (587 Academies, 7100 People, 911 Works). This project showed that Italian Academies could be considered as the first intellectual “social networks” of early modern Europe (Testa, 2015).

Their membership included pioneering scientists, literary polemicists, political thinkers, women as well as men, and representatives of all social classes. In addition to their intellectual pursuits, the Academies had a more playful aspect, including the delivery of orations based on paradoxes, the performance of games, or the invention of amusing names for the Academy, its members and its activities, often represented visually in punning illustrations and devices. The individual nicknames taken by members reflected the idea present in the name of the Academy. Members of Academies frequently published, for many different reasons, only under their Academy nicknames – and this fact constitutes one of the principal difficulties in researching Academy publications through standard, author-name catalogues.

Varying in size and importance, Academies were of two major types: some preferred to keep a low profile and gathered in privately maintained spaces, others became symbols of ostentation and often met to publicly celebrate courtly life, patrons, and events of both a secular and religious nature. Nevertheless, some common features may be found in all the Academies: an effective name, a logo, a motto, generally a noble or a celebrity who favoured its growth, interdisciplinary discussions and thoughts freedom. Often the place where Academies carried out their activities were unknown and sometimes, they corresponded to private houses.

Irace and Panzarelli (2011) show that in Naples, there were 161 Academies, but 99 places are only known nowadays (53 in private houses, 33 convents). The interests of Academies ranged very widely across the disciplines, from art and literature to the experimental sciences. A study on Academies in Bologna, Florence and Naples in Irace and Panzarelli (2011) analyses most relevant topics in the Academies: 7,7% was about Science and Maths.

First scientific Academy, “Academia secreta”, was founded in south of Italy (probably in Salerno, near Naples) by Girolamo Ruscelli, although few news about it can be found in literature (Ruscelli et al., 1984) and the place where it was born is still unknown.

In scientific Academies, some “geometric problems” were also discussed, taking into account both calculus and synthetic geometry solutions. Few details may be found about these “discussions”, also due to the general academic rules: the members could only have access to all the research material developed inside the Academy.

Academic Education: A New Learning and Teaching Methodological Approach

Starting from main characteristics of Italian Academies, a new learning and teaching methodological approach has been developed, authors named “Academic Education”.

Main features of this approach can be summarised as follow:

- A “new learning place”, an Academy, have to be created, also by choosing all details to identify it (logo, motto, wearing members, eventually rules). This place may be either virtual or real. Virtual Academies could connect students in all the world. Nevertheless, it should be better to context this place, also taking into account the surrounding territory.
- All the students have to be members of an Academy. More than one Academy may be “founded” in a class (or in an open classes group); in this case, heterogeneous groups have to be created, in agreement with ancient Academies members, just paying attention that females should be equally distributed into all the Academies.
- Social networks have to be used as a vehicle to disseminate learning:

- in a “free” way;

- in an anonymous way, depending on the student’s opinion, by using a pseudonym (nickname);

- with a “limited open access”: only the “members” may have a free access to discussions.

- The educational path should be interdisciplinary, focused around a main theme, but also including topics which could emerge from debate (both live and/or virtual debate), not necessary planned by the teacher.
- Virtual meetings should be organized on social networks, either synchronous (planned as in a forum) or asynchronous (chat).
- Live meetings in the blended Academy have to be organized together with students and teachers of different subjects, to give main effort to the interdisciplinary path.

In order to apply this new methodological approach, a scheme "step by step" is reported in Table 1

Table 1. Centre the Caption Above the Table

Action	Time	Teacher Role	Students Role	Observations
Choice of "Academy typology": blended or virtual	1 hour	Teacher takes a decision, depending on: time, topic to be experimented, number of students		- Blended is preferred if topic is hard, time is lower 10 hours, experimentation is limited to one classroom - Virtual Academy is preferred if topic is standard, time is over than 10 hours, experimentation is in open classes
Choice of the social network	1 hour	Teacher shows some "didactical" social networks, as Padlet, Edmodo...	Students suggest the most popular social networks they use (Facebook, WhatsApp)	In order to choose the "right" social network, it is important to take into account all the technical characteristics, e.g. possibility to share files, links, maximum dimension of the shared files, the opportunity to create closed groups.
Creation of the "Academy"	1 hour	Teacher and students choose, together, main characteristics of new Academy: name, logo, motto, eventually some rules.		
Choice of main topic	1 hour	Teacher chooses main topic and introduces it on the social network, just posting an image or a sentence, with no further information..	Students search on the web and/or on books/journals some information about main topic	The teacher introduction have to be effective, also to engage all the students and to arouse curiosity.
Virtual Debate	3 hours (this time is indicative, it depend on the topic)	Teacher takes part to the discussion only if the students ask for him.	Students share information between them on the social network.	Shared information could be partially mistaken or in contrast between them. Teacher does not "reveals", at this step, the mistakes
Planning/ realizing learning activities	3 hours	Teacher critically analyses student's discussion and suggests some learning activities to "confute" or "prove" student's idea	Some students carry out the activities suggested by the teacher and share the results on the social network	The criticality of this step is that not necessarily all the students actively carry out the "assigned works". Teacher has an immediate trace about it, but he hasn't to force students.
Extend topics in an Interdisciplinary Framework	3 hours	Teacher suggests some topics, connected to the main theme, but in different contexts (history, art, science, music and so on)	Serendipity gives the opportunity to extend main topic to new and interesting topics, in an interdisciplinary framework	Two experimentations of the same path could be very different between them, depending on this step. At this step, further teachers of different subjects could be added to the "Virtual Academy"
Live Meeting (only in case of blended Academy)	5 hours	Teachers of different subjects actively attend to the discussion	Students show their research and activities results; organize their own learning unit.	ICT are fundamental to better organize learning unit, nevertheless also traditional instrument can be used
Final product	2 hours	Teacher suggests realizing a final product, s	Students decide modality to realize final product	Final product should be: Multimedia, Easy to share, Effective, Interdisciplinary

A case study: The Baffling Academy

Taking into account the "Academic Education", an interdisciplinary educational path has been planned. Learning unit has been experimented with about ninety students, attending the second year at High School; times is in agreement with Table 1 (about 20 hours). The final live meeting (5 hours) has been realized together with History and Literature, Latin, Science, English and Maths teachers.

Students used their smart-phones and/or tablets, as in Bring Your Own Device (BYOD) practises, whereas a LIM and a PC have been used in the classroom, too. In order to verify Geometry theorems, interactive and dynamical geometry software GeoGebra, has been used. Historical texts have been also consulted, mainly on the web. Let's summarize experimental phases, following steps in Tab.1. Here we show results about a second class of a Scientific High School, composed by 27 students.

Choice of Academy typology

We created both types of Academies:

a) three virtual Academies, in which members communicate between them only by using social networks;

b) a blended Academy, with both virtual and live meetings. The motivation of this choice will be clarified later in the experimental details.

Choice of Social Network

After a debate between students and teacher, *WhatsApp* has been selected as social network, to create "closed virtual places", where they met and had their learning activities.

Choice of Main Topics

Maths teacher suggested, as main topic, "synthetic Geometry theorems and problems on triangles, which are missing in Maths schoolbooks, but largely diffused on the web (blogs, Maths Forums, Wiki, Youtube)".

Creating 2.0 Virtual Academies

At the beginning, three virtual Academies have been created (in this specific case, 9 students in each group), named as their specific research theme:

- Cevian Triangles
- Pedal Triangles
- Orthic Triangles

For each Academy, students chose: a logo, a motto, some communication and sharing rules. The “WhatsApp ImageGroup” was the Logo, chosen in agreement with all the members (which were all administrators, so nobody was the leader). Teacher was also added to each Academy group. Students used their nicknames to login on the social network.

An introductive message was posted in each Academy/group by the teacher, suggesting main topic, as an example:

“27/10/17, 18:14 Hi guys, now you are Pedal Academy members. Search on the web and post here all you can find about pedal triangles, both historical and geometric aspects”.

Informal language has been used by the teacher, too.

Virtual Debate - Planning and Realizing Learning Activities

Virtual members posted on the groups their web researches: video, images, idea, suggestions and comments. Teacher suggested some learning activities.

Communication was asynchronous, students felt free to have their research in each place and time, so this new peer to peer - cooperative e-learning was effective and students feel enthusiast.

Just as an example, let’s analyse a brief virtual dialogue, between students and teacher:

Pedal Academy

27/10/17, 18:28 - Mirko: I found and interesting link http://web.mclink.it/MC2113/geometria/java/Tpedali.html
28/10/17, 19:02 Paolo “I found definition of pedal triangle: in Geometry a pedal triangle of a point with respect a triangle is identified by the point projections on the triangle sides.”
[...]
05/11/17, 19:29 - Teacher: “Question: May I choose all the points I want?”
05/11/17, 19:42 Andrea: “Yes you can, orthocentre, incentre and circumcentre, too”
05/11/17, 19:43 Gabriele: “No, you can’t choose all the points, they have to be inside the triangle”
05/11/17, 19:47 Mirko: “I agree with Gabriele, just for an example, I think that the circumcentre of an obtuse triangle is out of the triangle, so I think it isn’t OK.”
Andrea: used an emoticon image to say “I LIKE”
05/11/17, 20:05 Teacher: “Have you tried to represent it with some special points?”
Andrea posted 3 Geogebra files (as you can see in the Topics section)
05/11/17, 20:12 Teacher: “You have just studied circumference, look if there is a

connection between pedal triangle and circumference."
05/11/17, 20:14 Gabriele "Prof, I'm trying... I draw the pedal triangle of the orthocentre (D), by Geogebra, I draw a circumference passing by D and a vertex C, CD is a diameter...
05/11/17, 20:20 Andrea "Gabriele, I put the Pedal of the Incentre, CD is always the diameter..."
05/11/17, 21:05 Giampietro "Diameter is perpendicular to the cord, it is obvious"
Teacher "Wonderful"
05/11/17, 21:50 Paolo: "I'm searching for historical origin of pedal word, but I didn't find anything...who invented this word?"

By analysing the web debates, we may answer to some research questions:

Students discuss about Mathematics between them, without any fear to make a mistake. Students use an informal language, also including "emoticon" to approve or disapprove, as in a friendly chat.

In this free scheme framework, students have the opportunity to do Maths research and rediscover some results, which are not present in their schoolbooks, but are strictly connected to standard geometric topics.

Students are very interested in the topics, so they continue to study Maths also in the evening. In the research phase, GeoGebra has a relevant role, as a flexible instrument to immediately verify some student's hypothesis and some theorems they found on the web.

Extended Topics

In order to better comprehend the context where this new methodology has been experimented, teacher suggested also, in each virtual Academy, to get information about some specific ancient Academies founded in Campania, which are connected between them, because founder of one Academy was also a member of another one, and so on. It is just a way to "follow a branch" of the complex ancient Academies network.

Some Criticisms in Virtual Academies: towards Blended Academies - Live Meetings

Students had some problems to virtually organize their web researches in a learning unit: a virtual discussion to individuate main elements and synthesize them in a learning unit was not trivial.

For this reason, all the students agreed to change "virtual Academies" in "blended" ones: members met at school, discussed about their topics and each Academy produced a poster, to be shown to the members of other Academies (e.g. see Figure 1 for the Cevian Poster).

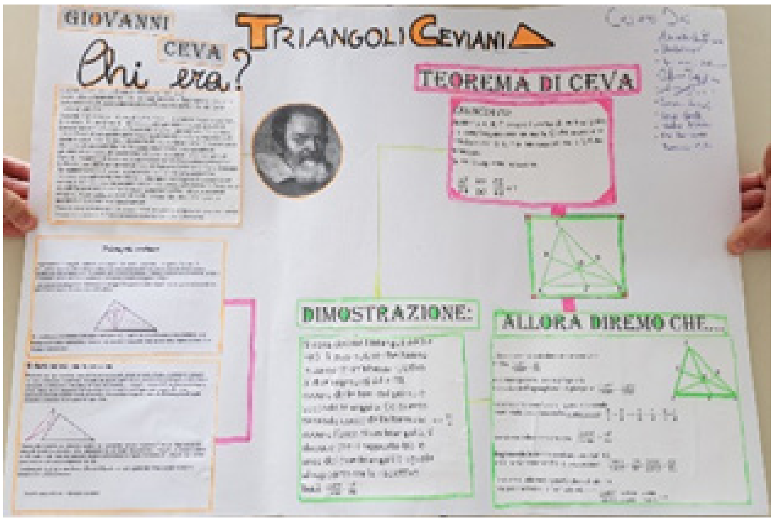


Figure 1. Poster realized by Cevian Triangles Academy. Similar posters have been realized by Pedal and Orthic ones.

A debate (Leron & Hazzan, 2006) between all the students belonging to the three Academies showed that there were some common features in the analysed topics.

Because of these similarities, and in order to realize a more complete learning unit, the three Academies fused together to create a new one, named *Baffling Triangles Academy*. Re-following the first steps, all details about this new Academy were established: the motto was "T*riangles: a universe letter"*, inspired to the Galileo's words. A uniform was suggested in a black sweatshirt, possibly with a hood.

A day trip to Langobard old town Salerno (a few chilometers far from the school) was also organized to better context the research activities, in particular to rediscover the place where the first Scientific Academy, Academia Secreta, (Ruscelli, 1984) was probably founded. Students were mainly fascinated by a specific geometry, releaved on the floor in San Pietro a Corte church (see Figure 2) and they chose it as Academy logo.

Figure 2. A mysterious Geometry on the floor in San Pietro a Corte
(Salerno, South of Italy).

Final Live meeting

Final live meeting of Baffling Academy was at the presence of all the students and teachers of different subjects (Maths, Latin, English, History and Literature, Science). Students showed main results about all the topics, also detailing the used historical sources and the ICT instruments they preferred.

Students used three different languages: Latin (for some historical fonts, i.e. Ceva), Italian (but often archaic italian) and English (e.g. Coxeter and Greitzer, 1967). They showed their results, both by using multimedia and posters. A debate between teachers and students was effective in order to give effort to the interdisciplinarity of the learning unit.

Final Product

Finally, students realized a multimedia product (video), summarizing their own point of view about this educational path. They also added some comments, which were similar to slogans, i.e.:

“From the past to the future: we worked as Academy members”
“Our Academies 2.0: comparison, dialogues and research”
“Learning all together is special!”

By analysing students’ slogans, we deduce that a strength of this methodological approach is the free cooperative comparison and research spirit: students feel part of an organization where they may discuss, without no fear to have a mistake.

Topics

Analysed topics are Geometry theorems about triangles, discovered after 1500, which are not classified, not well dated, not always organized, not present in Maths school books, but they are very useful, interesting and easy to be studied at High School. Here we show just some students researches from the three virtual Academies:

Cevian Triangles

A Cevian is any line segment in a triangle with one endpoint on a vertex of the triangle and the other endpoint on the opposite side.

Given a point S and a triangle ABC, the Cevian triangle PQR is defined as the triangle composed of the endpoints of the cevians though the Cevian Point S (see Figure 3).

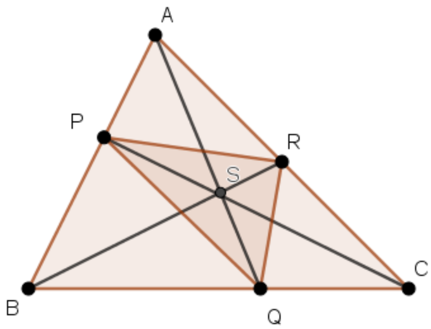


Figure 3. PQR: Cevian Triangle of the Main ABC Triangle, S = Cevian Point.

The condition for three general Cevians from the three vertices of a triangle to concur is known as Ceva's theorem.

Giovanni Ceva studied Geometry for most of his long life. In 1678, he published "De lineis rectis se invicem secantibus statica constructio", about applications of mechanics and statics to geometric systems, including the new theorem on synthetic Geometry in a triangle, known with his name.

Theorem 1 (Ceva's theorem)

In a triangle ABC, three lines AQ, BR and CP intersect at a single point S (i.e. they are concurrent) if and only if:

$$\frac{AP}{PB}\cdot\frac{BQ}{QC}\cdot\frac{CR}{RA}=1$$

Students verified it by using GeoGebra (See Figure 4)

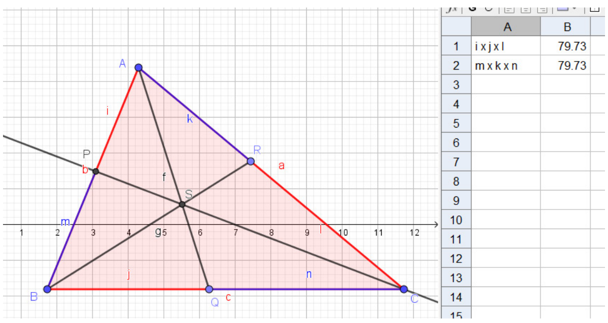


Figure 4. Test of Ceva's Theorem by Using GeoGebra.

Ceva's theorem is very important in Geometry, because it is simple to prove that medians, angle-bisectors, and heights are Cevians, i.e. they all concur in a Cevian point (barycentre, incentre and orthocentre points, respectively).

Students verified these properties by using GeoGebra and they found on the web some different proofs about it, also by looking for some Youtube videos, which they believed were effective and very simple.

Maths directly studied on Youtube channels is a further response to our question research: it can be considered as an instrument which is free, closer to their attitudes and it brilliantly substitutes a long, boring chapter about “Remarkable Points in a Triangle”.

This theorem is also important in Physics, in particular in the Mechanics and a debate about its physical aspects has been also done.

Pedal Triangles

A pedal triangle is obtained by projecting a point onto the sides of a triangle.

More specifically, let’s consider a triangle ABC, and a point P which is not one of the vertices A, B, C. Let’s drop perpendiculars from P to the three sides of the triangle (these may need to be produced, i.e., extended) and label L, M, N the intersections of the lines from P with the sides BC, AC, AB. The pedal triangle is the LMN one (see Figure 5)

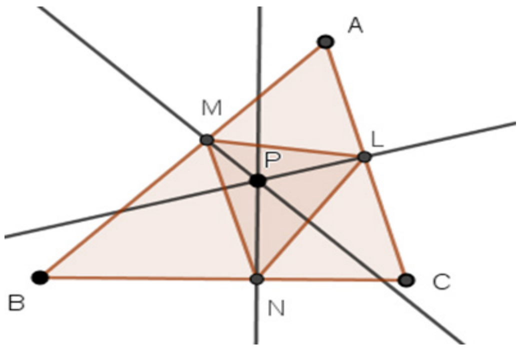


Figure 5. LMN: Pedal Triangle of Main Triangle ABC.

Several properties can be proved about pedal triangles, all starting from a “main property”:

Theorem 2 (Main Pedal Property) Given an ABC triangle and an $A_1B_1C_1$ pedal triangle respect to P point, then A, C_1, P and B_1 belong to a same circumference, with AP as a diameter” (Figure 6).

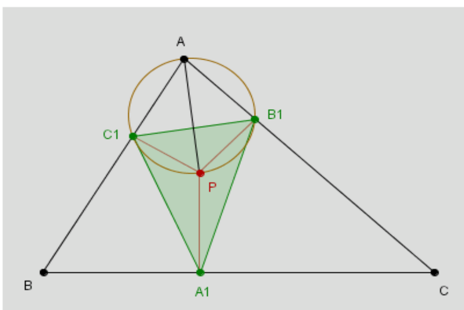


Figure 6. Pedal Triangles Main Property: A, C_1, P and B_1 belong to a same Circumference, Being AP the Diameter

Proof

Trivially, from the Pedal definition, angles AB_1 P =AC_1 P = 90° so both the triangles AB_1P and AC_1P are in a semi-circumference and the quadrilateral AB_1PC_1 is inscribed in a circumference, with diameter AP. Let's observe that this theorem corresponds to the "students' discovery" in the dialogue above.

Orthic Triangles

Given a triangle ABC, the triangle $H_AH_BH_C$, whose vertices are endpoints of the altitudes from each of the vertices of ABC is the orthic triangle. There are three cases:

if ABC is an acute-angled triangle, then the orthic triangle is inside ABC;
if ABC is a right-angled triangle, the orthic triangle degenerates in the hypotenuse height;
if ABC is an obtuse-angles triangle, then the orthic one is outside ABC.

In Fig.7 these three cases have been shown, as found on the web.

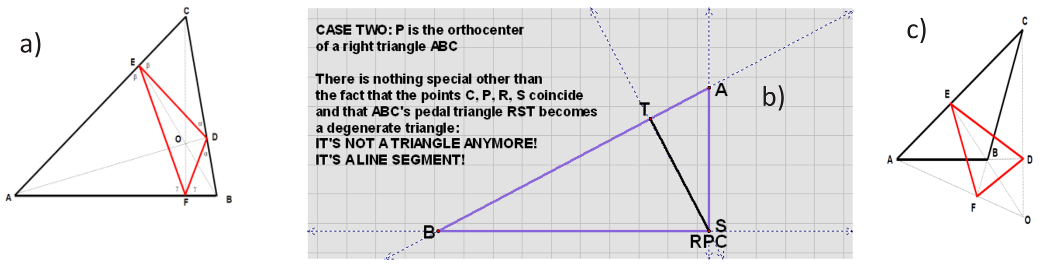


Figure 7. Orthic Triangle in case of a) ABC is an Acute-Angled Triangle, b) ABC is a Right-Angled Triangle, c) ABC is an Octuse-Angled Triangle.

It is important to observe that a bit of confusion can be found on the web, mainly depending on a no systematic arrangement about these topics; for example, in Fig.8.b it is written "Pedal" instead of Orthic triangle" Nevertheless, the Orthic triangle is both the Pedal and Cevian Triangle of a specific point, the Orthocentre.

An important property of Orthic triangle is the following one:

Theorem 3:

If is the orthic triangle of , then ABC heights are DEF angle bisectors, i.e. ABC ORTHOCENTRE is the Orthic triangle (DEF) INCENTRE.

Students verified this theorem in the ITC laboratory, by using GeoGebra, as shown in Figure 8.

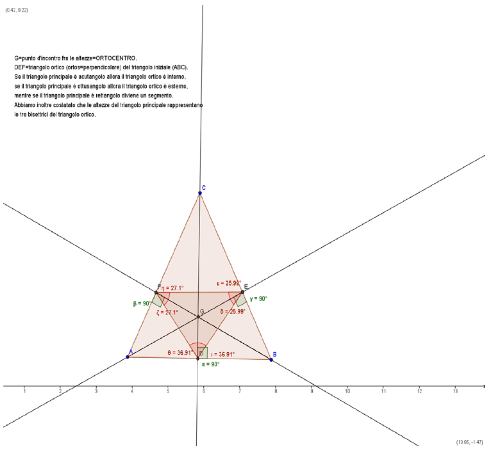
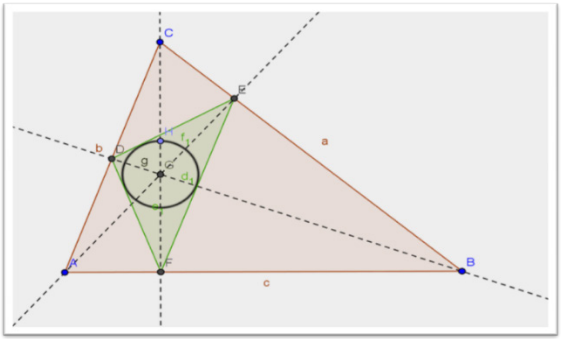



Figure 8. Test of the Property “ABC Orthocentre is the Orthic Triangle Incentre”

During 1700s, because of calculus inception, main discussions were about minimum and maximum problems.

A known minimum problem about these topics was introduced by Giovanni Fagnano in 1775 (Coxeter and Greitzer, 1967):

Theorem 4 (Fagnano’s problem)

For a given acute triangle determine the inscribed triangle of minimal perimeter. The solution is “the Orthic triangle”. Fagnano’ solution used the “calculus”, whereas L. Fej´er and While H. A. Schwarz gave a proof by using synthetic geometry (axial symmetries), in an independently way. Students verified Fagnano’s problem in the ITC lab, by using GeoGebra, nevertheless, they also analysed the L. Fej´er proof (Coxeter and Greitzer, 1967).

A lot of confusion is still on the web, and orthic and pedal triangles are still mixed up, for the Fagnano’s problem, too, as you can see in Gutkin (1997) where it is written “Among all inscribed triangles the pedal triangle has the least perimeter”, instead of the orthic triangle.

Conclusion

About 800 Academies were founded in Italy in 1525-1700 years, being a worldwide, very important phenomenon, that introduced a new way to acquire and disseminate knowledge. A new methodological approach, named “Academic Education”, has been introduced, starting from the simulation of sixteenth-seventeenth century Italian Academies, all details being specified to apply this approach step by step. Moreover, a case of study has been analysed, by using this methodological approach: an interdisciplinary learning unit has been planned and experimented with about ninety students attending the second year of a secondary school, focused on “synthetic geometry theorems, absent in the Italian maths schoolbooks”. Extended topics were about some ancient Academies in Campania, which were connected between them as in a social network.

By analysing students protocols, we deduced that Academy simulation gave a considerable boost to the Maths social use, which is very important to increase motivation to study scientific matters. They used and informal language on the social networks, and we observed that it encourage them to discuss about Mathematics out of the school context. Students feel enthusiastic about this new learning of way and their feeling were also evidenced in a final video they realized to summarize all the activities about this learning unit.

Moreover, historical aspects both about historical fonts of some theorems and researches about ancient Academies increased interest and curiosity in studying Geometry.

The use of ICT has been fundamental to immediately have a verification of all the Geometry properties.

Nevertheless, the use of web instead of schoolbooks could be a bit misleading, because of some conflicting information have been found on the net.

References

Coxeter, H. S. M., & Greitzer, S. L. (1967). *Geometry revisited* (Vol. 19). Maa.

Gal, H., & Linchevski, L. (2010). To see or not to see: analyzing difficulties in geometry from the perspective of visual perception. *Educational studies in mathematics*, *74*(2), 163-183.

Gutkin, E. (1997). Two applications of calculus to triangular billiards. *The American mathematical monthly*, *104*(7), 618-622.

Irace E. and Panzanelli Fratoni M. A. (2011). Le Accademie in Italia dal Cinquecento al Settecento [Academies in Italy from Sixteenth to Eighteenth century]. In Sergio Luzzatto and Gabriele Pedullà Editors, *Atlante della letteratura italiana*, (vol. II, pp. 314-322). Torino: Einaudi.

Jones, L. R., Wheeler, G., & Centurino, V. A. (2015). TIMSS 2015 science framework. *TIMSS 2015*, 29-59.

Leron, U., & Hazzan, O. (2006). The rationality debate: Application of cognitive psychology to mathematics education. *Educational Studies in Mathematics*, *62*(2), 105-126.

Özerem, A. (2012). *Misconceptions in geometry and suggested solutions for seventh* *grade students*. Procedia-Social and Behavioral Sciences, 55, 720-729.

Ruscelli, G., Eamon, W., & Paheau, F. (1984). The Accademia Segreta of Girolamo Ruscelli: A Sixteenth-Century Italian Scientific Society. Isis, 75, 327–342.

Testa, S. (2015). Italian Academies and Their Facebooks. In *Italian Academies and Their Networks, 1525–1700* (pp. 125-154). Palgrave Macmillan, New York.

Citation:
Adesso, M. G., Capone, R., Fiore, O., Tortoriello, F. S. (2019). Mathematics learning and teaching in an interdisciplinary framework simulating ancient academy. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 63-78). ISRES Publishing, ISBN: 978-605-69854-0-9.

Using GeoGebra for Correction of Incorrect Premises in Geometric Proofs

Jan Frank
University of West Bohemia, Czech Republic

Lukáš Honzík
University of West Bohemia, Czech Republic

Introduction

Mathematical proofs are often neglected in some cases, especially in primary schools. Let us admit, however, that their role is irreplaceable - among other things, they help to develop logical thinking and contribute correctly to a better understanding of the issue. At the same time, the lower age of pupils does not have to be a problem. One example is the well-known demonstration of the validity of the Pythagorean theorem, which almost everyone has encountered during their studies.

Recall that the proof (admitting at this point that it is not proof of a generally valid theorem "The square whose side is the hypotenuse in rectangular triangle is equal to the sum of the areas of the squares on the other two sides," rather than a visual demonstration which is quite accessible even for young pupils) of this theorem is based on a picture containing a pair of identical squares with their side lengths $a + b$.

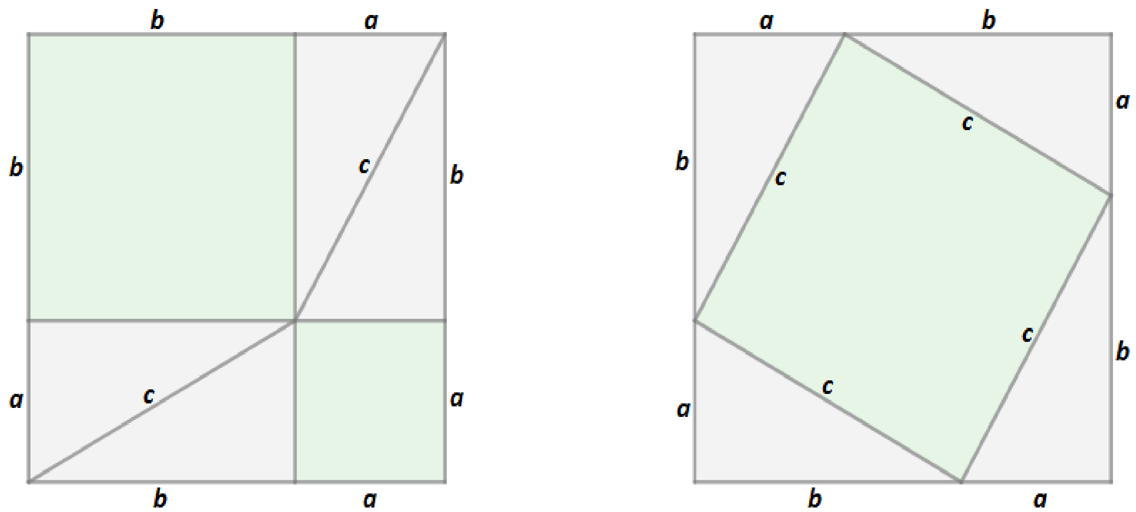


Figure 1. Graphical Proof of Pythagorean Theorem

In the first square, there are situated two smaller squares (green ones), one with the length of side a, the other with the length of side b. The remaining area is filled with four identical rectangular triangles. In the second square, the triangles are rearranged, the rest of the square is filled with a smaller square with side length c.

Now considering the same area of large squares and the same areas of four rectangular triangles, it can be deduced that the sum of the areas of squares with sides of lengths a and b is equal to the area of square with side length c.

This leads to a well-known formula representing the Pythagorean theorem in the form

$c^2 = a^2 + b^2$.

As has already been said, this is not a true proof, but a graphical interpretation of one situation. If we want to get rid of this deficiency and approach a more general version of the proof, we can use one of the dynamic geometry programs like GeoGebra. In these programs, using sliders and changing parameters, it is possible to switch from a static image to a dynamic figure, where you can experimentally validate the assertion for virtually any of the values *a*, *b*, and *c* (Fig. 2).

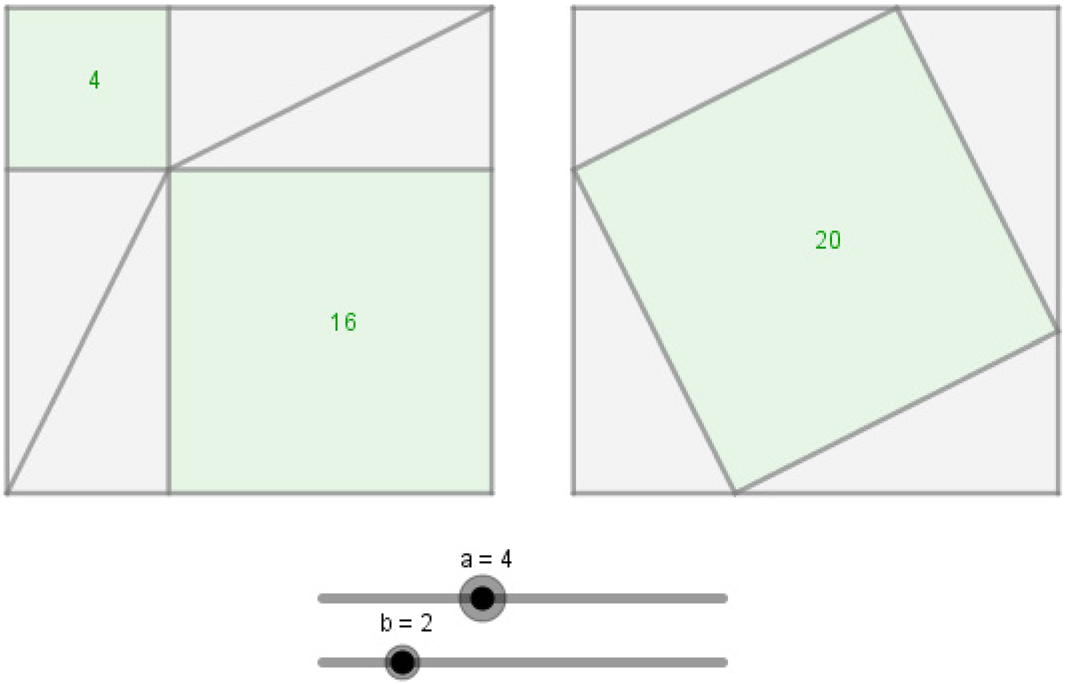


Figure 2. Dynamic figure of proof of Pythagorean theorem

Obviously, using dynamic geometry software offers an element of interaction and dynamics takes geometric proofs (or, more generally, mathematical proofs performed in a geometric way) to another level. At the same time, it can be hoped that software of dynamic geometry can in some cases eliminate certain inaccuracies that the solver can commit if he is to prove only by reasoning and a static sketch. Of course, at this point we have to also point out that when constructing a figure in dynamic geometry programs, it is necessary to consider the behavior of individual objects and the relationships between them in order to avoid possible mistakes resulting from the dynamics of the whole geometric construction.

Here are some examples of erroneous assumptions in geometric proofs. The evidence is supplemented by commentary explaining where the mistake is in the proof, as well as a preview of the problem through dynamic geometry.

441 = 442?

Assertion: Square of side 21 cm has the same contents as the rectangle with sides of 34 cm and 13 cm. (Dubnov, 1954)

Proof: Consider the square of side 21 cm divided into two rectangles of 13 cm × 21 cm and 8 cm × 21 cm. The first rectangle is divided into a pair of identical rectangular trapezoids with base lengths of 13 cm and 8 cm, the second rectangle then into a pair of identical rectangular triangles with lengths of 21 cm and 8 cm.

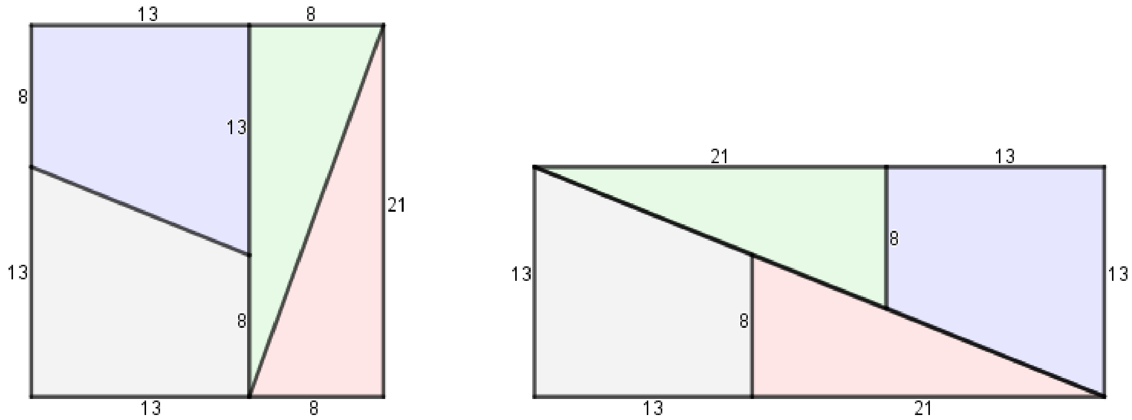


Figure 3. Dividing a square into four parts and their rearranging

As can be seen from Figure 3, a rectangle of sides 13 cm and 34 cm can be obtained by rearranging the parts. All you must do is place a right triangle with legs 8 cm and 21 cm on the respective base of a rectangular trapezoid to form a large rectangular triangle with legs 13 cm and 34 cm. If we place a pair of these triangles with the hypotenuse together, this rectangle is created.

The content of this is 13.34, i.e. 442 cm^2, while the content of the original square was $21^2 = 441$ cm^2. All parts that make up a square and a rectangle are identical. The question therefore remains where the excess square centimeter appeared. (Dubnov, 1954)

The answer to this question is quite simple and is not surprising for a reader who has already encountered similar tasks. The whole problem lies in the belief that the two large right triangles are really triangles. We have obtained this idea based on graphical interpretation, but we have no argument for it.

Proof of this assumption could be based, for example, on a comparison of the magnitude of the angles **α** and **β** shown in Figure 4. If the two angles were the same, the geometric figure formed by the composition of the small right triangle and the right trapezoid would be a right triangle.

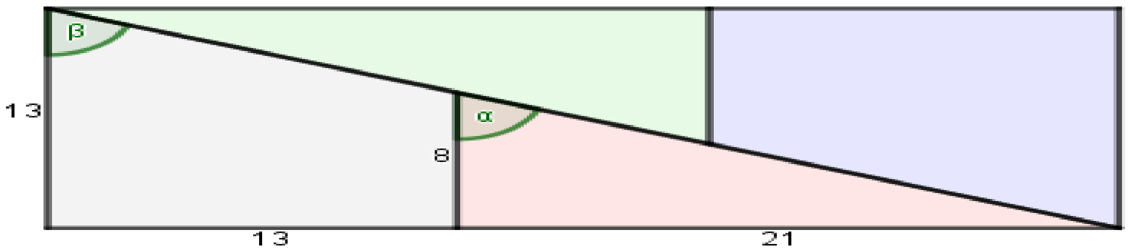


Figure 4. Comparing Angles

Calculation of both angles is easy. For angle α there is equality

$$\tan a = \frac{21}{8}$$

but for angle β there is equality

$$tan\beta = \frac{13}{5},$$

where we calculate the numerator as the difference of the size of the bases in a rectangular trapezoid.

From comparing fractions

$$\frac{21}{8} > \frac{13}{5}$$

there is also inequality

tan α > tan β.

Here, it is already clear that the angle α is greater than the angle β. Thus, the figure is not a right triangle, but a non-convex quadrilateral. The consequence of this is that the rectangle does not consist of two identical figures (i.e. large right triangles composed of a trapezoid and a smaller right triangle), but of three figures – a pair of identical non-convex quadrilaterals and a parallelogram between them.

If we use the software of dynamic geometry GeoGebra for our examination, it is possible to see the problem from a slightly different point of view – without using calculations as such, but at the same time a bit more clearly.

We construct a rectangle according to the assignment, mark individual geometric figures in it and at the same time use the Polygon tool to create the mentioned parallelogram. If this parallelogram is set to display a value in addition to its name, we will find its content equal to 1 cm^2, as shown in Figure 5. That is the square centimeter that makes the difference between the content of a square of side 21 cm and the content of a rectangle of sides 13 cm and 34 cm.

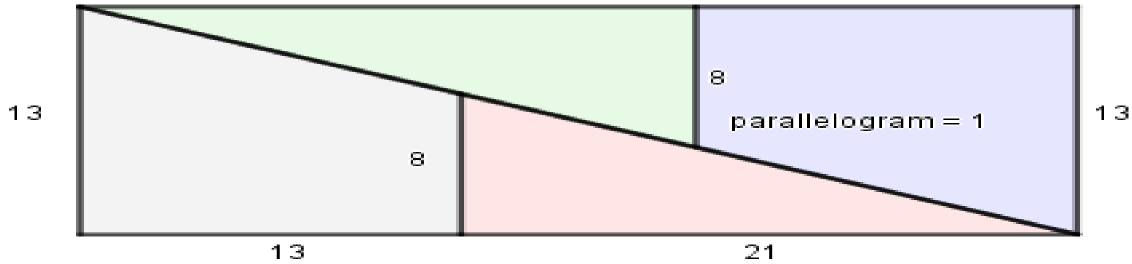


Figure 5. Representation of the Parallelogram and its Contents

Using sliders in a geometric figure makes the situation even clearer. We can experiment with different ways of dividing a given square. It can be divided into two rectangles with dimensions of, for example, 14 cm × 21 cm and 7 cm × 21 cm. Then it is quite clear that after the rearrangement of the created geometric figures, a parallelogram appears in the resulting rectangle. It is now clearly visible (Figure 6) and its content is even 49 cm^2.

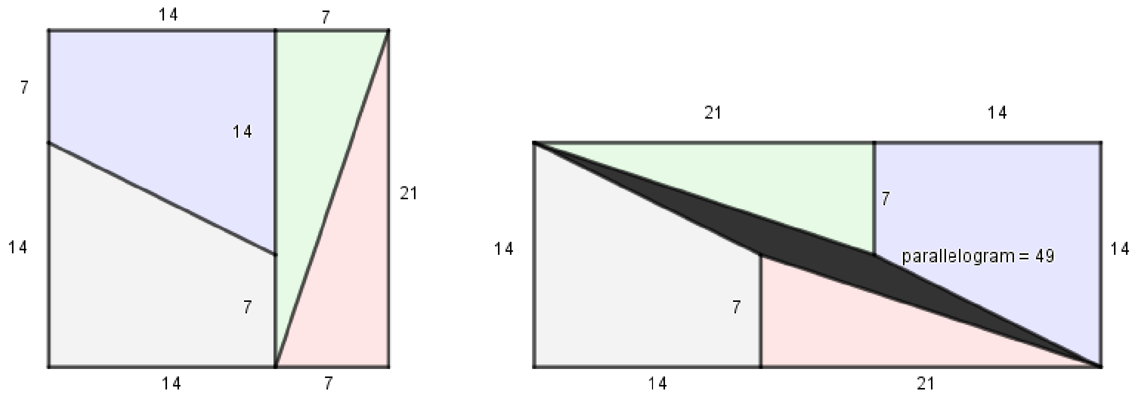


Figure 6. Other division of squares

For the sake of completeness, let's add that this task is actually just one of many variations of one and the same problem called the Curry's paradox, where an object is divided into several parts and these parts are rearranged, with the new object slightly, at first glance, imperceptibly, altered dimensions. Examples of this problem can be found in a task known as "endless chocolate": The chocolate bar is cut into several parts, rearranged, leaving one piece left which can be eaten. With appropriate selection of slices, this rearrangement can then be done several times and one piece can also be eaten each time. An observer who is unaware of this problem can thus feel that chocolate can be eaten without dwindling. The principle is shown in Figure 7. (Gardner, 2018; Thiele, 1985)

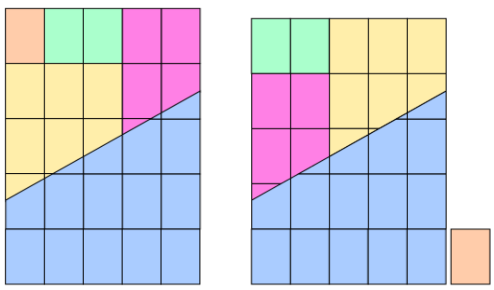


Figure 7. Endless chocolate

Circles with the Same Length

Assertion: All circles have the same length. (Dubnov, 1954)

Proof: To prove the assertion, use one of the practical ways of determining the length of the circle (or wheel circumference). This method is usually used to measure the circumference of a bicycle wheel, which is then set into a cycle computer. The procedure consists of selecting one specific point on the wheel circumference (e.g. bicycle valve) and drawing a mark on the road on which the wheel moves. The markings on the wheel circumference and on the road are initially in the same place and then we roll the wheel. We make a second mark at the point where the point on the wheel circumference again meets the road when rolling. By measuring the distance between the marks on the road we receive wheel circumference.

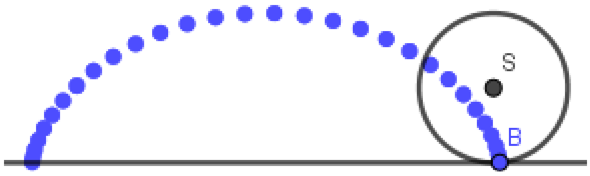


Figure 8. Wheel rolling

This experiment is shown in Figure 8. The path of the selected point B on the wheel circumference is also highlighted. The curve that the point describes during rolling is a cycloid described by parametric equations

$x = r.(t - \sin t)$

$y = r.(1 - \cos t)$,

where r is the radius of the wheel and t is the real parameter.

The distance between two points where point B touches the horizontal line determines the circumference of the wheel (or the length of the circle that is the boundary curve of the wheel).

Now consider a situation where two wheels of different radius are attached to one shaft, as shown in Figure 9. Wheels are fixed on the shaft, i.e. both wheels retain their mutual position when the shaft is rotated.

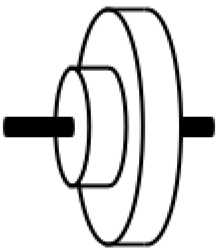


Figure 9. Two Wheels on the Same Shaft

Instead of the road from the previous description, we will now use a pair of parallel rails as a base. Each wheel will roll on one of them. This movement is phased in Figure 10. The figure shows clearly the path of point *A* on the larger wheel and the circumference of that wheel. However, it is worth noting the individual positions of point *A'*. As can be seen, the distance between two points where point *A'* touches the rail is the same as the distance between two points of point *A*. This implies that both wheels must have the same circumference.

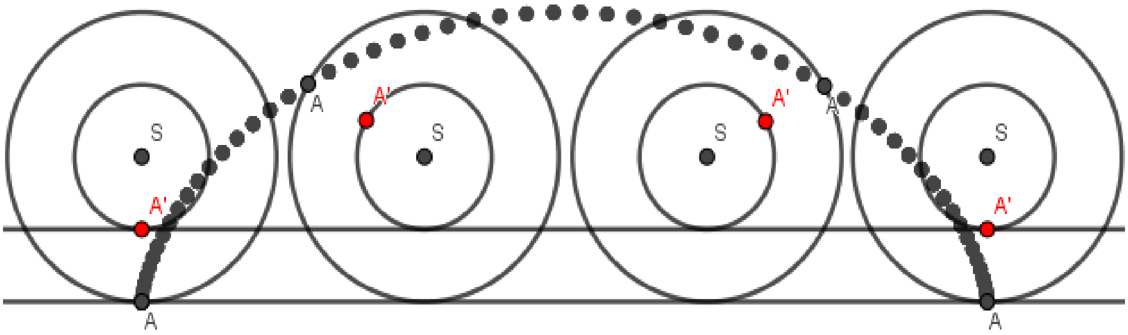


Figure 10. Rolling wheels on rails

Finally, we can generalize the previous statement and convert it back to the geometric level. Thus, it can be argued that the length of the circle is given regardless of the radius of the circle. In other words, two arbitrarily selected circles of different radii are always the same length. (Dubnov, 1954)

This statement is, of course, erroneous, as every reader knows from experience. It is enough to find a problematic passage in the chain of considerations to refute the statement. First, it should be noted that the whole problem is a kinematic issue rather than a geometric one. However, it is still possible to perform a geometric construction of a dynamic figure in software GeoGebra to detect the mistake.

For this purpose, we construct a pair of parallel lines showing both the rails, two concentric circles (in our case the larger circles have a double radius), each with one point *A* and *A'*, and use the slider at the same time. By using it we control the movement of circles in the direction of the lines and at the same time we use it to move the marked points. The movement consists of a displacement in the direction of the lines and at the same time a rotation around the center of both circles. The situation constructed in this way corresponds to the considerations described above, from which we have deduced the same length of both circles.

Now let's use the function to display the track of a moving object. We will focus on the traces of movement of both points *A* and *A'*. It is clear from Figure 11 that while point *A* leaves a trail corresponding to the cycloid while moving, point *A'* draws a different track.

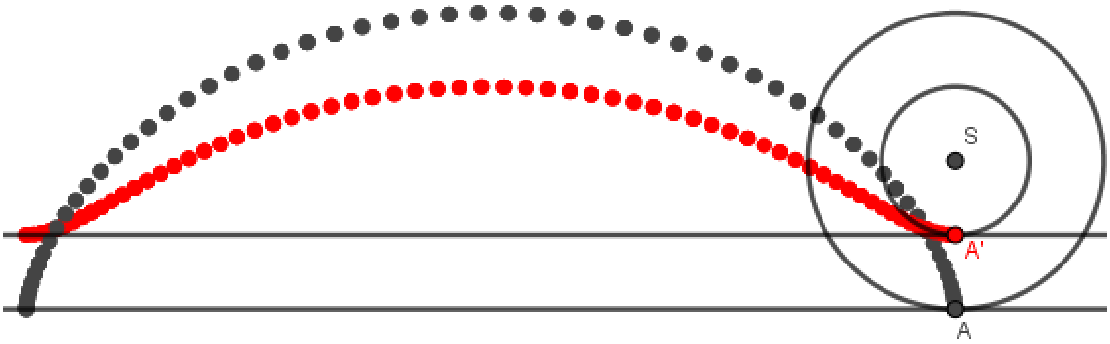


Figure 11. Traces of Marked Points *A*, *A'*

It is a so-called shortened cycloid whose parametric expression is given by a pair of equations

$$x = r.t - a.\sin t$$
$$y = r.1 - a.\cos t,$$

where $r = |SA|$ (i.e. the radius of the larger circle) a $a = |SA'|$ (i.e. the radius of the smaller circle), so the inequality $a < r$.

Since point *A'* did not describe the expected cycloid in its movement, but rather a shortened cycloid, we can assume that this is where the problem is being sought. The movement of point *A'* as it is modeled in the dynamic figure does not correspond to what it should actually look like.

Suppose we found a mistake, and at the same time we know the form of the output (the cycloid trace) we are looking for. With a little bit more work, we are able to complete the figure with another point *B*. When the track is switched on, it renders the cycloid again, but with half the period compared to the cycloid given by point *A*. The result is therefore a successful rebuttal of the false proof, since the length of one circle with half the radius relative to the radius of the other circle is also half.

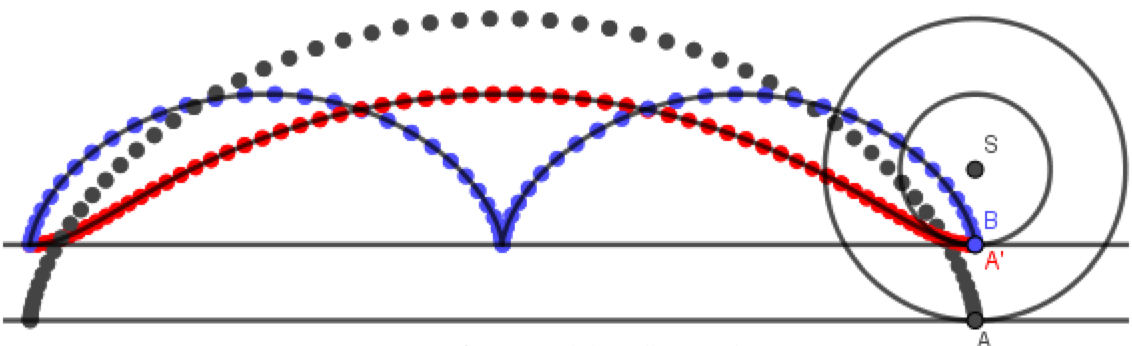


Figure 12. Traces of Points While Rolling With Correction

Finally, let's move from geometry back to kinematics and specify the mistake from the physical point of view. This mistake must be found in the fixed position of the two wheels on the same shaft, where the two wheels maintain their relative position when rotating. When the wheels roll on the rails, one of the wheels slips. Specifically, when rolling a larger wheel without slipping, this is a negative slip of the smaller wheel, thereby increasing the distance between the two marks on the appropriate rail. Otherwise, rolling the smaller wheel without slipping would be a positive slip of the larger wheel, which in turn would reduce the distance between the marks.

π = 2

Assertion: The number π is equal to 2. (Dubnov, 1954)

Proof: Let's have a line *AB* over which we construct a semicircle. The length of this semicircle is obtained from the formula for calculating the circumference of circle $C = 2\pi.r = \pi.d$ and it is equal to $\pi/2|AB|$. Then we halve the line *AB* and construct a semicircle above each of its halves, with the left semicircle placed above the line and the right semicircle below the line. This creates a "wavy" line resembling a portion of the sine graph, and for each semicircle, its length is half that of the original large semicircle above the line *AB*. The total length of the "wavy" line is therefore again $\pi/2|AB|$.

If we continue to halve existing lines and construct new semicircles in the same way, a "wavy" line is created, which is increasingly closer to line *AB*. This represents the limit of the "wavy" line for the number of halves going to infinity. However, the length of the "wavy" line is still equal to $\pi/2|AB|$. The size of the limit and line *AB* must also be the same. From equality $\pi/2|AB| = |AB|$ we obtain equality $\pi = 2$. (Dubnov, 1954)

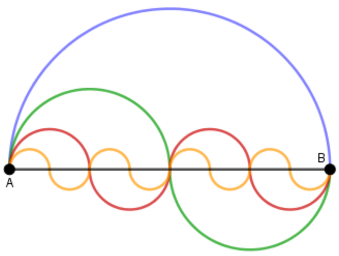


Figure 13. Softening the "Wavy" Line

The problem with this inference with a totally nonsensical consequence lies in a misunderstanding of the term "limit". Or more precisely, in the possible ambiguity of the term "limit". These two different senses may but also may not be equivalent and thus interchangeable.

On the one hand, it is a "wavy" line, which is essentially a sequence consisting of semicircles. The limit of this sequence is indeed the line segment *AB*. As the number of arcs increases, the arcs of the semicircles approach unlimitedly. On the other hand, it is a numerical sequence, the members of which are the lengths of the individual semicircles and whose sum is to be unlimited close to a certain fixed limit value.

The reader must not be fooled by the fact that with a very fine line segment, and therefore with very small semicircles, the "wavy" line practically does not differ from the line segment *AB* itself. To solve this problem in GeoGebra simply zoom enough.

At the same time, consider the following: The difference between the lengths of the semicircle and the line segment above which the semicircle is circumscribed is always non-zero (no matter how short the line is). With very small dimensions of the semicircles, these differences are slight, but they occur in very large quantities. However, even the smallest values can give an arbitrarily large sum in enough quantity.

In other words, the sequence of semicircles that consist of a "wavy" line is close to line *AB*, but the sum of their lengths has nothing in common with the line length as its limit.

As in the previous cases, let's try to use geometric software to illustrate the situation. In software GeoGebra, we construct a line *AB* and a default semicircle above it. Next, using slider and the Sequence command we create a lists of points and small semicircles. Moving the slider increases the number of semicircles to soften the "wavy" line at the same time.

As shown in Figure 14, irrespective of the change in the number of semicircles, the length of the "wavy" line is still equal to π (except for some small rounding variations in program calculations, which is set to 2 decimal places by default).

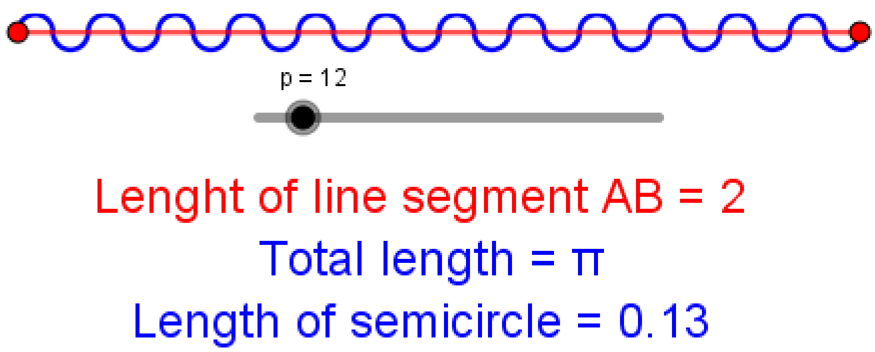


Figure 14. The Length of the "Wavy" Line

Conclusion

In this paper, we have presented some geometric evidence, which at first glance may seem correct, but lead to totally erroneous conclusions. Apart from our logical considerations, we relied mainly on the software of dynamic geometry GeoGebra, which proved to be a proficient helper in refuting the erroneous conclusions. Even though it is not primarily intended for proving geometric theorems. Nevertheless, as shown in the previous examples, it can also be used successfully in this area by allowing the user to perform demonstrations and experiments through interactivity and the ability to dynamically manipulate geometric objects. These can then clearly help to avoid hasty and erroneous conclusions that can be reached, for example, by elementary and high school pupils and students.

References

Dubnov, J. S. (1954). *Chyby v matematických důkazech*. Praha: Státní pedagogické nakladatelství.

Gardner, M. (2018). *Zábavné matematické hádanky*. Praha: Dokořán.

Thiele, R. (1985). *Matematické důkazy*. Praha: Státní nakladatelství technické literatury.

Citation:
Frank, J., Honzík, L. (2019). Using GeoGebra for correction of incorrect premises in geometric proofs. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 79-89). ISRES Publishing, ISBN: 978-605-69854-0-9.

Enhancing Calculus in Undergraduate STEM Education with Bloom's Taxonomy

Martene L. Stanberry
Tennessee State University, United States

Wanda R. Payne
Tennessee State University, United States

Introduction

In recent years, there has been increasingly more focus on science, technology, engineering, and mathematics (STEM) education from a national perspective (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012). In fact, in 2012, the President's Council of Advisors on Science and Technology developed an article on the state of STEM in America entitled *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*. This article emphasized the importance of increasing the number of graduates in STEM disciplines in order for the United States of America to maintain scientific preeminence. Yet, based on national college and university statistics, only about 40% of students who plan to complete a degree in a STEM discipline actually do so. Within the article, specific challenges that must be addressed in our college and university classrooms are outlined. Three recommendations were highlighted in the article: (i) *improve the first two years of STEM education* in colleges/universities, (ii) provide all students with the tools and resources they need to excel, and (iii) diversify pathways to STEM degrees (President's Council of Advisors on Science and Technology, 2012). College Calculus, which is a fundamental course for STEM areas of study, has the potential either to deter students from continuing in STEM or to provide students with a strong foundation for more advanced classes and prepare them with the confidence and skills to persist and excel in STEM. As faculty members at a university that awards many STEM degrees, the authors realized that there was a need to improve the success rate in Calculus in order to increase student persistence and graduation in STEM majors.

Since the establishment of colleges and universities the principal method of teaching has been the "teaching by telling" method also known as lecture (Freeman et al., 2014). One reason why this teaching technique has been widely used is because the instructor has the ability to share lots of information in a short amount of time, which leaves little concern about the ability to cover all of the course material during a given term. However, this style of teaching leaves little or no time available for student involvement in the learning experience beyond just listening. There are other theories and techniques which have been developed over the years, which focus on student centered learning and the literature provides evidence of the effectiveness of these methods.

Levels of learning have been the focus of educational research and have been studied extensively to describe the objectives of education (Karaali, 2011). Published in 1956, the original version of *Taxonomy of Educational Objectives* was authored by Benjamin Bloom with collaborators Max Englehart, Edward Furst, Walter Hill, and David Krathwohl. Commonly known as Bloom's Taxonomy, this framework uses a multi-tiered scale to organize the levels of expertise required to achieve measureable student outcomes. Bloom's Taxonomy involves three taxonomies: knowledge based goals, skills based goals, and affective (i.e. values, attitudes, and interests) based goals. Bloom's Taxonomy is a classification of types of thinking into six different levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. In 2001, an updated version of Bloom's Taxonomy was developed by Anderson and Krathwohl. This newer version reorders the two highest levels and converts the different category titles to their active verb counterparts: remember, understand, apply, analyze, evaluate, and create. Even today, this model is widely used at the collegiate level to develop instructional strategies and assessments that are complementary to the course goals and appropriately measure students' levels of mastery/expertise of the subject matter. Therefore, it is critical to design a Calculus I course that embodies the elements of *Bloom's Taxonomy* since Calculus I is a fundamental course for most students majoring in STEM disciplines.

In addition, it is important to implement strategies that engage students in the learning process. Studies have shown that teaching techniques that involve students as active participants improve retention of information and critical thinking skills and can greatly increase STEM major interest and persistence, compared with traditional lecture (President's Council of Advisors on Science and Technology, 2012). In recent years, there have been many studies supporting a move toward *active learning* in college classrooms, particularly in STEM education. The term active learning as it is currently interpreted dates to the early 1990s and the work of Bonwell & Eison (1991), building on the work of Revans (1983) (Conference Board of the Mathematical Sciences, 2016). Active learning encompasses several models of instruction, including cooperative and collaborative learning, problem based learning, inquiry-based learning, discovery learning, and experiential learning (Barkley, 2010). It is a process of education whereby students engage in activities, like reading, writing, discussion, or problem-solving that encourage analysis, synthesis, reflection and evaluation of class content.

Bloom's Taxonomy and active learning techniques have been successfully implemented in undergraduate STEM education to enhance student learning. Therefore, this manuscript will present a Calculus I instructional tool and assessment guide that embodies the elements of both Bloom's Taxonomy and active learning strategies. The goal of this work is to introduce two models that the authors of this manuscript believe have the potential to enhance Calculus I instruction through effective course design and student engagement. The models presented in this manuscript, Enhancing eXcellence by

Creating Engaged Learners (EXCEL) and Calculus in Bloom Model (CBM), will contribute to the body of knowledge in the area of best teaching practices in undergraduate mathematics education. The EXCEL Model development was inspired by the authors' desire to create a tool that could be used by faculty to guide their implementation of active learning and assessment design in Calculus I with an emphasis on levels of thinking. In conjunction with the EXCEL Model, CBM can assist in the development of assessment items to properly measure levels of thinking.

Literature Review

Levels of Thinking

Learning Calculus concepts requires varying degrees of cognitive demands. In the framework of Bloom's Taxonomy, these demands can range from a lower order thinking skill, such as knowledge, to a higher order thinking skill, such as evaluation. Lower order thinking skills involve recalling, understanding, and applying fundamental facts. Higher order thinking skills involve examining and applying information to determine relationships, draw conclusions, and make decisions. Lower order thinking skills include knowledge, comprehension, and application. Higher order thinking skills include analysis, synthesis, and evaluation. Depending on the degree of cognitive demand there may be some overlap in the level of thinking. What follows are summaries of recent studies that have been conducted in collegiate Calculus courses involving Bloom's Taxonomy and other classifications of levels of thinking.

Recognizing the characteristics of each level of cognition is essential to the successful implementation of the Bloom's Taxonomy framework in any academic endeavor. In 2011 Karaali summarized his experience with applying Bloom's Taxonomy to specific tasks in college Calculus by identifying the level of cognition associated with each task. The goal of his work was to create a Calculus task at the highest level of Bloom's Taxonomy, evaluation, and to assess student thinking at this level through a Calculus project (Karaali, 2011). The work presented by the authors in this manuscript instead focuses on identifying tasks (activities and assessments) at all six levels of Bloom's Taxonomy, which can be done by Calculus students throughout the course to enhance their learning.

While the research study by Karaali focused on utilizing Bloom's Taxonomy at the highest level for a single project assignment, in 2014 a study more closely related to the work done by the authors of this manuscript was conducted by White and Mesa. These researchers focused on the cognitive orientation of Calculus I tasks and summarized their examination of materials (bookwork, worksheets, and exams) collected from five instructors teaching Calculus I in a two-year college over a one semester period. The main goal of the study was to identify the quality of instructors' learning goals and students' opportunities to learn in a successful Calculus I program. This was done by categorizing in-class and out-of-class assignments that were used by instructors to assess student learning (White & Mesa, 2014).

In another classification of thinking skills, Brookhart describes transfer, critical thinking, and problem solving as higher order thinking skills (Brookhart, 2010). When compared to Bloom's Taxonomy these skills span comprehension, application, analysis, synthesis, and evaluation. In 2016, Maharaj and Wagh conducted a pilot study to determine what types of tasks could be formulated to target the development of Brookhart's higher order thinking skills in Calculus I students. The study showed that the higher order thinking skills were lacking among study participants (Maharaj & Wagh, 2016). This indicates that there is a need to develop methods of teaching that promote meaningful learning. Maharaj and Wagh indicated that they have a plan to incorporate active learning strategies in the classroom, such as the use of technology, to promote increased student learning in Calculus (Maharaj & Wagh, 2016), which is also an approach that is utilized by the authors of this manuscript.

Active Learning Techniques

For several decades, STEM educators have been encouraged to implement active learning techniques to model the methods and mindsets that are central to scientific inquiry and to give students opportunities to connect theoretical ideas to real world applications in order to gain skills and knowledge that persist beyond the course in which it was acquired (Allen & Tanner, 2005). Therefore, improving the level of student learning is heavily dependent upon the instructional and assessment components of course design. These are opportunities for students to develop multi-level thinking skills which are necessary to solve a range of problems from basic to advanced.

In 2015, Merkel and Brania reported on the implementation and results of a five-year study of a cooperative learning technique in Calculus I at an all-male historically black college or university (HBCU). The goal of the study was to determine the impact of peer-led team learning (PLTL) on retention and success rates and learning gains. The study included data from sixteen sections of Calculus I taught over a span of five years. To measure learning gains, data were obtained from sections of the course in which one instructor taught both a PLTL section and a non-PLTL section in the same semester. To measure retention and success rates, data from all sections were used. The results of the study indicated that PTLT did not significantly enhance students' learning and did not have an apparent effect on student retention. The researchers adhered closely to established guidelines for the implementation of the PTLT model, but suggested the issues of the length of the workshop and the quality of team leaders as being potential barriers to the positive results seen in other PLTL studies (Merkel & Brania, 2015).

In 2017, Fox et al. summarized data collected based on a study which focused on offering a project option in sections of Engineering Calculus II and Engineering Calculus III. If the project option was selected by a student, then they were exempt from taking the course final exam and their grade on the project would replace the final exam grade. Students who chose the project option were required to have a project advisor, not their Calculus instructor, who was a faculty member in STEM. The goal of this project option was to enhance student learning and assist students in making connections between the theoretical concepts covered in Calculus and real-life applications by creating an opportunity for them to complete a summative project in the course. Overall, students who selected the project-option performed better than students in the concurrent courses that were non-project based (Fox et al., 2017).

Development of the Enhancing eXcellence by Creating Engaged Learners Model

As instructors of Calculus at the collegiate level, it is critical to design courses and course activities that teach and inform students and also empower them to think and create independently. With the overarching goal of increasing student knowledge acquisition and success in Calculus I, an intentional and thoughtful effort has been made by the authors to improve this course using particular teaching techniques and assessment design. Unlike the traditional lecture approach, teaching is student centered and consists of lessons that promote student inquiry and discussion, encourage student collaboration, and connect classroom knowledge to real-life applications. It involves developing a strategic plan which includes: identifying the characteristics and academic interests of the students, developing activities that activate prior knowledge, and optimizing the class personality and strengths. This approach to teaching is referred to as Strategic Engagement for Increased Learning (SEIL) Model (Stanberry, 2018). Assessment is designed to complement the SEIL Model and to measure student learning outcomes at different levels of cognition utilizing ideas from Bloom's Taxonomy. Both formative (evaluation of student learning throughout a course) and summative (evaluation at the end of specific content coverage to determine the effectiveness of instruction) assessment items can be matched to learning outcomes and mapped to levels of Bloom's Taxonomy.

Calculus is foundational to STEM disciplines because it is the study of how things change. The knowledge acquired and the skills developed in the first course in the Calculus sequence are essential to studying changes in biological, physical, chemical, and other types of systems. Although the exact material covered in Calculus I varies from institution to institution and even within an institution, common to most courses are the following student learning outcomes: (i) the ability to compute limits of functions, (ii) the ability to select and apply the appropriate differentiation techniques to solve problems, and (iii) the ability to use the Fundamental Theorem of Calculus to evaluate integrals.

Moreover, how the content of Calculus I is taught is very important. In 2015, the Mathematical Association of America (MAA) produced its seminal work on a national study of college Calculus programs. It listed the following five actions as practices related to good teaching of Calculus I:

1. Create a positive atmosphere in which the instructors encourage students to ask questions.

2. Maintain a positive attitude towards students' mistakes.

3. Keep reasonable pacing of the lecture to ensure all students are on the same page, with time for individual, pair, or group work.

4. Set high standards and clear expectations that all students can meet.

5. Have availability to answer student questions and respond to students' needs. (Bressoud, 2015)

Bloom's Taxonomy is a valuable tool for helping professors plan and deliver instruction and design assessment items in ways that incorporate the practices recommended by MAA. The structure of the taxonomy allows for clear expectations to be set at each level of cognition. The hierarchy of the levels promotes meaningful learning that helps students achieve high standards because the lower order thinking skills help to develop the higher order thinking skills. Therefore, it is essential for professors to make sure that the classroom instruction and activities require lower order thinking skills as well as higher order thinking skills. Further, this exposes students to tasks that require higher levels of cognitive demand on formative as well as summative assessments. Studies have shown that higher levels of student achievement in mathematics are associated with higher order thinking skills (Bressoud, 2015).

The use of Bloom's Taxonomy as an instructional aid can be enhanced with the implementation of teaching techniques that promote active student engagement. Studies have shown that active learning techniques increase student performance in mathematics (Freeman et al., 2014). In fact, another recommendation made by the MAA for successful college Calculus programs was to allow time for individual, pair, or group work during instruction. This type of active engagement helps students develop skills at varying levels of cognitive demand.

There were several motivating factors that contributed to the authors' decision to develop and implement techniques beyond the traditional way of teaching Calculus. These factors include the following: (i) departmental Calculus I success rate trend, (ii) authors' experiences teaching Calculus I, and (iii) best practices in undergraduate mathematics education. During the last few years at the university where the authors are faculty members, the success rate in Calculus I has been below sixty percent. Based on classroom observations, interactions, and student feedback, the authors noticed that there was a need to address learning gaps and assist students with making connections between their prior knowledge and skills and Calculus content. Further, over the years there have been a multitude of studies which provide evidence supporting the implementation of teaching methods that engage students in the learning process.

Traditionally, the college Calculus classroom has been a place where professors lecture and students are expected to listen and learn with little to no participation. However, there has been a movement toward transforming the college classroom to foster dynamic student centered learning. The authors believe that even in this paradigm shift there is still value in using lecture as a teaching technique when paired with student centered techniques. The model presented here identifies active learning activities which can be used to supplement various modes of instruction.

While reflecting on the factors that contributed to the authors' motivation for developing the models presented in this paper, best practices in collegiate mathematics instruction were researched. Well-known theories and effective teaching techniques were combined with other innovative instructional methods that were created by the authors in order to fully develop the models. Enhancing eXcellence by Creating Engaged Learners (EXCEL) Model embodies the elements of Bloom's Taxonomy, course assessment design, and active learning strategies with different assessment goals paired with a task and active learning activity. This model can be quite useful in ensuring that class activities and assessments mirror the student learning outcomes and overall course objectives. In addition, EXCEL offers some examples of activities classified by Bloom's Taxonomy which support student engagement. This model will help faculty teaching Calculus create a Calculus course to increase student learning and improve student academic performance. The EXCEL Model is presented in Table 1. For each level of Bloom's Taxonomy, an assessment goal is listed, an associated task is given, and examples of active learning activities are identified.

The merit of the EXCEL Model is in its organization of the theoretical framework of Bloom's taxonomy in relation to Calculus assessment tasks and active learning activities. The design of this model provides information about how Bloom's Taxonomy can be applied to particular Calculus problems along with examples of active learning activities that can be used to assess the same type of problem. EXCEL gives instructors a clear idea about how problems that require both lower order thinking skills and higher order thinking skills can be created using Bloom's Taxonomy in conjunction with Calculus learning outcomes.

Table 1. Enhancing eXcellence by Creating Engaged Learners (EXCEL) Model

	Goal of Assessment	Assessment Task	Examples of active learning activities
Knowledge	The student will be able to recall fundamental facts.	State a theorem, properties, or definition.	Clicker quiz Warm-up question
Comprehension	The student will be able to demonstrate understanding of fundamental facts.	Use a theorem or properties to solve a problem.	Exit tickets Short writing exercise
Application	The student will be able to apply acquired knowledge in a new or different situation.	Solve a multi-step problem that involves more than one theorem or definition.	Think-pair-share Board work
Analysis	The student will be able to analyze information to determine relationships, structure, and relevance.	Determine if a theorem applies to a particular situation.	Cooperative learning Flipped classroom
Synthesis	The student will be able to examine information to arrive at a conclusion.	Generate a function based on given information and valid assumptions.	One-minute paper Write an explanation of problem, techniques for solving, and solution.
Evaluation	The student will be able to prove statements and make judgements based on a set of criteria.	Prove a theorem.	Problem presentation Problem based learning

While implementing class activities which involve students is important, it is also critical for the students to have opportunities to learn outside of the classroom. EXCEL is a powerful tool which can be implemented in-class, but it can also be extended to impact the coursework completed by students outside of class. One way to effectively communicate with students about the course expectations, share their individual progress, and promote student engagement is utilizing a student accessible online platform to post a variety of items, such as, the course syllabus, class notes, pre-reading assignments, information about additional resources to support their learning, and their grades. In addition, textbook assignments and handouts could be given as homework or an online site could be used for homework and quizzes. All activities should complement the course goals and student learning outcomes.

Development of the Calculus in Bloom Model

The Calculus in Bloom Model (CBM), which can be found in Table 2, was created by the authors to guide instructors in developing assessment questions and activities for Calculus I that can be categorized using Bloom's Taxonomy. CBM was created with the goal of identifying Calculus assessment items and or question types at all six levels of Bloom's Taxonomy in order to check student lower order levels of thinking and higher order levels of thinking. Considering the variety of types of assessment items that are available to use for testing in Calculus, this model was developed based Bloom's Taxonomy and the levels of different types of assessments given. Using CBM provides a structure for assessing different levels of thinking based on time available to test and the type of assessment (homework, class work, quiz, test, etc.). This is a powerful tool because it gives instructors insights into designing assessments that are aligned with student learning outcomes at particular levels of Bloom's Taxonomy for the major topics covered in Calculus I: limits, derivatives, and integrals. CBM can also be used by instructors to determine how their current assessments fit into the scope of Bloom's Taxonomy.

Table 2. Calculus in Bloom Model (CBM)

Level	Limits	Derivatives	Integration
Knowledge *Know definitions, theorems, rules, and properties.*	List the conditions necessary for a limit to exist. State the definition of the limit of a function. List the three conditions for continuity at a number.	List the rules for differentiation. State the Mean Value Theorem (MVT). State the limit definition of derivative of a function.	State the Fundamental Theorem of Calculus (FTC). State the formula to find the arc length of a curve. State the formula to compute the volume of a solid of revolution.
Comprehension *Understand definitions, theorems, rules, and properties.*	Find the limit of a function as x approaches infinity. Given the graph of a function identify limiting values.	Find the derivative of a function. Illustrate the graphic that models a related rates problem. Based on the domain of a function and a specified x interval, determine if MVT can be applied.	Find the antiderivative of a polynomial function. Find the definite integral of a function.
Application *Apply definitions, theorems, rules, and properties to solve problems.*	Show that a function is continuous at a number. Apply the Intermediate Value Theorem to an equation.	Describe how to take the derivative of a composite function using chain rule. Find the critical points of a function. Apply MVT to a function with a given interval.	Sketch the region bounded by multiple functions and find the area of the bounded region. Calculate the arc length of the graph of a function over an indicated interval.
Analysis *Analyze a problem to determine the concepts/theorems that apply.*	Classify the type of discontinuity. Explain why a rational function whose numerator and denominator have no common factors, will have vertical asymptotes at each point of discontinuity. Give an example that does not satisfy the definition of continuity.	Analyze the solution of a related rates problem. Determine the intervals on which a function is increasing/decreasing. Show that Rolle's Theorem is a special case of the Mean Value Theorem.	Use a change of variables to solve an integral using the appropriate techniques. Analyze an integral equation to determine why a function must be continuous to apply the FTC.

Synthesis *Use prior knowledge and skills to solve more advanced problems.*	Generalize the type of function whose graph has a vertical asymptote. Generate the graph of a rational function.	Use the First and Second Derivative Tests to generate the graph of a rational function. Find and label any extreme values, discontinuities, and asymptotes. Generate the graph of a function and its derivative.	Estimate the area under a curve using inscribed rectangles of equal width.
Evaluation *Make judgements based on concepts/ theorems*	Prove the limit of a function using the Sandwich Theorem.	Defend the hypothesis and conclusion of the MVT using a geometric interpretation. Given an optimization problem that can be modeled by a function with constraints. Optimize the function and justify your solution.	Assess the difference between computing integrals using Riemann sums and FTC.

By showing specific tasks at each level of thinking, the CBM is also an important resource for students. This tool allows students to see the connections between the various topics in Calculus I and the relationships between cognitive levels and different types of tasks. The authors believe that as students recognize these relationships, they will become more self-aware of their levels of learning. This awareness can help them to study with more purpose and increase the likelihood of new knowledge being retained.

In developing the CBM, the authors believed it was also important to develop a tool that could be used by students to inform them about what knowledge and skills are necessary to perform certain tasks in Calculus I. The prerequisite skills for learning Calculus (PSLC), which can be found in Table 3, highlights the three major topics covered in Calculus I: limits, derivatives, and integrals. The prerequisite skills needed to solve these types of problems are included in Table 3. For students, the CBM is a useful guide to understanding the connections that exist among the concepts in the course content. The PSLC extends these connections by showing students the relevant prerequisite skills necessary for mastering the content in Calculus I and can guide students in studying more effectively in order to meet the learning outcomes of Calculus I.

Table 3 Prerequisite Skills for Learning Calculus (PSLC)

Calculus I Concepts	**Calculus I Topics**	**Prerequisite Skills**
LIMITS	Definition of limit	• *Solve absolute value inequalities.*
	Finding limits	• *Evaluate for a given .*
		• *Simplify a rational function.*
		• *Rationalize the denominator/numerator.*
		• *Simplify a complex fraction.*
	Continuity	• *Evaluate for a given .*
		• *Graph a function.*

DERIVATIVES	Rate of change	• *Simplify the difference quotient.* • *Rationalize the denominator/numerator.* • *Simplify a complex fraction.*
	Chain Rule	• *Compose functions.*
	Implicit differentiation	• *Solve an equation for a certain variable of quantity.*
	Related Rates	• *Solve a right triangle.* • *Use formulas for perimeter, area, volume, etc. of basic figures.* • *Solve a linear or quadratic equation for an unknown variable.*
	Critical numbers	• *Determine the domain of a function.* • *Solve a linear equation.* • *Solve an equation by factoring.* • *Solve an equation using the quadratic formula.* • *Solve a trigonometric equation.* • *Find the zeros of a function.*
	Mean Value Theorem	• *Evaluate for a given .* • *Find the slope of a secant line.*
	Derivative tests	• *Graph a function.* • *Determine the domain of a function.* • *Solve an equation by factoring.* • *Solve an equation using the quadratic formula.* • *Find the zeros of a function.*
	Graphical methods	• *Determine the domain of a function.* • *Solve an equation by factoring.* • *Solve an equation using the quadratic formula.* • *Find the zeros of a function.* • *Find - and -intercepts.* • *Find vertical and horizontal asymptotes.* • *Find holes.* • *Graph a function.*
	Optimization	• *Solve a linear, quadratic, or higher order equation.* • *Evaluate a function at a given value.*
INTEGRALS	Change of variable	• *Compose functions.*
	Area/Volume	• *Graph a bounded region.* • *Solve for points of intersection of graphs.* • *Solve an equation.*

Assessment item types can be designed to test different levels of cognition. Instructors must decide how much the assessment material should focus on lower order levels of thinking and higher order levels of thinking based on the learning goals and student learning outcomes. Depending on the type of assessment, time allocated for the assessment, and the resources available to the students, the number of problems covering particular levels of Bloom's Taxonomy may vary. Generally, solving problems at lower order levels of thinking require less time than solving problems at higher order levels of thinking. It is also important to note that mastery at higher levels of cognition indicates a more in depth level of learning, which sometimes may exceed the expectations that must be met based on the student learning outcomes.

EXCEL and CBM are newly created models, which the authors believe have the potential to enhance student learning and academic performance in Calculus I. In the future implementation of these models the authors intend to use them to design assessments and learning activities which align with course learning outcomes. Depending on the type of assessment (homework, quiz, test, etc.), the authors will select problems at particular levels of thinking to measure student cognition. If the authors notice questions in a low stakes assessment, then those topics will be reinforced and presented again on a different assessment. This approach will allow the authors to clearly measure student levels of learning on specific topics in Calculus I and adjust their teaching to address learning gaps. The authors plan to share the PSLC with students at the beginning of the course so that they are aware of the learning outcomes paired with the prerequisite skills and knowledge they will need to be successful. This will give students an opportunity to review and prepare to use their prior knowledge in mathematics and apply it to Calculus topics. Future work will be done which will include an analysis of the data collected based on the implementation of EXCEL and CBM.

Implications and Future Research

Since Calculus I serves as a foundational course for most STEM disciplines, it is of paramount importance that students achieve success in this course. The teaching techniques of the professor play a major role in Calculus I student success. Therefore, thoughtful and deliberate care must be given to the way in which this course is designed and taught. The authors of this manuscript used the levels of learning of Bloom's Taxonomy along with active learning techniques to develop two models for instruction that have the potential to increase student success in Calculus I.

Aligning course and assessment design with the course learning goals is a major component of instruction at the collegiate level. Instructors must also decide the amount and types of opportunities students are given to learn. In addition, instructors must determine how much of the grade weight should be assigned to each particular type of assessment. Overall, the course goals, expected student learning outcomes, categorization of assessment items based on Bloom's Taxonomy, design of assessments, and the active learning activities should be complementary and work together to increase student cognition and enhance student academic performance in Calculus.

EXCEL and CBM have been developed to guide effective instructional practices and appropriate assessment design to aid instructors in developing teaching strategies and assessments that help to advance the levels of thinking of their students. With the Bloom's Taxonomy framework and active learning techniques combined in both models, this type of course planning and creation offers students many opportunities to learn at varying levels of cognition. The inclusion of active learning techniques in the EXCEL Model gives instructors the chance to create opportunities for students to actively engage and participate in the learning process. The specificity of the question types in the CBM is beneficial since it aligns content to assessment items and assessment items to levels of thinking. The authors believe that each of these tools offers opportunities for enhanced student engagement and increased learning in Calculus I, which can significantly increase student success.

While this manuscript reports on the creation of the EXCEL Model and CBM, the data collected will be used to report on the effectiveness of the models based on the performance of the authors' students. Data collection began during the 2018-2019 academic year and upon the full implementation of EXCEL and CBM into the authors' Calculus I classes, they plan to publish the results.

The authors have used the EXCEL Model and CBM to classify a variety of Calculus assessment items (clicker questions, quiz questions, test questions, problem presentations, etc.), which have been administered to their students. The authors are using clickers as a way to check lower order thinking skills and promote higher order thinking skills in preparation for other types of assessments.

Along with providing recommendations for course and assessment design and enhanced instructional practices, the EXCEL Model and CBM also help to extend the body of knowledge concerning collegiate Calculus education by suggesting several avenues for future research. CBM could be utilized to characterize how instructors design assessments, to assess how students perform on questions at varying levels of cognition, and to categorize how students achieve on different types of question items. In addition, EXCEL and CBM can be used with a student response system to inform about how to optimally implement active learning in a Calculus I course with this type of technology. Further, EXCEL can easily be adapted for use in other STEM courses. EXCEL, CBM, and PSLC provide opportunities for instructors to present the course content in more accessible formats which lead to students becoming more engaged learners with enhanced academic performance.

References

Active Learning for the College Classroom. Retrieved From the California State University Website: http://www.calstatela.edu/dept/chem/chem2/Active/main.htm In-text reference: (California State University)

Allen, D., & Tanner, K. (2005). Infusing active learning into a large-enrollment biology class: seven strategies, from the simple to the complex. Cell Biology Education: A Journal of Life Science Education, 4(4), 262-268.

Anderson, L., Krathwohl, D., & Bloom, B. (2001). A taxonomy for learning, teaching, and assessing: a revision of Bloom's Taxonomy of Educational objectives. Boston, MA: Ally & Bacon.

Bielefeldt, A. (2013). Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students. Sustainability, 5 4479-4501.

Bloom, B. & Krathwohl, D. (1956). Taxonomy of Educational Objectives: the Classification of Educational Goals. Handbook I: Cognitive Domain. New York, NY: Longmans, Green.

Bressoud, D. (2015). Insights from the MAA national study of college calculus. The Mathematics Teacher. 109(3):178. DOI 10.5951/mathteacher.109.3.0178.

Brookhart, S. (2010) How to Assess Higher Order Thinking Skills in Your Classroom. Alexandria, VA: ASCD.

Bush, H., Daddysman, J., & Charnigo, R. (2014). Improving outcomes with Bloom's Taxonomy: From statistics education to research partnerships. Journal of Biometrics & Biostatistics, 5(4):e130. DOI:10.4172/2155-6180. 1000e130.

Conference Board of the Mathematical Sciences. (2016, July 15). Active Learning in Post Secondary Mathematics Education. Retrieved from the Conference Board of the Mathematical Science website: http://www.cbmsweb.org/In-text reference: (Conference Board of the Mathematical Sciences, 2016)

Crowe, A., Dirks, C., Wenderoth, M. (2008). Biology in bloom: implementing Bloom's Taxonomy to enhance student learning in biology. CBE Life Sciences Education, 7, 368-381.

Eison, J. (2010, March). Using Active Learning Instructional Strategies to Create Excitement and Enhance Learning. University of South Florida.

Fink, L. (2013). Creating significant learning experiences: An integrated approach to designing college courses. San Francisco, CA: Jossey-Bass.

Fox, G., Campbell, S., Grinshpan, A., Xu, X., Holcomb, J., Beneteau, C., Lewis, J., Ramachandran, K. (2017). Implementing projects in calculus on a large scale at the University of South Florida. Journal of STEM Education, 18(3), 30-38.

Freeman S., Eddy S., McDonough M., Smith, M., Okoroafor, N., Jordt, H., & Wenderoth, M.(2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 111(23).

Gasiewski, J., Eagan, M., Garcia, G., Hurtado, S., & Chang, M. (2012). From gatekeeping to engagement: a multicontextual, mixed method study of student academic engagement in introductory STEM courses. Research in Higher Education, 53, 229-261.

Gosser, D. (1999). Project notes. Progressions: The Peer-Led Team Learning Workshop Project Newsletter, 1(2), 14.

Hodges, L., Anderson, E., Carpenter, T., Cui, L., Gierasch, T., Leupen, S., Nanes, K., & Wagner, C. (2015). Using reading quizzes in STEM classes – the what, why, and how. Journal of College Science Teaching, 45(1), 49-55.

Karaali, G. (2011). An evaluative calculus project: Applying Bloom's Taxonomy to the calculus classroom. Problems, Resources, and Issues in Mathematics Undergraduate Studies, 21(8), 721-733.

Kogan, M., & Laursen, S. (2014). Assessing long-term effects of inquiry-based learning: a case study from college mathematics. Innovative Higher Education, 39, 183–199.

Maharaj, A. & Wagh, V. (2016). Formulating tasks to develop HOTS for first-year calculus based on Brookhart abilities. South African Journal of Science, 112, 77-82.

Merkel, J. & Brania, A. (2015). Assessment of peer-led team learning in calculus I: a five-year study. Innovative Higher Education, 40:415-428. DOI 10.1007/s10755-015-9322-y

President's Council of Advisors on Science and Technology. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Washington, DC: White House Office of Science and Technology Policy. Retrieved from www.whitehouse.gov/administration/eop/ostp/pcast/docsreports

Prince, M. (2004). Does active learning work? A review of the research. Journal of Engineering Education, 93(3), 223-231.

Stanberry, M. (2018) Active learning: a case study of student engagement in college calculus, International Journal of Mathematical Education in Science and Technology, DOI: 10.1080/0020739X.2018.1440328

Stanberry, M. & Payne, W. (2018). Active learning in undergraduate STEM education: a review of research. In M. Shelley. & S. Kiray (Eds.), Research Highlights in STEM Education (pp. 147-164). ISRES Publishing.

Upton, R., Tanenbaum, C. (2014, September). The Role of Historically Black Colleges and Universities as Pathway Providers: Institutional Pathways to the STEM PhD Among Black Students. STEM at American Institutes for Research: Broadening Participation in STEM Graduate Education.

Washington University in St. Louis. Designing a Course. Retrieved from the Washington University website: http://teachingcenter.wustl.edu/resources/course-design/designing-a-course/In-text reference: (Washington University in St. Louis)

White, N., Mesa, V. (2014). Describing cognitive orientation of calculus I tasks across different types of coursework. ZDM Mathematics Education, 46, 675. https://doi.org/10.1007/s11858-014-0588-9

Yang, T., Fu, H., Hwang, G. & Yang, S. (2017). Development of an interactive mathematics learning system based on a two-tier test diagnostic and guiding strategy. Australasian Journal of Educational Technology, 33(1), 62-80.

Citation:
Stanberry, M.L. & Payne, W.R. (2019). Enhancing calculus in undergraduate STEM education with Bloom's taxonomy. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 90-105). ISRES Publishing, ISBN:978-605-698540-9.

SECTION 2
SCIENCE & ENVIRONMENTAL EDUCATION

Cognitive Theories of Learning on Virtual Science Laboratories

Hasan Ozgur Kapici
Yildiz Technical University, Turkey

Hakan Akcay
Yildiz Technical University, Turkey

Introduction

Inquiry based science learning has been used in science education since it enables students to build their own knowledge that is scientific and which can be used to predict and explain what they observe around them (van Joolingen, de Jong, & Dimitrakopoulou, 2007). In such a learning environment, it is expected that students determine problems, gather and analyze data, make inferences and assess their own progressive process (van Joolingen & Zacharia, 2009). In other words, it is supposed that students acts as scientists so as to gain scientific knowledge (Zacharia et al., 2015).

Although there are many different ways to use inquiry based science learning at schools, many researcher advocate that computer supported learning environments are one of the best appropriate modalities because it is suitable for using multiple representations, available to provide instant and individual feedback, and may provide scaffolding with respect to students' needs (Furtak, Seidel, Iverson, & Briggs, 2012; Gerjets, Scheiter, & Schuh, 2008; van der Meij & de Jong, 2006). In particular, computer simulations help students to recall their prior knowledge (e.g. through developing hypothesis) and enable them to reconstitute knowledge effectively (e.g. the data gathered from experiments or other sources is not consistent with the hypothesis) (de Jong, 2011). In the study done by van Joolingen, de Jong and Dimitrakopoulou (2007), they drew up several ways which show the appropriateness of computer simulations to create inquiry learning environments. One of them is stated as computer simulation makes easier to design experiment about wide scale phenomena into a simplified version. This situation is, for example, usually valid for astronomy topics which cannot be investigated without computer simulations in classes. Another convenience between computer simulations and inquiry learning is claimed as computer simulations provide several scaffolding tools such as hypothesis scratchpad, conclusion tool or data viewer, which enable students to manage their own learning process. The other way is advocated as computer simulations are proper to support collaborative learning among students to share and discuss data and results about the knowledge. The last point that they emphasized in their study is that computer supported environments might enable students to create their own models based on their theories. In this way, students' possible misconceptions might be revealed.

Because unguided discovery learning gives worse results for students' conceptual understanding than even direct instruction (Lazonder, 2014), computer supported inquiry learning requires guidance for students. For example, some studies (e.g. de Jong & Van Joolingen, 1998; Mulder, Lazonder, & de Jong, 2011) show that students have trouble while developing hypothesis, designing experiment and collecting data. There are also recent meta-synthesis studies (e.g. Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Furtak et al., 2012; Minner, Levy, & Century, 2010; Lazonder & Harmsen, 2016) which show that guided inquiry learning is more effective than unguided inquiry learning and direct instruction (de Jong & Lazonder, 2014). However, there is a discussion about amount of guidance and when it should be given to students (Lazonder, 2014). One of the two main perspectives claims that students should have all relevant knowledge and skills before designing and implementing their own experiments by themselves (Kirschner, Sweller, & Clark, 2006). The other view advocates that information (support) should be provided *just-in-time* or *on-demand basis* while students are in inquiry based learning process (Hmelo-Silver, Duncan, & Chinn, 2007). The help served for students may be into form of cognitive tools or scaffolds for computer supported learning environments (van Joolingen et al., 2007). De Jong and Lazonder (2014) categorize the types of support into six different forms. One of the support forms is called as *process constraints*, which aims that to diminish the complexity of the learning environment by limiting the number of options for students to deal (de Jong & Lazonder, 2014). This type of guidance can be used when students have fundamental inquiry skills and able to apply those through the investigations but have insufficient experience to use them for more demanding circumstances (de Jong & Lazonder, 2014). Another form of support is called as *performance dashboard*, which provides data about students' learning process' progress for students and also gives data about gained knowledge by students (de Jong & Lazonder, 2014). This type of support enables students to understand about their own learning process and learning outcomes. The other guidance type is *prompts*, which act as reminder for students to fulfill the learning task (de Jong & Lazonder, 2014). It is mainly used when students have related skills but may not use them by themselves. *Heuristics* are another type of guidance in computer supported learning environments. It is similar to prompts but more specific since they provide suggestions about how to perform particular action (de Jong & Lazonder, 2014). They are used when students have no knowledge about when and how to continue their task. Another support type is known as *scaffolds*. They act as components of learning process and are used when the task is so complicated or when students lack of competence to handle with the learning process (de Jong & Lazonder, 2014). Last type of support defined by de Jong and Lazonder (2014) is that *direct presentation of information*. Although this type of support contradicts with nature of inquiry based learning, it is used when students have lack of prior knowledge or they are unable to do the main task (de Jong & Lazonder, 2014).

There is no certain conclusion about the relation between types of guidance and students' level or age. In other words, it has been discussing that effectiveness of guidance types in inquiry based learning environment with respect to education and age levels. Based on the literature, de Jong and Lazonder (2014) advocate that more open types of guidance are more suitable for older students.

Another topic about guidance types is that whether supportive tools might be used in a combination form such as prompts and scaffolds together or they should be used alone. There are also contradictive results about this issue in the related literature. Some studies (e.g. Fund, 2007; Zhang, Chen, Sun, & Reid, 2004) concluded that the more guidance students received the higher scores in their posttest scores (de Jong & Lazonder, 2014). Some other studies (e.g. Eckhardt, Urhahne, Conrad, & Harms, 2013) reached totally opposite results, in which the group who received the combined guidance types had lower posttest scores (de Jong & Lazonder, 2014).

As a conclusion, it can be said that guided inquiry learning is more effective than unguided one but there is still uncertainty about the amount and types of guidance in order to support students. These (amount and types of guidance) might be different based on the students' age and education level.

Go-Lab as an Inquiry-Based Learning Environment

Go-Lab is a research project funded by the European Commission and provides online science laboratories for inquiry learning. Go-Lab platform consists of three main parts, which are online laboratories, applications, and inquiry learning spaces. Firstly, there are two kinds of online laboratories in the platform, one of which is remote laboratories and the other one is virtual laboratories. In remote laboratories, students are able to reach real laboratory setup, real location and materials from their own places. In the virtual laboratories, laboratories are simulated versions of real laboratories. There are more than 750 remote and virtual laboratories in the platform about physics, chemistry, biology, astronomy, technology, engineering, environmental education, astronomy, earth sciences, and mathematics. For example, in the Figure 1, some views of the virtual electrical circuit laboratory are shown. Students are able to create their own circuits and can do measurements on it. The virtual laboratory involves resistors, bulbs, power supplies and batteries and switches. In addition to these, it is possible to add ammeter, voltmeter and ohmmeter into the circuits.

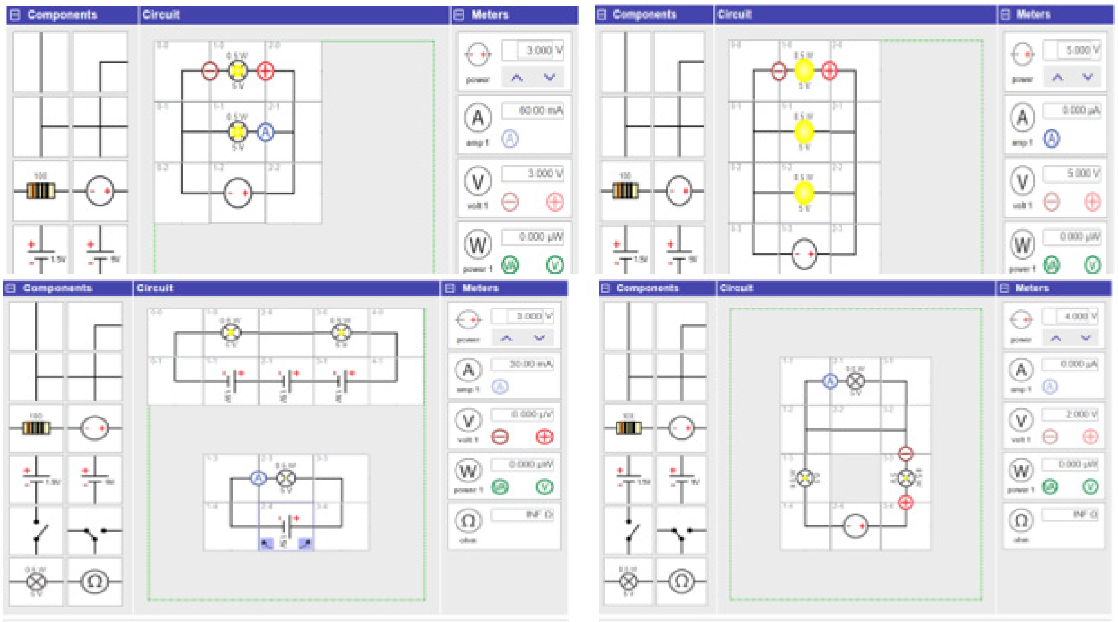


Figure 1. Some Views from the Virtual Electrical Circuit Laboratory

Another example is about remote laboratories. In the Figure 2, some views from Archimedes' principle are shown. It's a kind of remote laboratory and aims to teach students about the principle of objects floating and sinking in liquids with respect to Archimedes' principle.

Younger students (10-12 years old) can do observations for floating and sinking objects but older students (16-18 years old) can design their own experiments and determine the density of the object.

Secondly, there are web based software applications in the platform. These applications can be added into the inquiry learning space together with online laboratories. Some examples of the applications can be hypothesis scratchpad, experiment design tool, reflection tool, conclusion tool, concept mapper and data viewer. These applications act as scaffolding tools in computer supported inquiry based learning environments.

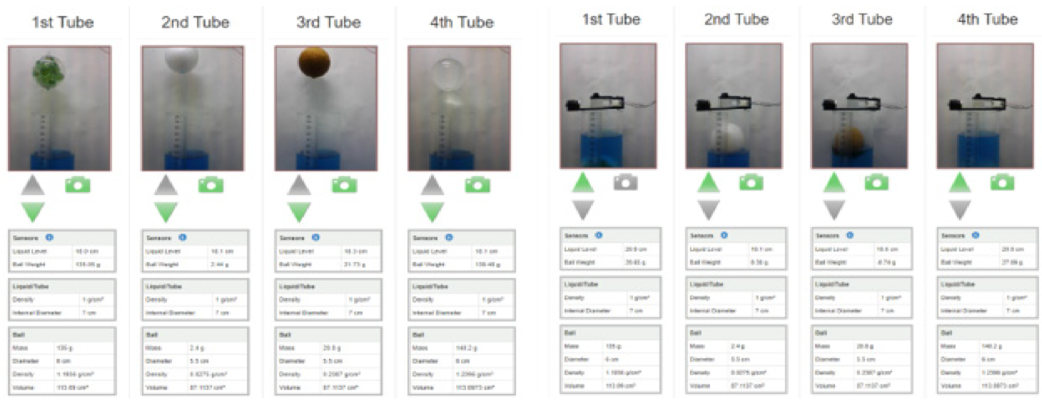


Figure 2. Some Views from the Archimedes' Principle Remote Laboratory

One of them, for example, is hypothesis scratchpad which helps students to create hypothesis. In the tool, predefined concepts are presented to students and then students compose hypothesis through drag and drop. And they can also add their own concepts by using 'type your own' box. Figure 3 shows an example of hypothesis scratchpad.

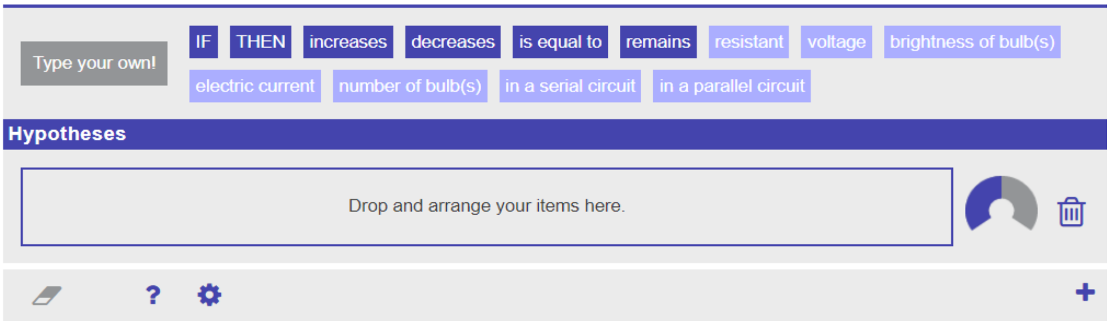


Figure 3. Hypothesis Scratchpad

The observation tool is another scaffolding tool provided by the Go-Lab platform and enables students to take notes based on their observations while preparing, conducting and analyzing experiments. Figure 4 shows the observation tool as an example.

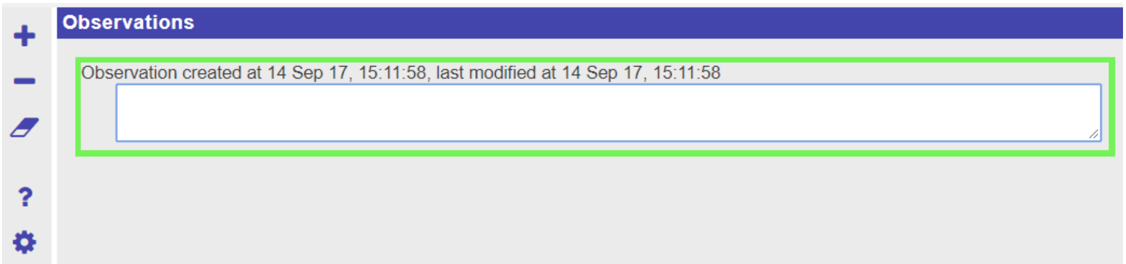


Figure 4. Observation Tool

Conclusion tool is also useful tool which is used commonly in ILSs. The tool allows students to check whether the results of experiments are compatible with the hypothesis created at the beginning of investigation. It is possible to reach hypothesis and observation notes via the tool. Figure 5 shows some examples of the conclusion tool.

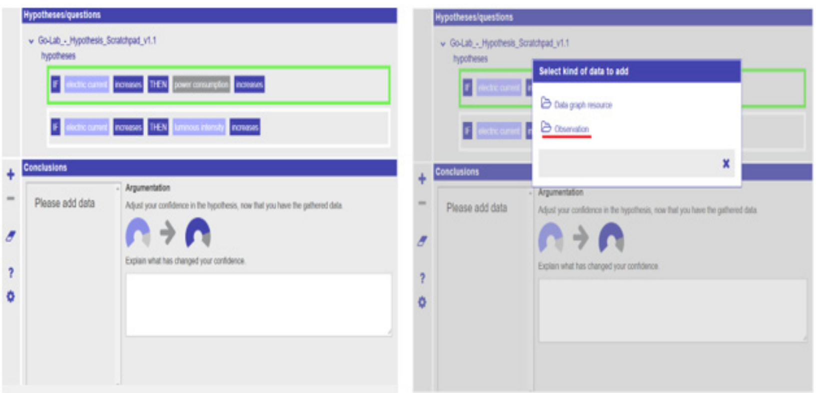


Figure 5. Conclusion Tool Enables Students to See Their Hypothesis and provides Observation Notes Taken by the Student

The third part of the platform is inquiry learning space, which is a learning environment that can contains online laboratories, applications like hypothesis scratchpad and other learning sources such as pictures, texts or videos. The learning space involves five main steps, which are orientation, conceptualization, investigation, conclusion and discussion (see Figure 6). Teachers produce inquiry learning spaces for their students and are able to share with other teachers through the system.

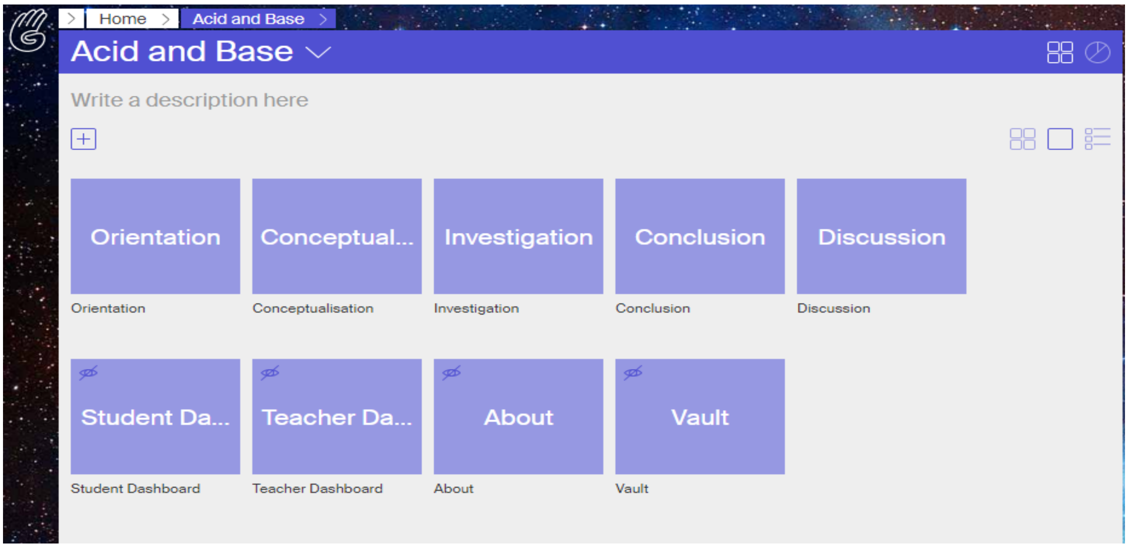


Figure 6. Main steps in an ILS

ILSs are appeared by students as Figure 7. They can move among the phases, watch videos or read texts, if exists, then they can design and implement their investigations via virtual or remote laboratories to gather data, take notes through observation tool and reach a conclusion by conclusion tool.

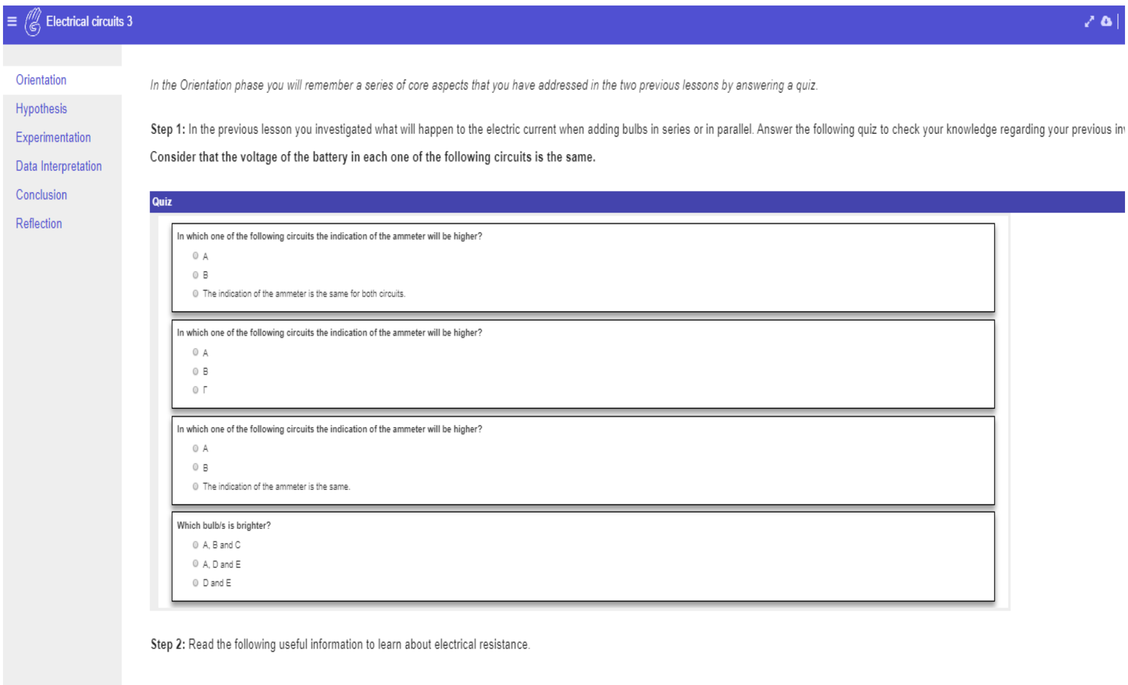


Figure 7. A View from an ILS in Terms of a Student's View

As discussed above, inquiry learning gives better outcomes if it is supported with guidance. Go-Lab platform has sufficient and useful tools to encourage students through learning process.

In addition, some cognitive learning theories also support the view that if the load on working memory decreases, then learning occurs better. In the next steps of the chapter, cognitive load theory, multimedia learning principles and importance of physicality in school science laboratories are discussed.

Cognitive Load Theory

The reason why guidance is important in inquiry based learning environment can be explained that appropriate support may help students in order to cope with the limitations of working memory and enable them to store new knowledge into long-term memory (de Jong & Lazonder, 2014). Working memory is responsible for the processing of information (de Jong, 2010, p.105). It is comprised of partially independent processors which are related to different sensory channels (Hollender, Hofmann, Deneke, & Schmitz, 2010, p.1279). There are two main deficiencies of working memory, which are holding limited amount of information and content knowledge in working memory are lost in very short duration without reiteration (Sweller, 2005). That's why; instructional designs should take in consideration these limitations.

Furthermore, there are relations between working memory and long-term memory. Long-term memory is a kind of storage, in which information is held. Cognitive activities, such as learning, done by a human are driven by information held in long-term memory (Sweller, 2005). One of the efficient ways in order to deal with the limitations of working memory while learning a new information is that using stored knowledge held in long-term memory (Sweller, 2005). In other words, understanding a concept may be explained based on the relations between working memory and long-term memory (Marcus, Cooper, & Sweller, 1996). Sweller (2005) states that schemas held in long-term memory direct the information processed in working memory in order to be organized. In other cases, for example, if there is no schema or organized information about new knowledge, then random generation based on the tests of effectiveness is followed (Sweller, 2005). Out of randomly organizing information and then testing for effectiveness, schemas held by other people can be used to organize the information (Sweller, 2005, p. 26). On the other hand, many instructional designs, like all inquiry based instructions, prefer to involve random generation followed by testing, instead of other people's knowledge (Sweller, 2005). Based on these facts, cognitive load theory was developed mainly by Paas, Renkl and Sweller (2005), Sweller (1994; 2005) and Sweller and Chandler (1991). Sweller (2005) defines cognitive load theory as an instructional theory based on our knowledge of human cognitive architecture that specifically addresses the limitations of working memory (p. 28). There are three basic categories of the theory, which are: extraneous, intrinsic and germane cognitive load.

Extraneous cognitive load is caused by improper instructional designs which ignore the limitations of working memory and does not directly promote learning (de Jong, 2010; Sweller, 2005). Because of this, instructional designers want to minimize extraneous cognitive load. There are several principles such as worked example, split-attention, redundancy, expertise-reversal effect and modality effect to minimize extraneous cognitive load. A worked example, for example, decreases extraneous cognitive load by eliminating search (Sweller, 2005). Another principle, which is split-attention, claims that learner's attention shouldn't be divided in multiple sources of information; instead, different sources of information should be integrated temporally and physically (Ayres & Sweller, 2014) if all the sources required for understanding (Hollender et al., 2010). Redundancy is the other type of principle and it also deals with multiple sources of information. Sweller (2005) explains that if there are multiple sources and both of the sources present the same information in different forms, then one of the sources is enough for understanding and the other source is unnecessary. Eliminating the second source may reduce the extraneous cognitive load. This is called as redundancy. The expertise-reversal effect is another reason for extraneous cognitive load. Detailed and exhaustive information might be useful for novice learners but not for experts because although the information is necessary for novice learners, it is redundant for expert individuals (Kalyuga, Ayres, Chandler, & Sweller, 2003; Sweller, 2005). Last but not least, modality effect has an important role to decrease for extraneous cognitive load. It advocates that instead of integrating different sources of information physically, verbal material should be presented in spoken form rather than written form (Sweller, 2005). All these principles are vital for reducing the extraneous cognitive load, which is not directly relevant for learning and learners should not spend their time and resources for the processes that cause extraneous cognitive load (de Jong, 2010).

Intrinsic cognitive load is another cornerstone for cognitive load theory. It is relevant the complexity of information and the interactivity of the elements (Sweller, 2005). In other words, material that contains a large number of interactive elements is regarded as more difficult than material with a smaller number of elements and/or with a low interactivity (de Jong, 2010, p. 106). Whereas low interactivity material refers to simple and single elements like word or number, high interactivity means that combination of single or simple elements such as sentence or adding/abstracting numbers (Sweller, 1994). Because of the fact that intrinsic cognitive load is related with the materials, instructional treatments have no impact on it (de Jong, 2010). Furthermore, it cannot be changed (Hasler, Kersten, & Sweller, 2007). In related literature, there are some ways to reduce intrinsic cognitive load such as simple to complex approach (van Merriënboer, Kirschner, & Kester, 2003) and whole-part approach (van Merriënboer, Kester, & Paas, 2006). These approaches are seen suitable with cognitive load theory because both of the approaches start with few elements and the complexity increases step by step (van Merriënboer & Sweller, 2005). As a consequence, intrinsic cognitive load tries to explain why some types of materials are more difficult than others and how this may influence the load on memory (de Jong, 2010, p.107).

The third type of cognitive load is germane cognitive load. Cognitive load theory advocates that learning occurs through construction and automation of schemas (Sweller, van Merriënboer, & Paas, 1998). Within this respect, germane cognitive load is a kind of cognitive load caused by effortful learning resulting in schema construction and automation (Sweller, 2005, p.27. Mayer (2002) states that organization of information, interpreting and classifying it, inferring and exemplifying are some required process for constructing schema, which are important constructions due to the fact that they help to reduce the load on working memory (Anglin, Vaez, & Cunningham, 2004). Instructional designs help students to expose these processes in order to engage schema construction and automation and in this way, germane cognitive load increases (de Jong, 2010). To sum up, it stems from schema construction, which is useful for teaching (Hollender et al., 2010).

These three types of cognitive load are additive (Sweller, 2005, p.27). Sweller (2005) claims that in order to provide learning better, extraneous cognitive load should be decreased through proper instructional procedure. In this way, free capacity in working memory increases. This capacity may be used by germane cognitive load, which is helpful for learning. Besides if complexity of information is low, that is lower intrinsic cognitive load, then the capacity for germane cognitive load may increase even with high levels of extraneous cognitive load since low intrinsic cognitive load gives rise to low cognitive load (Sweller, 2005). As a conclusion, the relations among these three types of cognitive load are asymmetrical and in a loop shaped (Kılıç Çakmak, 2007). Kılıç Çakmak (2007) says that reducing the extraneous cognitive load via efficient instructional designs will provide extra capacity for germane cognitive load on working memory and then schemas will be constructed more easily. After schemas are constructed, then intrinsic cognitive load will decrease at the next step.

Multimedia Learning

The theory of multimedia learning was mainly developed by Richard E. Mayer and other cognitive psychology researchers. The researcher claims that multimedia instruction encourages the way that human brain learns (Sorden, 2012, p.155). The theory benefits from cognitive load theory for developing proper multimedia based learning environment (Mayer & Moreno, 2002). The main principle of multimedia learning is individuals learn better when words and pictures presented together, instead of using them alone (Mayer, 2005). Mayer (2005) defines words as spoken or written text and defines pictures as graphs, illustrations, maps and photos in a static form or animations and videos in a dynamic form.

The theory of multimedia instruction also focuses on working memory (Mayer, 2005) similar to cognitive load theory. In his study, Mayer (2005) introduces the cognitive structure of the theory as on Figure 8.

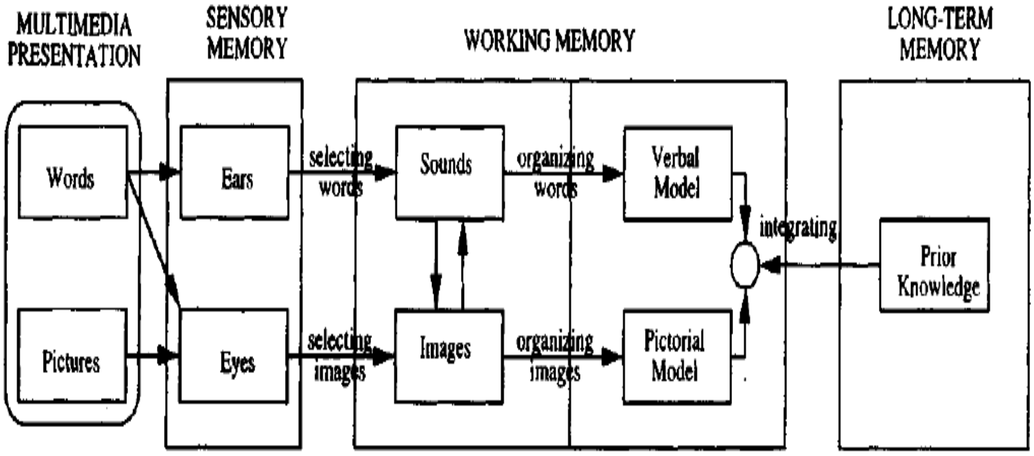


Figure 8. Cognitive Theory of Multimedia Learning

Mayer (2005) explains that structure of a human cognitive comprised of three main parts, which are sensory memory, working memory and long-term memory. Stimulus in the form of verbal and non-verbal structures receives to the sensory memory through ears and eyes. Pictures and written form of texts are held as exact visual images for a very short duration in visual sensory memory. Similarly, speech form of words and other sounds are held as exact audial images for a very short time in auditory sensory memory. The arrow from word to ears mentions the registered form of spoken text in ears and the arrow from words to eyes emphasizes the registered form of written/ drawn text in eyes. The arrow from pictures to eyes represents the registered picture in the eyes. Mayer (2005) claims that working memory composes of two parts and whereas visual images of pictures and sound images of words come into working memory as raw materials to the left side, which are visual and audial modalities. In the right side of the working memory, knowledge construction occurs through verbal and pictorial models and the transfer between them. The arrow from sounds to images means that the conversion from spoken form to visual from. For example, when an individual heard the word 'dog', s/he forms the mental model of dog. The arrow from images to sound represents opposite form the process like when some sees a dog, s/he can mentally hear the word of dog. There is also long-term memory on the right side of the figure. After organizing the material into coherent form in working memory, related prior knowledge from long-term memory is brought and integrated to the organized material. The arrow from long-term memory to working memory indicates this process.

The major cognitive processes in multimedia learning are represented with the arrows labeled as selecting words, selecting images, organizing words, organizing images and integrating (Mayer, 2005). He (2005) divides sensory memory and working memory into two channels, one of which is interested in audial and verbal from of the materials and the other channel deals with visual images and non-verbal form of the materials. Due to the fact that the capacity of working memory is limited, just a few images can be held in the visual channel of working memory and just a few sounds can be held in the auditory channel of working memory (p. 45). Mayer (2005) explains that selecting words and images from sensory memory to working memory, organizing words and images in working memory and integrating the prior knowledge from long-term memory with the organized material in working memory enable an individual to be active during these processes, which is vital for meaningful learning.

The framework mentioned above was developed by three assumptions which were put forwarded by Mayer (2005). He (2005) defines these assumptions as dual channels, limited capacity and active processing. For dual channels assumption, he (2005) says that human cognitive has two channels in order to process the information. When someone is received information through eyes, then the information started to process in the visual channel. Similarly, when the information is received in the form of sound or non-verbal from, then it goes to the auditory channel. Indeed, this assumption is mainly based on Paivio's dual coding theory (Paivio, 1990) and Baddeley's working memory model (Baddeley, 1986; 1992). Furthermore, although the information is received through one channel, an individual may convert the representation from one channel to the other (Mayer, 2005).

Limited capacity assumption is related with the limited capacity of each channel at one time (Mayer, 2005). He (2005) clarifies the assumption as when an illustration or animation is presented, the learner can hold only a few items in his/her working memory at any time. These held items represent pieces of the presented material. Similarly, when an individual exposes to an expression, the learner can just hold a few words in his/her working memory at any one time. The roots of limited capacity assumption based on Sweller's cognitive load theory and Baddeley's working memory model.

The next assumption is active-processing assumption, which means that human actively engage in cognitive processing to construct a coherent mental representation of their experiences (Mayer, 2005, p.50). These cognitive processes includes being interested in the material, selecting and organizing the incoming information and integrating it with the knowledge from long-term memory (Mayer, 2005).

Out of these three assumptions introduced for cognitive theory of multimedia learning, Mayer (2005) advocates that learners should engage in five cognitive processes, which were also mentioned on Figure 1 that shows cognitive structure of multimedia learning, in order to expose meaningful learning. He (2005) collocates these processes as (i) *selecting relevant words for processing in verbal working memory*, (ii) *selecting relevant images for processing in visual working memory*, (iii) *organizing selected words into a verbal mental model*, (iv) *organizing selected images into a visual mental model* and (v) *integrating verbal and visual representations as well as prior knowledge* (p. 54). For the processes selecting words and images are required because the limited capacity of working memory. Each channel, that is verbal and visual, has capacity limitations, so selected part(s) of the information pass through sensory memory. After receiving the selected verbal and/or visual information, another cognitive process, which is organizing them, starts. Whereas verbal knowledge structure process occurs in auditory channel, visual knowledge structure process takes place in visual channel. Learners try to build connections among pieces of information that they received. Yet, due to the limitations of working memory, it is not possible to connect all the relations among pieces of information, so simple constructions have priority. For the last process, Mayer (2005) states that the most crucial step, in which word-based and visual-based representations integrate with each other and also with the prior knowledge called from long-term memory. Integration process happens in both visual and verbal channel and includes the coordination between them. This step might be inflictor for learners because it requires influential use of cognitive capacity. Learners should focus on the underlying structure of the visual and verbal representations and be able to use prior knowledge, stored on long-term memory, when they need (Mayer, 2005, p.57).

Mayer and Moreno (2002) state that in multimedia learning, individuals gain deeper learning since they receive multi medium presentations, instead of single medium one. They claim that multimedia works better but not always. In order to investigate when multimedia works efficiently, they examined four different conditions for computer-based multimedia learning, which are contiguity aids, coherence aids, modality aids and redundancy aids. For example, in contiguity aids, visual and verbal representations are presented to students simultaneously. When learners expose to such a condition, they performed better than the group, who received the representations successively (Mayer & Moreno, 2002). This finding is compatible with the cognitive theory of multimedia learning because when the representations are presented successively, then learners expose the full information twice which contradicts with the limited capacity of working memory. Mayer and Moreno (2002) also examined the coherence aids, which means that presenting information whether with some extra information or background music or not. When they compared the two groups, the one who received a concise narrated animation in which basic visual and verbal information presented simultaneously reached better score than the other group who exposed the same presentations with extra words and sounds. This result also supports the view of multimedia learning's cognitive structure because of the limited capacity of working memory. Modality aids were also investigated by Mayer and Moreno (2002). The aim of modality aids is to reduce the load on working memory by directing the information into the different channels, which are auditory and visual. In the study done by Mayer and Moreno (2002), they compared the learning outcomes of students who were taught through animation and narration with the group who learnt from animation and text. They concluded that students in animation and narration group outperformed than their counterparts. This result is appropriate with cognitive structure of multimedia learning. Redundancy aids are another type of aids in computer-supported multimedia learning. The aid examines that whether presenting animation, narration and on-screen text is beneficial for students' learning or not. Mayer and Moreno (2002) compared two groups in their study. One of groups received instruction based on animation and narration; the other group were taught with animation, narration and text. The result showed that animation and narration group reached better score. Mayer and Moreno (2002) state the reason of this result as adding on-screen text may cause a split-attention effect and may give rise to overload on working memory. All these types of aids focus on the same critical point, which is limited capacity of working memory. In order to deal with the problem, several aids as mentioned above were emphasized in related literature review.

The Advantages of Physicality in a Hands-on Laboratory Environment

Out of cognitive processes of learning, the other important issue in a virtual laboratory environment is physicality. Physicality refers to actual, active and intentional tactile actions done by someone in order to realize an object's hardness, temperature, surface shape or weight and so on (Loomis & Lederman, 1986). In a hands-on laboratory environment, touch sensory input is provided by directly touching the physical materials and apparatus (Zacharia, 2015). Yet, it is difficult to provide such kind of physicality in a virtual laboratory environment because all materials are on screen and there is no direct touching to the materials. In order to handle with this situation, haptic devices added to the virtual laboratory environment. Based on these facts, there is no certain conclusion about the topic whether physicality is prerequisite for learning in science education. There are some studies (e.g. Kontra, Lyons, Fischer, & Beilock, 2015) which found that students in hands-on laboratory environments, in which physicality is available, gained more knowledge than virtual laboratory environments without touch sensory input or haptic devices. On the other hand, there are also studies (e.g. Zacharia, Olympiou, & Papaevripidou, 2008) which concluded that virtual laboratory environment is more beneficial for students than hands-on laboratory environment. There are also studies (e.g. Zacharia & Olympiou, 2011) that reached each type of laboratory environment is equally effective for students' conceptual understanding. With respect to these studies, Zacharia (2015) states that physicality is not necessary for learning because students reached better scores in some studies, in which there is no physically touching or haptic devices, than their counterparts, who were taught in a hands-on laboratory environment, where touch sensory input was active. Zacharia (2015) and some other researcher (e.g. Triona & Klahr, 2003) advocate that manipulation is more important process for learning rather than physicality. Manipulation requires the learner to intentionally interact with the material and apparatus in a skillful manner and does not necessarily require touching the materials (Zacharia, 2015, p.117). In other respect, physicality might be required for developing certain motor skills especially on younger learners.

There are two main theoretical perspective about tactual manipulative, which are embodied cognition and additional (touch) sensory channel (Zacharia, 2015, p.118). According to the embodied cognition theory, learning (or thinking) necessitate s actual and dynamic activations of sensory and motor systems (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Fischer & Zwaan, 2008; Niedenthal, 2007). Sensorimotor experiences drawn from embodied cognition help for meaningful learning (Zacharia, 2015). Kontra et al. (2015) explains that when the content, which will be taught, connected with physical activities, ensuing activation of sensory and motor systems might promote learners' reasoning ability. Within the context of science education, usage of touchable manipulative encourages to perform physical sensorimotor actions which cause to construct motor schemas that can help students to have conceptual metaphors about certain science concepts (Zacharia, 2015).

Another theory about the importance of physicality on learning is the additional (touch) sensory channel theory. McNeil and Jarvin (2007) state that providing additional touching opportunity for students, then they receive more knowledge about the manipulative included in the experiment such as physical structure, temperature and so on. Adding tactile experience of a physical phenomenon with visual and audial modalities may have an impact on learning more complex concepts (Bivall, Ainsworth, & Tibell, 2011) because each modality has its own processing channel (Burton & Sinclair, 2000). In other words, the information might be divided into multiple processing channels which give rise to decrease cognitive load (Chan & Black, 2006). Zacharia and Olmypiou (2011) explain two ways about how activating touching sensory channel effects learning through science experimentation. For the first way, they (2011) say that if the same type of information that travels through the visual or the auditory channels is transferred through the sensory channel of touch, the cognitive load on the visual and auditory storage systems are abridged (p. 119), which causes idle capacity in central working memory to sustain the processing for complex understanding. The second approach offered by Zacharia and Olympiou (2011) is that if different type but complementary information carried via visual or auditory channels to the touching sensory channel, then learning would be enhanced since amount of information received to the learner's working memory increases without augmentation the cognitive load for each individual channel.

These two theories reveal the importance of touching through learning process but Zacharia (2015) states that there is no research about combining touching sensory channel modality with visual or auditory modalities in order to investigate how compounding affects an individual's cognitive load.

Conclusion

Fundamental cognitive theories of learning about multimedia-based learning discussed in this chapter focus on the specific working system of human brain. In order to encourage an individual to have permanent learning, each theory proposes definite ways to decrease cognitive load on working memory. Besides, it is seen that theories are interrelated and compatible with each other. Based on the facts derived from the theories, firstly, it is suggested that researchers should provide more data about the conditions for meaning learning by using the theories. Secondly, teachers should take consider the ways discussed in cognitive learning theories while organizing their teaching approach and environments. Thirdly, multimedia developers should pay attention to the theories in their products.

References

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology, 103*(1), 1-18.

Anglin, G. J., Vaez, H., & Cunningham, K. L. (2004). Visual Representations and Learning: The Role of Static and Animated Graphics. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (Vol. 2, pp. 865-916). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Ayres, P., & Sweller, J. (2014). The Split-Attention Principle in Multimedia Learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd Edition ed., Vol. 2, pp. 135-146). Cambridge, MA: Cambridge University Press.

Baddeley, A. (1986). *Working memory*. Oxford: Clarendon Press.

Baddeley, A. (1992). Working memory. *Science, 255*(5044), 556-559.

Barsalou, L. W., Kyle Simmons, W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences, 7*(2), 84-91.

Bivall, P., Ainsworth, S., & Tibell, L. A. E. (2011). Do haptic representations help complex molecular learning? *Science Education, 95*(4), 700-719.

Burton, H., & Sinclair, R. J. (2000). Attending to and remembering tactile stimuli: A review of brain imaging data and single-neuron responses. *Journal of Clinical Neurophysiology, 17*(6), 575-591.

Chan, M. S., & Black, J. B. (2006). *Direct-Manipulation Animation: Incorporating the Haptic Channel in the Learning Process to Support Middle School Students in Science Learning and Mental Model Acquisition*. Paper presented at the International Conference on Learning sciences, Bloomington, Indiana.

De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. *Instructional Science, 38*(2), 105-134.

De Jong, T. (2011). Instruction based on computer simulations. In P. A. Alexander & R. E. Mayer (Eds.), *Handbook of research on learning and instruction* (pp. 446-466). New York, NY: Routledge.

De Jong, T., & Lazonder, A. W. (2014). The guided discovery principle in multimedia learning. In R. E. Mayer, J. J. G. Merriënboer, W. Schnotz, & J. Elen (Eds.), *The Cambridge handbook of multimedia learning* (pp. 2015-228). Cambridge: Cambridge University Press.

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations? *Instructional Science, 41*(1), 105-124.

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*(6), 825-850.

Fund, Z. (2007). The Effects of scaffolded computerized science problem-solving on achievement outcomes: A comparative study of support programs. *Journal of Computer Assisted Learning, 23*(5), 410-424.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching:A meta-analysis. *Review of Educational Research, 82*(3), 300-329.

Gerjets, P., Scheiter, K., & Schuh, J. (2008). Information comparisons in example-based hypermedia environments: Supporting learners with processing prompts and an interactive comparison tool. *Educational Technology Research and Development, 56*(1), 73-92.

Hasler, B. S., Kersten, B., & Sweller, J. (2007). Learner control, cognitive load and instructional animation. *Applied Cognitive Psychology, 21*(6), 713-729.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99-107.

Hollender, N., Hofmann, C., Deneke, M., & Schmitz, B. (2010). Integrating cognitive load theory and concepts of human–computer interaction. *Computers in Human Behavior, 26*(6), 1278-1288.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23-31.

Kılıç Çakmak, E. (2007). Çoklu ortamlarda dar boğaz: Aşırı bilişsel yüklenme [The bottle neck in multimedia: Cognitive overload]. *Gazi Eğitim Fakültesi Dergisi, 27*(2), 1-24.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86.

Kontra, C., Lyons, D. J., Fischer, S. M., & Beilock, S. L. (2015). Physical experience enhances science learning. *Psychological Science, 26*(6), 737-749.

Lazonder, A. W. (2014). Inquiry learning. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (pp. 453-464). New York, NY: Springer.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*(3), 681-718.

Loomis, J. M., & Lederman, S. J. (1986). Tactual perception. In K. R. Boff, L. Kaufmann, & J. P. Thomas (Eds.), *Handbook of perception and performance* (pp. 1-41). New York: Wiley.

Marcus, N., Cooper, M., & Sweller, J. (1996). Understanding instructions. *Journal of Educational Psychology, 88*(1), 49-63.

Mayer, R. E. (2002). Multimedia learning. *Psychology of Learning and Motivation, 41*, 85-139.

Mayer, R. E. (2005). Introduction to multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 1-18). Cambridge: Cambridge University Press.

Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational Psychology Review, 14*(1), 87-99.

McNeil, N., & Jarvin, L. (2007). when theories don't add up: disentangling he manipulatives debate. *Theory Into Practice, 46*(4), 309-316.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Mulder, Y. G., Lazonder, A. W., & de Jong, T. (2011). Comparing two types of model progression in an inquiry learning environment with modelling facilities. *Learning and Instruction, 21*(5), 614-624.

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*(5827), 1002-1005.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Paivio, A. (1990). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Sorden, S. D. (2012). The cognitive theory of multimedia learning. In B. J. Irby, G. Brown,

R. Lara-Alecio, & S. Jackson (Eds.), *The handbook of educational theories* (pp. 155-168). Charlotte: NC: Information Age Publishing.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 19-30). Cambridge, MA: Cambridge University Press.

Sweller, J., & Chandler, P. (1991). Evidence for cognitive load theory. *Cognition and Instruction, 8*(4), 351-362.

Triona, L. M., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction, 21*(2), 149-173.

Van der Meij, J., & de Jong, T. (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction, 16*(3), 199-212.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Van Joolingen, W. R., de Jong, T., & Dimitrakopoulou, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning, 23*(2), 111-119.

Van Joolingen, W. R., & Zacharia, Z. C. (2009). Developments in inquiry learning. In N. Balacheff, S. Ludvigsen, T. de Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-enhanced learning: Principles and products* (pp. 21-37). Dordrecht, the Netherlands: Springer.

Van Merriënboer, J. J. G., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology, 20*(3), 343-352.

Van Merriënboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist, 38*(1), 5-13.

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: recent developments and future directions. *Educational Psychology Review, 17*(2), 147-177.

Zacharia, Z. C. (2015). Examining whether touch sensory feedback is necessary for science learning through experimentation: A literature review of two different lines of research across K-16. *Educational Research Review, 16*, 116-137.

Zacharia, Z. C., Manoli, C., Xenofontos, N., de Jong, T., Pedaste, M., van Riesen, S. A. N., Kamp, E. T., Maëots, M., Siiman, L., & Tsourlidaki, E. (2015). Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: A literature review. *Educational Technology Research and Development, 63*(2), 257-302.

Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: Experimental research. *Journal of Computer Assisted Learning, 20*(4), 269-282.

Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. *Learning and Instruction, 21*(3), 317-331.

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. *Journal of Research in Science Teaching, 45*(9), 1021-1035.

Citation:
Kapici, H.O. & Akcay, H. (2019). Cognitive theories of learning on virtual science laboratories. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 107-126). ISRES Publishing, ISBN:978-605-698540-9.

Chemical Laboratory Safety: A Neglected Topic in Science Curriculum Design

B.H.S. Thimmappa
Manipal Institute of Technology, India

Introduction and Background Information

The basic human survival needs include oxygen, water, food, sleep, and safety. Scientific research results have a profound impact on the modern world and changed lifestyles. Chemicals and chemical reactions are indispensable in a highly technical society of 21st century. It is essential for people to work in humane and safe conditions in all the scientific laboratories as it is one of the defining pillars of scientific growth. The professionals must have their awareness of the sociological implications of their research and development work and observe a code of conduct to protect our environment for a better future. The societal and technological transformation, funding availability for the proper maintenance of laboratory facilities, training of safety personnel, and the recruitment of safety officers have driven the improvement in the practice of laboratory safety during the last three decades (Amburgey-Peters, 2002). The statistical data on laboratory incidents form a vital component in the quest to achieve safer scientific laboratories worldwide. But the safety survey on workplace conducted in 2013 indicates the significant laboratory risks causing minor to severe injury for the research scholars and the employers should ensure the safety of the lab participants (Noorden, 2013).

We have to understand the factors causing lab accidents supported by scientific facts and by eliminating the cause/s one can limit the prospect of an incident and protect ourselves from potential dangers. The causes of laboratory accidents include the lack of experience or working understanding of hazards, improper or unintended use of equipment, distractions or lack of attention to task, the use of broken, damaged glassware or equipment, and carelessness. These parameters can be traced back to the fundamental lack of necessary chemical background and failure to make connections between the academic concepts and laboratory safety (NRC, 2014). Academic lab accidents can result in loss of life, and multiple injuries, economic loss, property destruction, and harm to the environment. It is essential to identify the cause or causes, and by eliminating the causes, accidents will be reduced.

The safety extension from laboratory scale to pilot plant to industrial scale comes with scale up operations involving several chemical plants, products and processes (AICE, 1990; ICE, 1983). An unhealthy work environment such as hazardous chemicals, chemical waste, biological species, noise, metal fumes and monotonous nature of work in the industries are known to cause disabilities and diseases (Freeman & Whitehead, 1982). Industrial safety has not received the required attention and importance, especially in small and medium scale undertakings. If we take suitable steps to promote safety in an industrial setup most of the accidents are preventable, thus helping with the healthy growth of the community (Kharbanda & Stallworthy, 1988).

The changes to transform chemical laboratory safety begins with the course of trying to review the current situation. Some undergraduate colleges do not have proper laboratories, training in safety aspects, a chemical safety plan for instruction, and quality control mechanism. It is extremely important to develop the sense of rights and the responsibilities of a learner, researcher, or professional worker in these laboratories. There is an increasing need to have an active educational program on safety to bring attitudinal change among all the stakeholders to enable them to contribute immensely to the overall safety through a series of efforts. The education on safety will help the learner to unlearn certain misperceptions, misconceptions, misunderstandings, incorrect assumptions, and help understand the real concepts and broader understanding of many other factors related to safety. We have to become conscious of the value of safe procedures and develop a proper mental attitude to promote safety in the laboratory. Proper education about laboratory safety has to be accorded on a priority basis to change the attitude towards safety to a large extent (Schroder et al., 2016).

The various circumstances of the contemporary lab settings lead us to consider the fine line between safety and risk and open the door to a new vision of a unique rapid reaction world expecting the unexpected. Advances in the chemical sciences with the help of modern technology have resulted in an explosion of knowledge about safety. The advances in the transient techniques have allowed us to understand certain realities of reaction dynamics. Some unexpected instantaneous incidents remind us that the past, present, and future are linked by concerted or stepwise mechanism. The existence of a well-established reaction mechanism for the solution of safety issues will enable a suitable action to what might otherwise end in danger. Laboratory safety research has become more important in the last decade as indicated by the increasing number of published papers in the field and their extreme relevance for human security. The research journals on different safety topics include the Journal of Safety Research, Biosafety, Structural Safety, Safety Science, Fire Safety Journal, Applied Biosafety, Journal of Chemical Education, Journal of Laboratory Chemical Education, and Journal of Chemical Health and Safety. The journal 'Loss Prevention Bulletin' published by the IChem, UK publishes various process safety case studies related to laboratory and industrial safety including near miss cases.

Humans have prepared, found or used over 50 million unique chemicals, each with a distinct chemical composition, and chemical industry archives contain more than 62,000 commercial chemicals.[3)] From the soft baby foods to the powerful destructive bombs, many products are manufactured worldwide for a multitude of purposes. Many companies are introducing innovative products to meet specific needs of customers in addition to standardized products. It is indeed a difficult task to collect, analyze and assess the safety aspects of each of these products and find out protection methods for a safe laboratory experience. The principle danger exists in ignorance of specific hazards and negligence during working and experiments with chemicals need to be looked at closely with caution (Fig. 1.) The lack of available data on lab incidents and injuries may be due in part to an out-of-court settlement in many legal cases, and it is not mandatory to report such accidents to concerned people or media in certain organizations. It is our responsibility towards the scientific community to report such accidents and to suggest preventive actions be taken to reinforce laboratory participants to follow safety principles regularly. There is a need to provide safety education that enables scientific understanding of issues, the primary reasons and deduce solutions to various safety issues, including readiness to cope with an emergency. A systematic research study of various safety aspects with a molecular level perspective and the development of chemistry associated with them will reveal some unknown properties of certain chemicals and unpredictable reactions. The discussion above establishes the importance of the study of safety in science curricula and for the conduct of chemical education. The basic safety skills can be cultivated and developed by practice, but often neglected in curriculum.

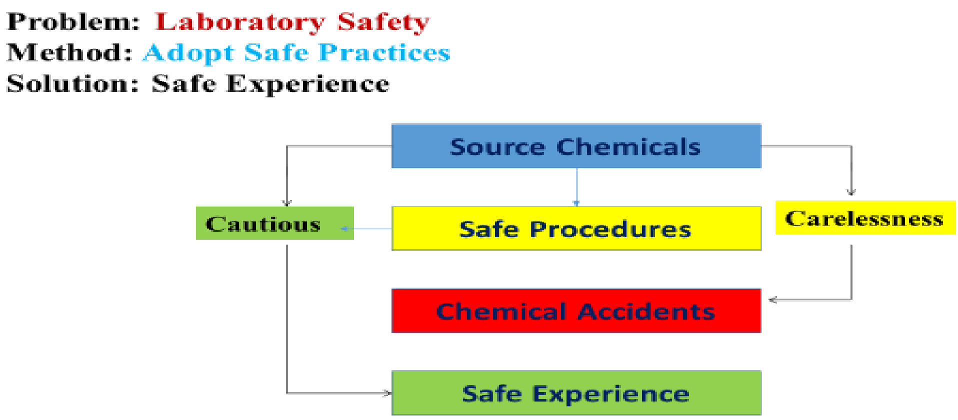


Figure 1. Flowchart Depicting Linked Steps in the Overall Safety Net.

The purpose of this paper is to draw the attention of general readers to the chemical laboratory safety aspects and impacts as one of the neglected topics in curriculum design. Our concern is to upgrade the academic laboratory safety infrastructure and follow the standard best practices to reconnect with the real reader in a more extended manner to think about the unintended consequences. This article is intended to promote safety awareness and encourage safe working practices in the chemical laboratory and to anticipate, evaluate and recognize hazards that may occur during laboratory operation. It attempts to explain briefly the nature of the safety issues and general line of control and preparation for emergencies. The discerning reader can get a complete picture or additional details through numerous cross references of original work, review articles, books or monographs. The text is divided into sections concerned with a brief history of laboratory accidents, understanding the safety aspects, enhancing laboratory safety, professional development approaches, towards a safer world of a laboratory, and conclusions and future directions. An academic laboratory safety course is included in the appendix A concerning the needs of the modern scientific practice. A subdisciplinary content on 'Academic Laboratory Safety Course' is presented in a dedicated unit, and the syllabus itself does have value. The idea is to fully explore the immense possibilities within the purview of the scientific facts and choose a better course of action in any given set of circumstances, which has severe consequences for the future of safe laboratory practices. The genuine spirit of creating a thinking framework allows people to imagine different risk possibilities and re-engineer all aspects of safety through the knowledge of chemical sciences. In addition to the understanding the general and specific safety issues, tracking the distinctly different trajectories at the molecular level is paramount to reduce specific risks involved. The content of the paper is useful to audiences such as laboratory instructors, workers, teachers, and students. It will be of interest to the non-specialist readers, research scholars, educational advisers, curriculum writers, consultants, graduate level students as well as some research-minded scientists in government laboratories and industry.

Understanding the Safety Aspects

It is necessary to provide a safe working environment at your workplace to promote science, engineering, and technology.[4, 5)] In this context, a proper study of safety related broader issues and facilitating sharing of scientific knowledge about safety management practice in the classroom and laboratory demonstrations of concepts of safety becomes critical. Interdisciplinary approaches to laboratory safety have become paramount in addressing a broad range of safety issues at both local and global levels. Most of the industrialized nations have taken action to reduce the frequency of laboratory accidents and teach the students how to handle chemicals safely, how to avoid accidents and what to do in the event of an accident. It is now common to see laboratory spaces completely separated from offices in the layout of modern science laboratories. In the Indian context, the understanding of laboratory safety and its significance becomes very critical when we consider the significant increase in the number of higher education institutions and universities in the recent past.[6)] There is an acute shortage of necessary infrastructure and insufficient and inadequate safety devices except for a few established laboratories. Lack of adequately trained personnel as a result of a failure of safety management and planning also contributes to the problem. Further, many undergraduate students now take part in research activities, and this could involve risks with consequences such as physiological injury (disability and death), damage to standard equipment, financial loss, psychological impairment and other long-term implications. Moreover, the disposal of toxic acids, solvents and other chemicals of unknown toxicity would have a direct impact on air, water and soil quality, posing environmental issues **(**NRC, 1995)**.**

The awareness about laboratory safety is less due to the lack of interest in students and the administration and incredible diversity of solution chemistry. There are inherent engineering challenges to overcome safety issues in several industrial processes and find out the best methods to manufacture products or extracting certain metals from their ores (Sax & Lewis, 1988). The mainstream media need to improve their presentation of safety matters written by journalists with specialized scientific knowledge and soft communication skills. A journalist's efforts should be aimed at arousing safety awareness among the readers and making them conscious of their responsibilities towards safe experimentation to obtain practical knowledge. The safety message in forceful, clear terms from a magazine or newspaper can make the readers act intelligently and promptly to prevent laboratory accidents. The laboratory safety is necessary to prevent the adverse health effects of exposure to chemicals, personal injury or injury to fellow workers, laboratory equipment hazards - if not maintained properly, and damage to equipment. As there is increasing concern about the academic laboratory safety in the recent past, prudent practices in the laboratory provides a sense of confidence and social responsibility (NRC, 1981).

The government should support for basic safety measures, frame protection policy to promote safety in scientific laboratories and monitor the proper adoption of sustainable safety practices. Regular cleaning activities within the laboratories in all higher education organizations should become a part of the educational program involving the practical components. Sustainable strategies for safety management include educating laboratory users to get aware of safety rules and regulations through posters, slide shows, awareness notes, banners, safety quizzes, and workshops, among others (Author, 2006). Other learning resources on safety in the form of audio books or video are impactful in education. It is crucial to read the fine details on the label carefully to find out the summary of product characteristics and the critical safety information of the chemical that we are about to use. In addition to having safety rules and regulations and extensive safety support systems, there has to be a massive safety sensitization program to bring an attitudinal change among all stakeholders. Participation of multiple participants is essential for effective safety management. A new perspective involving safety mission, detail orientation, and making intelligent decisions based on scientific evidence, observations, case histories and knowledge will help in addressing various safety challenges and concerns in our professional lives everyday (Sanders, 2005). Depending on the nature of the safety problem, we have to decide what is the best course of action that can be safely be used and should be followed. Users often waste precious time and by doing so may allow a controllable process to a harder to control stage (Cote & Wells, 1991).

It is essential to enhance our perception skills to go beyond the average human eye and train the brain to analyze more data in a much faster way to take proactive and immediate action of every aspect of safety including unexpected effects (Weiss, 1986; Windholz, 1976). There is a paucity of safety data available on new laboratory chemicals. The actual safety information on a diverse range of products should flow from suppliers (chemical manufacturers, importers, distributors) to employers and then to the workforce to ensure their safe handling under actual academic operating conditions with the professional operating ethos.[7)] The professional societies should provide a platform for the exchange and transfer of safety knowledge and information about research and development through their activities. A researcher should be made aware of various potential safety issues in instrument rooms with lasers, pressurized gas cylinders, cryogenic liquids and high pressure/temperature reactors, to improve overall safety. The interrelated safety aspects of lab practice such as prudent practices in practical work, precautionary measures in violent reactions, visual inspections of maintenance work, controlled conditions using safety devices, emergency techniques in fire accidents, first aid in physical injuries, professional help in health problems, and control mechanism in preventing environmental pollution are necessary to develop safety consciousness (LeFèvre & Shirley, 1997; Meyer, et al., 2007; NFPA, 2010). In the light of overall safety development, we have to blend the right benchmark principles of safety into laboratory practice by controlling our thoughts and actions in the right safety spirit. The safety is the fundamental requirement to overcome the investigation challenges that demonstrate our quest to understand and discover the world through various natural and artificial mediums, methods, materials, and scientific interpretations, assessments, analyses, and expressions (Girolalmi, et.al, 1999, Shriver & Drezdzon, 1986, Skoog et al., 1994).

Enhancing Laboratory Safety

The modern chemical laboratories are safer with all the safety measures in place, and proper precautions are taken for safety during experimentation phase. Proper laboratory safety and a chemical hygiene plan help in minimizing the risk of chemical exposure, reducing the danger of lab work-related injury and illness, lowering the risk to the environment, and comply with applicable regulations and standards. It is important to increase reporting of laboratory incidents, provide safety training to react swiftly and with sensitivity to victims, and have a worldwide awareness campaign to reignite core values and safety precautions to develop a real safety culture.[8)] The specific objective of safety program should be to achieve the four E's- education, expertise, experience, and exposure to a range of safety aspects and develop, implement and maintain a particular standard of good laboratory practice. At the end of the safety program, the learner will be able to understand and employ safety knowledge and have strong safety ethics in laboratory practice. They should have the technical background and the ability to understand, analyze and explain the impact of laboratory safety-related incidents and suggest suitable safety measures in particular situations.

Each university should start a formal safety program development, depending on the need and requirements of local affiliated colleges and intense involvement of industry experts on safety will help to raise the bar on safety quality. There should be a robust linkage between the safety specialist in education institutes and those in industrial laboratories to strive for a stronger safety culture in an academic setting (Staehle et al., 2016). The primary emphasis is on bringing radical changes in the concerned departments and fixing accountability on higher education providers. Universal eligibility criteria for a safe scientific lab and high safety standards must be maintained as a step towards prevention of accidents. Conducting proper training and refresher courses by competent training authorities would help us to understand the nature and magnitude of the problem, the impact of safety measures, and the relationships between safe practices and the number of lab incidents. It is important to ensure enough human resources and other technical assistance to adhere to global safety standards to reduce unnecessary risk or the magnitude of the risks involved. Improving professional standards and commitment to ethical values along with an efficient safety management system to implement safety measures to a sufficient level will go a long way in addressing the problem of academic lab safety. National council for safety research and training can conduct meetings to reflect, discuss, and debate on thematic organization and presentation of topics in the safety course and arrive at a point to enhance the quality of learning activities and experiences. The laboratory activities must be consistent with the standard best practices followed by the top level universities for many years to achieve our safety goals (RSC, 1986).

Professional Development Approaches

The different common types of chemicals present or produced in the chemical laboratory include toxic compounds, reactive species, carcinogenic agents, compressed gasses, corrosive chemicals, irritant fumes, lachrymatory vapors, flammable liquids, explosive substances, shock-sensitive compounds, pyrophoric chemicals, radioactive materials, and peroxide-forming reagents.[9,10)] The various types of incidents include explosions due to mishandling, accidents during disposal of used chemicals, fire mishaps, injuries due to sharps, inhalation of toxic fumes, chemical/electrical/thermal burns, and UV/X-ray exposure (Luxon, 1992). There is a requirement to create a climate of safety for achieving distinct results, technological advances through educational professionalism and research work, which could be useful in the public interest, the institution, and the nation. Safety education in the right perspective should be actively encouraged in universities to enable a learner to make a proper use of safety knowledge during the subsequent period of their scientific life while performing lab activities. The accidents caused by unsafe conditions can be improved by conducting regular safety audits and inspections, maintenance of equipment, encouraging reporting, and good housekeeping, whereas those due to unsafe acts can best be prevented from developing and establishing a better safety culture.[11)] This culture can be drawn up by making conscious efforts in the direction of thoughts, actions, habits, character, and destiny, each of which reinforces the next.

The development of a safety culture includes personal, behavioral, and environmental factors that condition our mind to make the working environment safer and take steps to remedy unsafe situations. This transformation could involve changing perceptions and paradigm shift by overcoming deep-underlying thought patterns and major concerns at the subconscious level. The persons with a well-trained and organized mind can work more efficiently and effectively and will be able to use the brain power to think clearly, concentrate and to perform meaningful experiments without giving scope for accidents to happen. There is an urgent need for laboratory safety education and awareness activities at the undergraduate level that can indeed be an enabler and a driver of positive change (Hill, 2016). The study of safety and achievement of educational objectives depends upon the practical content, the way in which it is taught, rigorous follow-up and evaluation.[12,13)] Higher educational organizations need to be sensitized, and colleges should include safety aspects and impacts in training curricula and enhance the industry-institution interface. Students with strong safety education should be preferred for industrial jobs or safety research groups to minimize the risks through an organized application of safety knowledge.

The educational objectives of integrated safety development drive should include the following; i) to increase the level of awareness of laboratory safety among learners by providing safety knowledge and safety ethics ii) to present recent developments that can help reduce the number of laboratory accidents leading to serious injury or death iii) to show that chemical reactions can be useful to find concrete solutions to many significant problems without injuries from chemical events iv) to share the right information about chemical principles and techniques, phenomena, fundamental concepts, and chemistry core ideas relevant to develop a sense of the kinds of chemical and other laboratory hazards one might encounter v) to develop a proper safety consciousness through selection of relevant scientific content and educational methods, vi) to establish a safety management system and to instil stronger safety practices in chemical research (Stuart & McEwen, 2016) and vii) to promote chemical science to young learners with safe practices to minimize the risks of hazards through proper mentor-learner relationship.

The formal safety course could be taught to regular students as a stand-alone course or as an integral part of the general science curriculum. It is important to activate and develop the right cerebral functioning with emphasis on logical thinking, scientific reasoning, problem-solving ability and creativity skills. Teaching lab safety for faculty members and other technical staff as a formal safety education is important to minimize risks (Hall, 1993). The systematic safety education approach must be outcome based or impact driven by innovative ideas, management skills, and efficiency. The educational outcome could be measured by formal learning assessment modules involving objective type questions, very short answer, short answer or long answer type questions on different aspects and impacts of academic laboratory safety. The questions must consist of a well-balanced composition involving easy, moderate and challenging questions (E, M, and D in ~ 60, 30, & 10 %). This structure will enable a vast majority of students to answer the easy ones without much difficulty. The questions with an increased degree of difficulty should be such that only above average students can provide conclusive answers to these. The remaining questions should be such that the students who can apply knowledge learned in the regular class right in the examination hall can only respond to these. The proposed safety syllabus has been used before as a comprehensive material in a unique and educational way in classes of average strength fifteen using PowerPoint presentation methods and handouts distributed as supplementary materials to promote active learning. The response of students to the interpretation of particular aspects of safety was excellent as reflected in their active participation in classroom activities as well as their best performance in examinations.

Further safety information can be obtained from the relevant literature survey, material safety data sheets (MSDS) available in CDs/printed version, the Merck Index, Chemical Laboratory Information Profile (CLIP) in J. Chem. Ed. (ACS), online databases, audiovisual materials, and CD read only memory products (CD-ROM form)[14-17]. A data bank of hazardous reactions was launched recently, and researchers can add their incident reports in this new chemical safety library service, helping to minimize dangerous reactions from being repeated.[18] In certain universities, the "Safety Quiz" has been introduced, and safety cell circulates 'Caution Notes' periodically for continual improvement. Surfing the internet sources to find some generic safety-related information (PDF or PPPs) and participating in global scientific conferences will allow us to switch between different themes in unconventional learning. The links to flashpoints, carcinogenic substances, MSDS data sheets, radioactive materials is included in the appendix B. Compiled information on various websites with their distinctive features along with detailed safety reports, interconnected conceptualized paintings, illustrative pictorializations and captured photographs can make a huge impact in scaling up learning levels. Further, audio-visual aids, cartoons, charts, diagrams, films, graphs, and models can be applied in the teaching-learning process that helps to see things in a broader perspective. We have to look for factual safety information and ready to walk that extra mile to seek long-term solutions to safety problems (Haynes, 2017). The stages of safety-problem solving include recognizing that a problem exists, assembling information relevant to the problem and selecting and implementing the best solution. Most chemicals are toxic and dangerous chemical reactions include many more reactions than the reference library (Yoshida, 1987). If there is no published information on the hazardous properties of a chemical compound, this does not mean that no hazard exists (Saxena, 1984). It is better to keep track of the safety news to be aware of any dangerous properties and potential safety problems in our functional domains to enable us to make more informed judgments. Incorporation of safety data, including new guidelines and new policy matters in a laboratory information management system (LIMS) under analytical and managerial level tasks, would help address more immediate challenges and adapting to safety regulations.

The safety issue should be handled with extreme care while participating in various lab activities. The science, engineering and technology institutions take the lead in sensitizing the stakeholders about the various aspects of safety, reform their mindset, and educating them about safety culture is vital for the future. A regular theoretical training and practice sessions, including emergency action plan and response for the researchers to equip them with new skills required in safe laboratory operations and prudent practices, help in reducing the number of laboratory accidents. It is essential to develop strategies to an unblocked thought process and imagination to view things in their true relation or relative importance, with increasing concerns of environmental consciousness in the stakeholders. The scientific community should not allow workers to perform any potentially dangerous activities in an ordinary laboratory unless special safety requirements are met, and adequate risk management measures are in place (Sax & Lewis, 1987). The safety signs and symbols have become a core part of our communications, and the visual recognition carries profound significance. The forensic work for the investigative purpose could include establishing the cause of suspicious fires, academic hazard issues, hazardous equipment use and analyzing the presence or absence of various toxic substances in body fluids and tissues after the incident. The recruitment of safety management executive and recognition of safety teachers as scholarly practitioners at the university level will certainly boost the morale and confidence of those involved. The safety storage, waste disposal and emergency planning and response services have to be managed at the institutional level. The research activities related to safety problems are necessary to understand processes at the molecular level that cause them. Scientists and engineers have studied the spread of fire or gas inside the laboratories through computer simulations to find out practical solutions for several issues involving fire or toxic gases. Creating a trained, expert and motivated safety management task force in each university plays a pivotal role in the process of promoting safety. A regular audit of laboratories for safety can alert us to accidents waiting to happen and taking certain precautions during lab activities help prevent many accidental injuries.

Towards a Safer World of Laboratory

Depending on the stage of development of an institution and available resources, established laboratories (10 + years), young laboratories (5-10 years) and new laboratories (under five years) have to be considered for various safety development activities. The priority should be given to improving existing equipment, facilities and construction of new ones to support safety-related activities. Further, establishing the integrated safety facility by providing critical safety infrastructure would help in building bridges between institutes in proximity. Also, installing sophisticated surveillance systems can drastically transform the behavior of those working in the laboratories. An online, print, electronic and outdoor media campaign may be necessary to have strict safety measures in the workplace. Student poster competition and safety-related activities for students as well as conduct regular workshops or crash courses on the basics of safety in academic laboratories help in promoting a safe work environment. It will be more useful, relevant, intellectually stimulating, and more productive to have 'bridging the gap' course on safety in an undergraduate program in chemistry, chemical engineering, biotechnology, medical lab technology, microbiology, pharmacology, biomedical engineering, and materials science (ACS, 2017). Experimental studies at the interface of these subjects may encounter unexpected or new hazards. It is the responsibility of the authors to report any such hazards in safety notes while publishing the results of experimental work. We have to facilitate learning by providing supporting information in the form of student handout (PPT) on the topic, and instructor notes (PDF) and experimental protocol should be supervised by the experienced teachers. Also, it is essential to assess learner's knowledge, attitude and behavioral practices towards safe laboratory experimentation through a battery of tests. The safety curricula must be brought up to date continuously because of the rapid developments in the field. We have to meet the needs of the environment and contribute to finding processes that reduce environmental hazards and consumes less energy.

Online centralized safety management system by the university grants commission or the national safety council can also minimize the number of safety-related incidents in wet chemistry laboratories, but active participation of university officials, safety managers, researchers, activists, enthusiasts, and the academic community is essential. Starting a universal safety portal (USP) to record lab incidents and lessons to learn more about the academic lab safety, and helping the researchers with the much needed valuable data or analysis. There should be an electronic system to provide alerts, and automatic updates of advances in safety-related research activities around the globe to face the new challenges. The way forward includes the government support in technology adoption and safety infrastructure development, optimal utilization of resources, engaging professional management, and promoting safety-related research activities. Promoting safety culture within an organization ensures a comfortable working environment and practical experimentation can be quite safe under carefully controlled conditions.

The area of chemical research holds the potential to produce many new compounds or elements, which has significant consequences for understanding safety under extraordinary conditions. The design of molecules with targeted chemical, electrical and optical properties for application in drugs, vaccines and those with mechanical, magnetic and thermal properties for application in materials science poses a significant risk of causing minor to severe injury. New research may reveal sudden, unexpected chemical process caused by the impact of nanoparticles leading to safety related issues. The discovery of new biological species, including pathogenic fungi, bacteria, and virus have far-reaching consequences in changing our safety knowledge. The global committee on lab safety (GCLS) has to be set up to act as a coordinating body for safety awareness activities throughout the world, and a newsletter can publish, review and promote the exchange of safety ideas and the dissemination of information on lab safety all over the world. The idea of universal basic safety (UBS) requires serious deliberation and subsequent implementation in the interest of every citizen of the country leading to improved work environment and productivity. The government and the private sector should jointly respond to the agenda of universal safety system through public-private partnership (PPP) models to support safety initiatives and to achieve an improved level of safety.

Conclusions and Future Directions

A brief history of laboratory accidents in the recent past indicates the gravity of the safety problem on multiple experimental platforms. The academic lab safety is a neglected topic in chemistry, chemical engineering, chemical technology related subject curricula and it is important to incorporate safety course in such programs. Knowing the sources and reasons of lab incidents is a definite aid to avoiding accidents by taking proper preventive actions. The article is concerned with and outlines the academic laboratory safety issues that exist in higher education institutions and highlights multiple analytical perspectives of safe lab practice. Laboratory safety is a significant aspect of every laboratory session that requires safe laboratory procedures and training for all users to develop safety-related skills, safety knowledge, and proactive attitudes. It is vital to prevent adverse health effects from exposure to chemicals, personal injury or injury to fellow workers, and damage to common equipment. It is important to recognize chemical hazards that may occur during laboratory operation and apply controls to minimize the risks of these hazards and to significantly reduce the number of incidents. The difficulties in chemical safety are that each chemical has a different risk and the users usually cannot analyze the level of risks involved, and risks are not necessarily how they are perceived. A chemical may react violently with the evolution of heat or produce flammable/toxic products. It is a thinking and visualization about the eventuality and consequences with the reasons for the worst possible situation in laboratory operations and taking a quick and wise decision to favorable incident transformation in the direction of safety. The discussion on the roadmap for a paradigm shift through a change of mindset should occur at the user level, and safety should be at the forefront of our consciousness. A laboratory safety management plan (LSMP) should be designed as a baseline preventive model for teachers at tertiary level that can be replicated elsewhere in schools, colleges, and universities.

The research community should use common pool resources for safety related development activities and better resource management to safeguard lab user rights. The funds need to go into well-thought-out projects to make a visible impact. The chemical labs had to be housed in one place and redesigned wherever required, keeping in mind the major safety aspects and ecological impacts. Apart from the commitment to the safety of the university, it also requires a deep understanding of the challenges of the safety in academic laboratories to create a culture of safety. It is essential to take sufficient proactive steps during experimentation, including initial attention, closer inspection, keen observation, instant inference, empirical evidence, quicker recognition of potential danger, and taking immediate action applicable for tackling the emergency situations. The safety teachers have to become scholarly practitioners and professionals through the development of pedagogical content knowledge (PCK) and best practices (ACS, 2001). In the pre-laboratory session, elaborate instructions on the safety protocol, while performing the laboratory activities should be provided. In the post-laboratory experience, students should be asked to discuss appropriate safety measures taken to experiment safely and efficiently (Corwin, 1999; Grant & Meyer, 1996). It is essential to store the MSDS sheets of the common chemicals used in a particular laboratory electronically or in a filing cabinet. The recent trend of a lab on a chip (LOC) to scale down the size of the analytical or preparative platform would certainly help in addressing safety issues to some extent.

The electronic surveillance system by installing the closed circuit television (CCTV) camera network with enhanced surveillance features at various lab locations can have a significant impact on work life. A machine readable quick response (QR) code that contains safety information about the individual chemicals must be made available in all the chemical science laboratories. The scan-based image platform available on smartphones with Android and iOS operating systems will be a boon to laboratory users. Tangible safety initiatives are essential to drive good candidates to promote talent, training, education, experience, dedication and delivery aspects of right decision making at the right time to enable them in performing physical experiments. Apart from the increased primary focus on infrastructural development, establishing a safety management system with integration of proper attitudes towards safety at the university level would have a direct impact on research. A joint research program on selected safety related topics may provide insights to bring about a change in current academic laboratory security scenario and provide opportunities for careers in safety science. An independent study of different safety characteristics of each chemical would throw light on possible physical risks, provide adequate information to foresee and prevent accidents by taking proper precautions for its safe handling.

It is time to set up the global level academic safety council and national level laboratory safety regulatory authority to frame safety policy, recommend improvements, monitoring safety standards, and incident reporting on scientific research/academic laboratories to foster growth and development in the area of fundamental and applied science, engineering, and technology. It is necessary to constitute a national academic safety council or safety enforcement directorate (SED) with safety experts to look into various aspects of laboratory safety and establishing a laboratory accident fund can cater to injury or death and provide appropriate compensation. Formation of safety resource center (SRC) with a national safety network with necessary knowledge, skills, and information about safety devices helps in the implementation of safety objectives. The department of safety policy and promotion at the university level should monitor the various organizations through lab safety and compliance program. Multidisciplinary safety committees at the institute level should strictly enforce a control in all science laboratories and demonstrate a new way of safety education and reward quality over quantity will transform the way the university functions. A planning and construction division can manage and monitor funds for development projects responsibly, and a resource center should be established in select universities to conduct regular refresher courses on safety. The extra and sustained efforts towards safety with the right intent and on a priority basis is the key to bringing in change. A sustained and systematic effort to nurture the safety culture by facilitating a favorable learning environment is required. It is important to share knowledge, skills and attitude aspects with chemical safety communities and implement regulations through safety officer/inspector and faculty resource and action initiative (FR & AI). Further, incentive award for institutions or individuals for their outstanding contribution in the safety field would encourage innovativeness. It remains to be seen if the detailed roadmap for the future would lead to getting significant results while we ultimately act in the general interest of society. We can hope to have a considerable impact on work life by further evolution in laboratory technology and practice resulting in enhanced safety culture and a decline in the laboratory fatalities in the coming years.

References

Amburgey- Peters, J.C. (2002). Implementing Temporary Facilities for Organic Chemistry Laboratory, *J. Chem. Educ*. 79, 607-610.

American Chemical Society (2017) *Safety in Academic Chemistry Laboratories*, 8th Edn., Washington D.C.

American Chemical Society (2001). *Chemical Safety for Teachers and their Supervisors*, Washington D.C.

American Institute of Chemical Engineers (1990) *Safety, Health and Loss Prevention in Chemical Processes*, New York.

Corwin, C.H. (1999). *Prentice Hall Laboratory Manual for Introductory Chemistry*, 3rd Edn., California, American River College.

Cote, R. P. & Wells, P.G. Eds., (1991). *Controlling Chemical Hazards*, London, Unwin Hyman, 310.

Freeman, N.T., & Whitehead, J. (1982). *Introduction to Safety in the Chemical Laboratory*, London, Academic Press.

Girolalmi, G. Rauchfus T. & Angelici, R.J. (1999). *Synthesis and Technique in Inorganic Chemistry*, 3rd Ed, Sausalito, CA, University Science Books.

Grant, G.J., & Meyer, G. M. (1996). *Laboratory Manual for General Chemistry*, 5th Edn., Salem, Sheffield Publishing.

Hall, S.K. (1993). *Chemical Safety in the Laboratory*, California, CRC Press.

Haynes, W.M. (2017). Ed., *CRC Handbook of Chemistry and Physics*, 97th Edn., Boca Raton CRC Press.

Hill, R.H. Jr. (2016). Undergraduates Need a Safety Education, *J. Chem. Educ*. 93, 1495-1498.

Institute of Chemical Engineers, (1983). *Loss Prevention and Safety Promotion in the Process Industries*, London, Pergamon Press.

Kharbanda, O.P. & Stallworthy, E.A. (1988). *Safety in the Chemical Process Industry*, London, Heinemann Publishing Ltd.

LeFèvre, M. J. & Shirley, C. (1997). *First Aid Manual for Chemical Accidents*, New York, John Wiley & Sons, Inc.

Luxon, S.G. (1992). Ed., *Hazards in the Chemical Laboratory*, 5th Edn., Cambridge, Royal Society of Chemistry.

Meyer, R., Köhler. J. & Homburg A. (2007). *Explosives*, 6th Edn., Weinheim, VCH-Verlag.

National Research Council (1995). *Prudent Practices for Disposal of Chemicals from Laboratories*, Washington D.C. National Academy Press.

National Fire Protection Association (2010). *Fire Protection Guide to hazardous Materials*, 14th Edn., Quincy.

National Research Council, (2014) *Safe Science: Establishing and Promoting a Culture of Safety in Academic Lab Research*. Washington D. C., National Academy Press.

National Research Council, (1981). *Prudent Practices for Handling Hazardous Chemicals in Laboratories*, Washington D.C., National Academy Press.

Noorden, R.V. (2013) Safety Survey Reveals Lab Risks, *Nature*, 493, 9-10.

Royal Society of Chemistry (1986). *Guide to Safe Practices in Chemical Laboratories*, London.

Sanders, R.E. (2005). *Chemical Process Safety, Learning from Case Histories*, 3rd Edn. Oxford, Butterworth-Heinemann.

Sax, N.I., & Lewis, R.J (1988). *Dangerous Properties of Industrial Materials*, 7th Edn., New York, Van Nostrand Reinhold.

Sax, N.I., & Lewis, R.J (1987). *Rapid Guide to Hazardous Chemicals in the Workplace*, New York, Van Nostrand Reinhold Co.

Saxena, J. (1984). Ed, *Hazard Assessment of Chemicals: Current Developments*, Vol.III, Orlando, Academic Press Inc.

Schroder, I, Huang, D.Y.Q., Ellis, O, Gibson, J.H., Wayne, N.L. (2016). *J. Chem. Health Safety*, 23, 12-23.

Shriver, D. F., & Drezdzon, M.A. (1986). *The Manipulation of Air-Sensitive Compounds*, 2nd Edn., New York, Wiley.

Skoog, D. A., West, D.M., & Holler F. J. (1994). *Analytical Chemistry*, 6th Edn., Philadelphia, Saunders College Publishing, 562.

Staehle, I.O. Chung, T.S. Stopin, A. Vadehra, G.S. Hsieh, S.I. Gibson, J.H. & G-Garibay, M.A. (2016). An Approach to Enhance the Safety Culture of an Academic

Chemistry Research Laboratory by Addressing Behavioral Factors. *J. Chem. Educ*. 93, 217-222.

Stuart, R.B. & McEwen, L.R. (2016). The Safety "Use Case": Co-developing Chemical Information Management and Laboratory Safety Skills, *J. Chem. Educ*. 93, 516-526.

Weiss, G. (1986). Ed. *Hazardous Chemicals Data Book*, 2nd Edn., New Jersey, Noyes Publications.

Windholz, M. Ed., (1976). *The Merck Index*, 9th Edn., New Jersey, Merck & Co, Inc. Author., (2006).

Yoshida, T. (1987). Ed., *Safety of Reactive Chemicals*, Oxford, Elsevier.

Citation:
Thimmappa, B.H.S. (2019). Chemical laboratory safety: A neglected topic in science curriculum design. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 127-143). ISRES Publishing, ISBN:978-605-698540-9.

Argument Based Inquiry Approach Accompanied by Models in Primary Science Teaching

Serpil Kara
Necmettin Erbakan University, Turkey

Sevgi Kingir
Hacettepe University, Turkey

The follow-up of the scientific process steps that support scientific thinking is realized by questioning (Akben, 2015; Baxter and Kurtz, 2001). It is stated that when the argument-based inquiry approach and the model-based inquiry approach, which constitute the basis of scientific research and scientific literacy, are used together, the models formed by the student are actually student claims about a scientific concept. The ability of students to create, use and evaluate their own scientific models is expressed as an effective way of rendering thinking visible (Braaten and Windschitl, 2011). The aim of the model-supported inquiry is to make the students' objectives visible and to reach these goals by using models. As a class leader, a teacher should aim at ensuring that students present problem situations in which they can express and solve scientific terms. For this purpose, students should be ensured to make definitions and explanations by creating a model rather than individualized activities regarding the solution of a problem. In this case, students are given the opportunity to learn from each other and question themselves in a group. While the importance of using model and argumentation applications in order to contribute to the development of inquiry skills used in understanding the concepts of science and the production of scientific information and presentation of scientific explanations related to this situation are emphasized, it is also stated that they are related to each other (Mendonça and Justi, 2013; Passmore, Stewart and Cartier, 2009; Passmore and Svoboda, 2012). On the other hand, there are few studies that specifically investigate the relationship between model and argumentation (Mendonça and Justi, 2013).

Argument Based Inquiry Approach

Argument Based Inquiry (ABI) is a kind of inquiry-based learning approach where the processes of question, claim and evidence, which are the basic elements of argumentation, are brought to the forefront. Its original name is the Science Writing Heuristic, which was put forth by Keys, Hand, Prain ve Collins (1999) in order to integrate language activities, argumentation and inquiry for effective science instruction. When testing questions posed within ABI approach, it is essential to use scientific facts and evidence. The claim serves as an answer to a question determined for investigation. Evidence based on numerical data, observations and facts is used to support the claim (Yang and Wang, 2014). With the ABI approach, students construct information through inquiry by asking questions, conducting experiments and observations and creating claims and evidence. Additionally, it provides students with opportunities to define scientific events, organize and observe scientific concepts and to be able to explain the relations between events (Yang and Wang, 2014). In this context, the ABI approach includes two templates for teachers and students (Keys et al., 1999). The template recommended for teachers (See Table 1) is intended to be a guide that enables teachers to take into account the basic criteria of the ABI approach when preparing lesson plans. Student template (See Table 2) provides a framework for students to follow up both the inquiry activities within a scheme and to write research reports as a result of the activity.

Table 1. ABI Teacher Template

1. Revealing preliminary information through a concept map individually or as a group
2. Pre-laboratory activities where informal writing, observation, brainstorming and questioning techniques are used.
3. Participation in laboratory activities
4. I. Negotiation phase - Conducting personal writing events in laboratory activities (e.g. diary writing)
5. II. Negotiation phase - Sharing and comparing interpretations of data obtained from observations in small groups (e.g. drafting as a group)
6. III. Negotiation phase - Comparison of ideas with books or other sources (for example, taking group notes to answer initial questions)
7. IV. Negotiation phase - Conducting individual reflection and writing activities (for example, preparing presentations such as reports or posters for informants)
8. Finding out what is learned at the end of teaching through concept map

Table 2. ABI Student Template

1. Initial thoughts - What are my questions?
2. Tests - What did I do?
3. Observations- What did I see?
4. Claims- What can I claim?
5. Evidence - How did I understand? Why do I make these claims?
6. Reading - How do my thoughts compare to other thoughts?
7. Reflection- How have my thoughts changed?

Literacy activities in science subjects are proposed as a tool for improving students' scientific literacy (NRC, 1996). Many studies have emphasized that the template used for students helps students to improve meaningful learning (Hand, Wallance and Yang, 2004; Hohenshell and Hand, 2006; Keys et al., 1999). Students stated that they had difficulty in writing tasks rather than reading tasks due to lack of writing skills (McNeill, 2011). Therefore, the importance of having a template for full writing tasks is emphasized (Yang and Wang, 2014). A structured writing template improves students' argumentation skills better (Jang and Hand, 2017) and it provides a heuristic template to guide students' reasoning and scientific inquiry activities (Hand, 2008). Its most important difference from other inquiry-based learning approaches is that it provides peer negotiation while justifying scientific explanations. Learning by understanding is of great importance in the construction of knowledge. Negotiation is defined as the interaction between the students' own knowledge and their peers' knowledge; it supports meaningful learning and increases the knowledge retention (Keys et al., 1999; Norton-Meier, Hand, Hockenberry & Wise, 2008). Students' acquisition of scientific knowledge is one of the main objectives of science education.

In the ABI approach, which is a student-centered approach, at the beginning of the implementation process, the teacher should first design different activities that can reveal the students' prior knowledge. The rules that can increase the interaction in the classroom should be reminded and should be guiding the students toward listening to and understanding each other. Students should be helped in issues such as producing qualified questions on which they can conduct research within the scope of the implementation and the provision of materials that they want to use in order to find answers to the questions they produce. The course should support individual or group work that enables all students to be active. The teacher should be a guide, be able to test whether students understand or not and should encourage each student to present his/her opinion instead of giving the correct answer to the questions asked by the students (Keys et al., 1999).

In the implementation process of the ABI approach, students are required to determine questions that they want to investigate, to design activities in order to test their own questions. They record their observations and data which they collected during the activity process. At the end of this process, they construct claims and evidence based on their observations and data. They share their claims and evidence first in the group and then as a whole class in the negotiation process. In this process, they ask each other questions. They write their experiences in a reflective manner in accordance with ABI format as a result of the feedback they received from the negotiation process (Keys et al., 1999).

Writing, an essential part of ABI approach, is recommended as a good learning tool (Emig, 1977; Chen, 2013). Traditional writing (lecture notes, etc.) remains weak regarding students' construction of scientific knowledge (Yore, Bisanz and Hand, 2003). On the other hand, writing studies aimed at learning have been put forth by Emig (1977), who states that the acquisition of knowledge and skills is accomplished through the combination of listening, speaking, reading and writing processes. Writing activities aimed at learning provide contributions such as helping the students learn, increasing their existing knowledge and improving their skills such as remembering, commenting, reinforcing and communication (Hewson, 1981). The benefits of writing activities for learning purposes are summarized as follows in general (Daşdemir, Cengiz and Uzoğlu, 2015):

1. It improves conceptual understanding and communication skills of individuals by providing concept change.

2. It enables individuals to build meaningful connections between previous and new knowledge and build their existing knowledge on solid foundations.

3. It increases the retention of the knowledge by reinforcing the new information learned.

4. It facilitates the learning of complex concepts by processing them with the knowledge and links that exist in the mind.

Another essential part of ABI approach is argumentation. The contributions of using argumentation in science can be summarized as follows: (1) To support access to cognitive and metacognitive processes that characterize expert performance and to enable modeling for students. (2) To support the development of communicative competences, particularly critical thinking. (3) To support the achievement of scientific literacy and strengthen students' ability to speak and write scientific languages. (4) To promote the incorporation of science culture into practices and to develop epistemic criteria for knowledge evaluation. (5) To support the development of reasoning, in particular the selection of theories or positions based on rational criteria (Jiminéz-Aleixandre and Erduran, 2008, p.5).

Learning Through Models

In general, a model is defined as the representation of an event, an object or an idea (Gilbert, Boulter and Elmer, 2000; Mahr, 2011). In science, a model is defined as the visualization of a more familiar (source) object, natural phenomenon or idea (target) by way of representation (Gilbert, 1991; Tregidgo and Ratcliffe, 2000). According to Halloun (2004), the function of a model is to express a pattern that can correspond to the questions it can answer, to explain and to describe the problem. Models are external representations of mental concepts and can be in the form of diagrams, three-dimensional physical structures, computer simulations, mathematical formulas and analogies (Krajcik and Merritt, 2012).

The model provides individuals with the opportunity to question how a job is done and its outputs, to evaluate different situations, while, on the other hand, it supports the process of making arguments through negotiations by producing question-claim-evidence regarding the model formed, and contributes to individuals' understanding of science concepts and scientific writing skills (Chen, Benus and Yarker, 2016; Yarker, 2013). For students to understand the learning processes and products better, regarding science education, Hodson (1992) suggested three purposes being the learning of science, that is, understanding of ideas produced by science; learning about science, that is, understanding the important topics in the philosophy, history and methodology of science; and learning how to do science, that is, being able to take part in these activities which lead to the acquisition of scientific knowledge (cited in Justi and Gilbert, 2002b). In line with the purposes mentioned, it is explained that models and modelings have a central place in science education as follows (Justi and Gilbert, 2002b; Justi and van Driel, 2005; Reinisch and Krüger, 2018): (1) To learn science, students should know the nature, scope and limitations of certain scientific models. (2) To learn about science, students must learn the nature of models and recognize the role of models in the accreditation and dissemination of scientific inquiry products. (3) Students should be given the opportunity to create, express and test their own models in order to learn how to do science. The production and use of models play a central role in the growth of scientific knowledge. In understanding events, these objectives can be achieved through the creation of appropriate representations of the mental models that are formed or the actions of scientific modeling. For the development of mental models, first of all, it is necessary to have some direct or indirect, qualitative or quantitative experiences and observations about the phenomenon being modeled in consensus. Scientists expressed that consensus models can be formed by comparing and testing individual models (Justi and van Driel, 2005). The consensus models are the historical models of those currently used in research or those that are nowadays aimed at research (Justi and Gilbert, 2002b). Thinking and reasoning with models allow scientists to visualize abstract processes and beings they are investigating, make explanations to them and make predictions about them among other things (Justi and van Driel, 2005).

Models are external representations of mental concepts and are defined as thinking tools for both scientists and engineers to think and understand events and to provide possible solutions to problem situations (Duit and Glynn, 1996; NCR, 2011).

Scientists construct mental and conceptual models of phenomena and develop and use models to convey and criticize their ideas. Students are also expected to develop, use and revise their models to share and discuss ideas in the classroom (NRC, 2012; Nersessian, 2002; Passmore, Gouvea and Giere, 2014). In science education, although different types of models are used, it is in general possible to gather models under three headings as mental, conceptual and physical models. Mental models are psychological representations of real or imaginary situations, and they serve as a tool to think, predict, and build a sense of experience (Franco and Colinvaux, 2000; NRC, 2012). Individuals perceive and conceptualize situations in the world as they occur in their mind (Franco and Colinvaux, 2000). The quality of the mental models formed by students has an important role as an indicator of whether the concepts are understood or not, whether the information has been structured or not. At the same time, the most important feature of the mental models formed based on the analogy models is that they provide the opportunity to evaluate the extent to which an individual can improve his/her cognitive abilities (Ünal and Ergin, 2006). A conceptual model is an external representation created by teachers or scientists who facilitate the understanding or teaching of systems or situations around the world (Greca and Moreire, 2000). It also helps scientists visualize and understand the necessary solution to a problem (Greca and Moreire, 2000; NRC, 2012). These external representations may take place as mathematical formulations, analogies or concrete products. A representation illustrating the operation of a water pump, the similarity between Rutherford's atom and the solar system, or mathematical formulations of the shell model for nuclear physics are examples of conceptual models (Greca and Moreira, 2000). Since the drawings assessed in the conceptual model category are related to mental models, the use of student drawings in the teaching environment focuses on developing a spatial and causal/dynamic model rather than students' memorizing vocabulary (Clement, 2000). Therefore, drawings based on learning can be used as a record of easily accessible thoughts (Clement, 2000). Brooks (2009) stated the importance of children's drawings as: "When we see children's drawing as a form of communication and a means of producing meaning, the social, cultural and historical relationship with this process of gaining meaning requires careful consideration." It is also aimed to explore the engineering understanding of primary school students (Weber, Duncan, Dyehouse, Strobel and Diefes-Dux, 2011) and to assess their attitudes and misconceptions about scientists and engineers (Knight and Cunningham, 2004) by using drawings and writing approaches together.

Regarding physical models in science education, the model described as representation by Gilbert (2008) is defined as "internal representation" if it exists in the mind of the individual and "external representation" if it can easily be accessed physically by others. In teaching practices, models are considered as the heart of scientific research and are therefore emphasized as the cornerstones for developing knowledge about the nature of science (NRC, 2000). Regarding the teaching and application of concepts in science education, *in the framework program entitled "Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas"* (NRC, 2012) the importance of scientific methods has been emphasized and an understanding of moving away from uniformity through different methods and techniques has been adopted. On the other hand, modeling process is expressed as experimental testing of mental models (Justi and Gilbert, 2002a). Therefore, suggestions such as causal reasoning, evaluation, evidence, argumentation and model development-use were brought to the forefront. In the literature examined in this context, it is seen that science education advocates and supports the place of model based science education (Nersessian, 2002).

In the studies comprising the examination of modeling, model suggestion, evaluation and remodeling as a process, it is seen that the general focus is on analyzing the learning of concepts and sometimes emphasizing the collaborative aspect of conceptual development processes (Mendonça and Justi, 2013). In order to better understand the pedagogical functions of modeling teaching, in a compilation study of the last decade, one of the conclusions reached was that although conceptual understanding is the most common pedagogical element defined for modeling, it is rarely used in developing practices and understanding science (Campbell, Oh, Maughn, Kiriazis and Zuwallack, 2015). At the same time, a common finding of the previous studies was learning through modelling supports conceptual understanding (Hafner and Stewart, 1995; Sunyono, Leny and Muslimin, 2015; Thomson and Stewart, 2003). In teaching concepts, it is primarily aimed at questioning, putting forth arguments while questioning, and evaluating by forming a model based on this information. For this purpose, a model-based science teaching approach is an effective method for systematic teaching and learning of scientific concepts. With this approach, the design, construction, evaluation and development of models in the modelling process aimed at the understanding of the system, object or idea are thought to have an important place in the questioning, structuring and advancing of scientific knowledge (Mendonça and Justi, 2013; Passmore et al., 2009).

Campbell and Oh (2015) examined modeling pedagogy and their frequency of use in their studies. Pedagogical actions where models are frequently used are experimental modeling, evaluative modeling, and cyclic modeling. In experimental modeling, students construct hypotheses and predictions from models and test them by testing phenomena. At the same time, students review their mental models in accordance with new evidence obtained in practical or thought experiments. In evaluative modeling, students compare alternative models that address the same phenomenon or problem, evaluate their benefits and limitations, and select the most appropriate model/models to explain the phenomenon or solve the problem. In cyclic modelling, students are interested in model development, evaluation and development processes to complete long-standing science projects. It is seen that in the frequency table of these three pedagogical modeling actions, experimental modeling was reported to be the least used with 20% (Campbell and Oh, 2015). However, models can be seen as the center of scientific activities.

Model-based teaching and learning activities are seen to have a major impact on science education, not only in relation to scientific methods and perceptions, but also in designing curricula that are considered to be more concerned with teaching approaches and goals (Develaki, 2016). When the literature is examined, it is stated that some conclusions were reached such as the courses conducted with model based science education supporting students' conceptual development and facilitating understanding (Baek, Schwarz, Chen, Hokayem, and Zhan, 2011; White, 1993), ensuring that they act more courageously in understanding scientific methods and in applications (Hestenes, 1992; Hodson 1992; Lederman, 2007) and improving the development of their metacognitive abilities (Gilbert, 1995; Gobert, O'Dwyer, Horwitz, Buckley, Levy and Wilensky, 2011; White, 1993). In addition, it is stated that mentally modeling knowledge and contents (Schwarz and White, 2005; Oh and Oh, 2011), questioning and reasoning abilities (Böttcher and Meisert, 2011; Nersessian, 2008) develop together with model-based education. Another important point mentioned in the literature on this subject is the consensus on idea that models should be used by teachers and students in order to understand the scientific concepts and the nature of science, as stated by Gilbert (1991). Another common point that can be obtained from the studies on the model may be that neither teachers nor students have sufficient information about the model and therefore they have insufficiency in using it (Aktan, 2016; Langan, Dunleavy and Fielding, 2013; Nelson and Davis, 2012; Oh and Oh, 2011; Yenilmez Türkoğlu and Öztekin, 2016).

In addition, there are also studies regarding the empirical evaluation of how epistemological information of how students at various grade levels understand issues such as the nature and purpose of models representing the theoretical framework of various models, design and formation and testing of models (Grünkorn, Upmeier zu Belzen and Krüger, 2014; Gogolin and Krüger, 2018; Schwarz, 2002; Tasquier, Levrini and Dillon, 2016), and it is stated that this information ensures students to use models in science and conceptual understanding in the models used. The American Association for the Advancement of Science (AAAS) stated that students at grade 3 and 5 could see and evaluate the results of the changes made on a model on the corresponding entity. In addition, it is stated that geometric shapes, series of numbers, graphs, diagrams, maps and stories were used to show objects, events and processes in real life, but they were aware that they could not meet the truth in every detail (Project 2061, 1993, cited in *Ünal* and Ergin, 2006). It was stated that 3rd and 5th grade students began to make changes on the models in their hands and discuss their limitations within their natural games, started to create their own mental models regarding events they cannot directly observe and thus understand the science subjects (Ünal and Ergin, 2006). In addition, when the aim is a student's being able to make a successful scientific model, states such as understanding scientists' views on the nature of the model, the appropriate experience of the phenomenon represented, knowledge of why the model was originally built and why it should be learned, understanding how the model works, the information of the source on which the target model and/or the teaching model was established should be gained (Justi and Gilbert, 2002a).

In order to understand how knowledge is produced, analyzed, justified, evaluated and reflected in social practices, the process of inquiry is required. The findings obtained in this process can be criticized, discussed and reviewed by presenting them to the peer community. Discussion is a process that scientists' communities test, develop and accept temporarily. It is stated that participating in scientific debates (i.e. examining the relationship or connection with evidence and then accepting or rejecting it, and being able to associate theoretical ideas put forth in an explanation or evidence with theory) is defined as the process of constructing arguments, and scientific theories, modeling and argumentation are defined as dynamically intertwined and interdependent structures (Clark and Sengupta, 2013). The process of producing, testing, evaluating and reviewing models considering the permanence of scientific knowledge can be seen as the center for the development, critical evaluation and dissemination of scientific knowledge (Giere, 2001; Gilbert and Boulter, 1997; Nersessian, 2002).

Argument Based Inquiry Accompanied With Models (ABIAM)

Various approaches have been developed to analyze the structure and quality of the arguments, and the framework proposed by Toulmin (1958, 2003) for the structural analysis of the arguments is still widely introduced and used even today in research in the field of science education. While the diversity of these approaches also points to some theoretical and methodological problems related to the uncertainty of existing analysis methods, it is emphasized that while many frameworks are limited to explaining only parts of the controversial processes, there are several methodological difficulties that arise in the context of Toulmin's structural analysis of arguments (Böttcher and Meisert, 2011). Böttcher and Meisert (2011) argue that the inclusion of cognitive science results related to the role of mental modeling in discussion and problem solving processes and the use of a model-supported argumentation approach will help to overcome these difficulties.

Lehrer and Schauble (2006) proposed three important points for coordinating an effective approach: (1) using a model to identify evidence for information needs, (2) developing models using the argumentation process, and observing/revising them and reinterpreting new information; (3) using a set of models to represent ideas. Based on these three important points, Chen, Benus and Yarker (2016) developed a Science Negotiation Pedagogy framework, which combines arguments and model applications that can be used in science courses (See Figure 1). Based on the framework, Scientific Negotiation Pedagogy provides effective use of argumentation practices in science courses by supporting them with models.

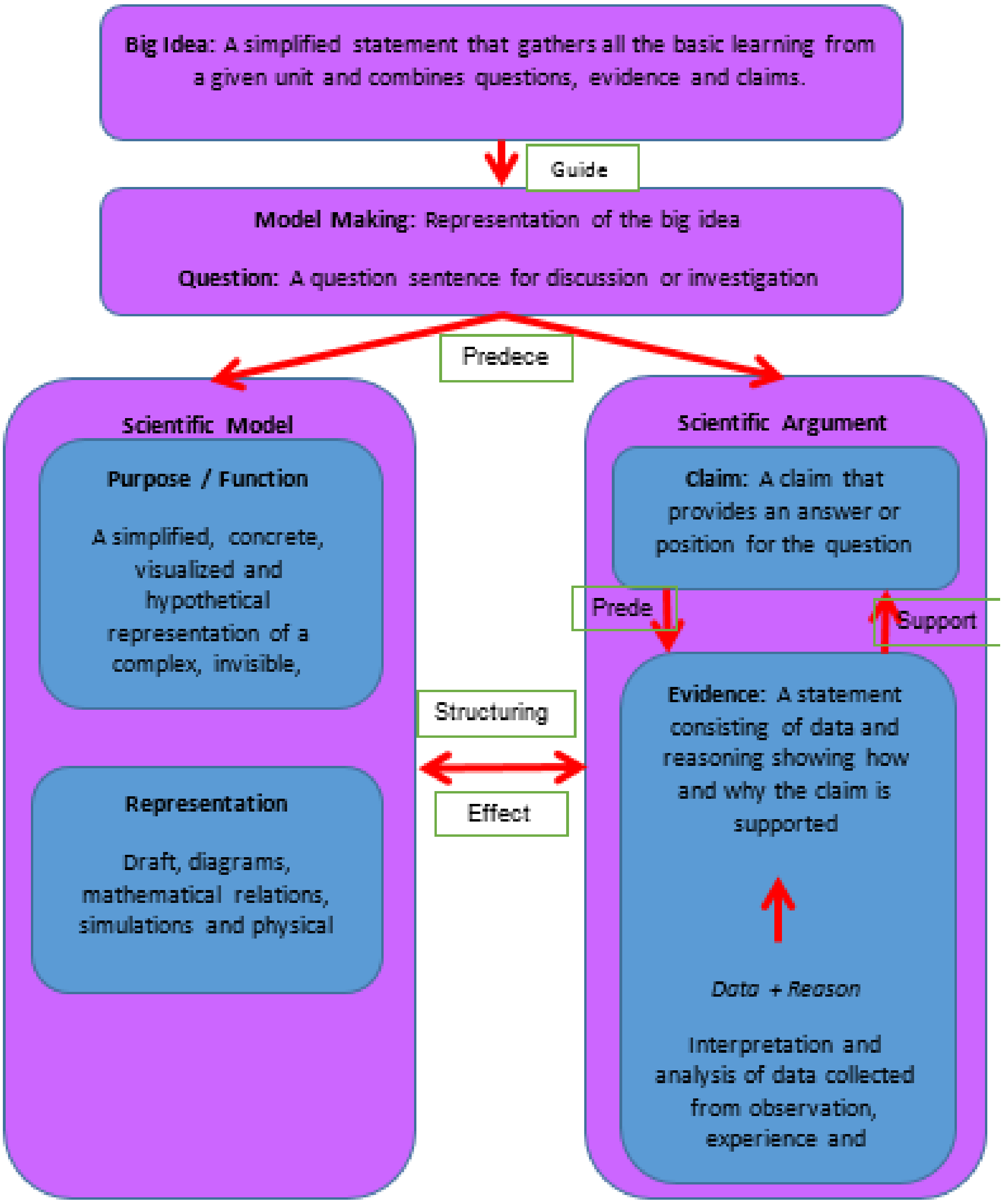


Figure 1. A framework for Scientific Arguments and Models in Science Subjects

This framework is based on Argument Based Inquiry Approach and includes six steps:

Step 1: Creating a beginning question that can be investigated. Students should be able to produce a good question in the first step of the application process of ABI approach. As a criterion for a good question, it should be a testable, researchable question, and should not contain short answers such as yes or no.

Step 2: Building a temporary model as a group. In order to answer the questions they form, students first design a mental model. They draw these models in their minds as conceptual models and then turn them into physical models. Thus, students have the opportunity to test their own negotiated ideas and the answers to the questions they have formed on their own models.

Step 3: Forming a temporary argument as a group. Using the models they have created in the previous step as a tool, the students construct a scientific argument including claims and evidence. The data includes not only quantitative information but also qualitative information. Students are ensured to form their written arguments in the framework of a form presented to them to write arguments.

Step 4: Discussing models and arguments through negotiation as a whole class**.** Students are provided to discuss and evaluate their models and arguments through negotiations as a whole class. At this step, activities are conducted for students to understand and discuss the big idea and to persuade and cooperate. Thus, students are ensured to recognize the strengths and weaknesses of their own ideas and to be able to revise their models and arguments.

Chen and Steenhoek (2013) define the cycle of negotiation that they propose to support argumentation on science issues as determination of a research question by the students, their conducting research on this research question as a group, presentation of an argument regarding the questions as a group, comparison of the arguments with books and other resources, learning-revising common concepts and reflecting what they have learned through individual writing.

Step 5: Consulting experts (internal and external resources: books, videos, all kinds of data that can be gathered in the classroom, Internet, newspapers, etc.). This step is designed to provide an opportunity for students to compare their current models and arguments with those of experts. It evaluates situations such as data, evidence, models, writing samples and videos that are formed by the student and can be described as internal resources; or as external sources, it utilizes situations such as textbooks, other books, Internet resources, newspapers and invited speakers.

Step 6: Reflecting the final arrangements through writing. In scientific research, students are encouraged to write a reflective individual text by reviewing their model and argument, similar to the methods by which scientists state how information progresses.

The purpose of using a model is to test ideas by representing connected transaction systems and to assess them with real-world evidence (Windschitl, Thompson and Braaten, 2008). Students need substantial experience to fully develop model practices that can be supported by social negotiation. At the same time, students can use and review models when working with experimental data from different sources, such as classroom experiments or authentic research data (Bielik, Damelin, Krajcik, 2019).

It is argued that regarding all contemporary education levels and science courses, a connection will be established with contemporary philosophy of science by in-depth analysis of model supported science education and research and innovation applications

(Adúriz-Bravo, 2011).

Conclusion

In conclusion, Argument Based Inquiry Accompanied With Models (ABIAM) successfully makes explicit modelling and argumentation within inquiry approach. It provides students to learn science concepts by creating models while constructing arguments in scientific investigations. In addition, elements of ABIAM approach -inquiry, argumentation, and designing/constructing models - were emphasized in Turkish Elementary Science Curriculum (MoNE, 2018). Therefore, it is concluded that teaching science with ABIAM approach is significant and important.

Acknowledgement

This study was produced from the literature review section of the PhD dissertation of Serpil KARA, conducted under the supervision of Assoc. Prof. Dr. Sevgi KINGIR.

References

Adúriz-Bravo, A. (2011). Fostering model-based school scientific argumentation among prospective science teachers. *US-China Education Review, 8*(5), 718-723.

Akben, N. (2015). Improving science process skills in science and technology course activities using the inquiry method. *Education and Science, 40*(179), 111-132.

Aktan, M. B. (2016). Pre-Service science teachers' prceptions and attitudesdes about the use of models. *Journal of Baltic Science Education, 15*(1), 7-17.

Baek, H., Schwarz, C. V., Chen, J., & Zhan, L. (2011). Engaging elementary students in scientific modeling: The models fifth-grade approach and findings. In Khine, M. S., & Saleh, I. M. (Eds.*), Models and modeling: cognitive tools for scientific enquiry (pp.195-218). Dordrecht: Springer.*

Bielik, T., Damelin, D., & Krajcik, J. S. (2019). Shifting the balance: Engaging students in using a modeling tool to learn about ocean acidification, *EURASIA Journal of Mathematics, Science and Technology Education, 15*(1), 1-17.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualisation of scientific explanation for science education. *Science Education, 95*, 639-669.

Brooks, M. (2009). What Vygotsky can teach us about young children drawing. *International Art in Early Childhood Research Journal, 1*(1), 1-13.

Baxter, L. M., & Kurtz, M. J. (2001). When a hypothesis is not an educated guess. *Science & Children, 38*(7), 18-20.

Böttcher, F., & Meisert, A. (2011). Argumentation in science education: A model-based framework. *Science & Education, 20*, 103-140.

Campbell, T., & Oh, P. S. (2015). Engaging students in modeling as an epistemic practice of science: An introduction to the special issue of the journal of science education and technology. *Journal of Science Education and Technology, 24*(2-3), 125-131.

Campbell, T., Oh, P. S., Maughn, M., Kiriazis, N., & Zuwallack, R. (2015). A review of modeling pedagogies: Pedagogical functions, discursive acts, and technology in modeling instruction. *Eurasia Journal of Mathematics, Science & Technology Education, 11*(1), 159-176.

Chen, Y. C. (2013). Constructing and critiquing arguments. *Science and Children, 50*(5), 40-45.

Chen, Y. C., Benus, M., & Yarker, M. B. (2016). Using models to support argumentation in the science classroom. *The American Biology Teacher, 78*(7), 548-559.

Chen, Y. C., & Steenhoek, J. (2013). A negotiation cycle to promote argumentation in science classrooms. *Science Scope, 36*(9), 41-50.

Clark, D. B., & Sengupta, P. (2013) Argumentation and modeling: Integrating the products and practices of science to improve science education. In Khine MS, Saleh IM (Eds.), *Approaches and strategies in next generation science learning* (pp. 85-105). IGI Global, Hershey, PA.

Clement, J. (2000). Model based learning as a key research area for science education. *International Journal of Science Education, 22*(9), 1041-1053.

Daşdemir, İ., Cengiz, E. & Uzoğlu, M. (2015). Öğrenme amaçlı yazma aktivitelerinden mektup yazmanın 7. sınıf ışık ünitesinde öğrencilerin akademik başarılarına ve bilimsel tutumlarına etkisi. *ODÜ Sosyal Bilimler Araştırmaları Dergisi (ODÜSOBİAD), 5*(11)*,* 89-103*.*

Develaki, M. (2016). Key-aspects of scientific modeling exemplified by school science models: some units for teaching contextualized scientific methodology. *Interchange, 47*, 297-327.

Duit, R., & Glynn, S. (1996). Mental modelling. In G. Welford, J. Osborne, & P. Scott (Eds.), *Research in science education in Europe: Current issues and themes* (pp. 166-176). London: Falmer.

Emig, J. (1977). Writing as a mode of learning. *College Composition and Communication, 28*, 122-128.

Franco, C., & Colinvaux, D. (2000). Grasping mental models. In J. K. Gilbert & C. J. Boulter (Eds.)., *Developing models in science education* (pp.93-118). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Giere, R. N. (2001). A new framework for teaching scientific reasoning. *Argumentation, 15*, 21-33.

Greca, I. M., & Moreire, M. A. (2000). Mental models, conceptual models, and modeling. [Electronic version]. *International Journal of Science Education, 1*, 1-11.

Grünkorn, J., Upmeier zu Belzen, A., & Krüger, D. (2014). Assessing Students' Understandings of Biological Models and their Use in Science to Evaluate a Theoretical Framework, *International Journal of Science Education, 36*(10), 1651-1684.

Gilbert, J. K. (1995). *The role of models and modelling in some narratives of science education learning*. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

Gilbert, J. K. (2008). Visualization: An emergent field of practice and enquiry in science education. In Gilbert, J. K., Reiner, M., & Nakhleh, M. (Eds.), *Visualization: Theory and practice in science education* (pp. 3-24). Dordrecht: Springer.

Gilbert, J. K., & Boulter, C. J. (1997). Learning science through models and modelling. In B. J. F. K. Tobin (Eds.), *International handbook of science education* (pp. 53-66). Dordrecht: Kluwer.

Gilbert, J. K. Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert & C. J.Boulter (Eds.), *Developing models in science education* (pp.3-17). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gilbert, S. W. (1991). Model building and a definition of science. *Journal of Research in Science Teaching, 28*(1), 73-78.

Gobert, J. D., O'Dwyer, L., Horwitz, P., Buckley, B. C., Levy, S. T., & Wilensky, U. (2011). Examining the relationship between students' understanding of the nature of models and conceptual learning in biology, physics, and chemistry. *International Journal of Science Education, 33*(5), 653-684.

Gogolin, S., & Krüger, D. (2018). Students' understanding of the nature and purpose of models. *Journal of Research Science Teaching, 55*, 1313-1338.

Hafner, R., & Stewart, J. (1995). Revising explanatory models to accommodate anomalous genetic phenomena: Problem solving in the "context of discovery". *Science Education, 79*(2), 111-146.

Halloun, I. A. (2004). *Modeling theory in science education*. Dordrecht: Kluwer Academic.

Hand, B. (Ed.). (2008). *Science inquiry, argument and language: A case for the science writing heuristic*. Rotterdam, The Netherlands: Sense.

Hand, B., Wallace, C. W., & Yang, E. (2004). Using a science writing heuristic to enhance learning outcomes from laboratory activities in seventh- grad science: quantitative and qualitative aspect. *Intenational Journal of Science Education, 26*(2), 131-149.

Hestenes, D. (1992). Modelling games in the Newtonian world. *American Journal of Physics, 60*(8), 732-748.

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383-396.

Hodson, D. (1992). In search of a meaningful relationship: An exploration of some issues relating to integration in science and science education. *International Journal of Science Education, 14*, 541-562.

Hohensell, L. M., & Hand, B. (2006). Writing-to-learn strategies in secondary school cell biology: a mixed method study. *International Journal of Science Education, 28*(2-3), 261-289.

Jang, J., & Hand, B. (2017). Examining the value of a scaffolded critique framework to promote argumentative and explanatory writings within an argument-based inquiry approach. *Research in Science Education, 47*(6), 1213-1231.

Jiménez- Aleixandre, M. P., & Erduran, S. (2008). Argumentation in science education: An overview. In S. Erduran & M. P. Jiménez- Aleixandre (Eds.)*, Argumentation in science education: Perspectives from classroom-based research*. Dordrecht: Springer.

Justi, R. S., & Gilbert, J. K. (2002a). Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science. *International Journal of Science Education, 24*(12), 1273-1292.

Justi, R. S., & Gilbert, J. K. (2002b). Modelling, teachers' views on the natüre of modelling, and implications fort he education of modellers. *International Journal of Science Education, 24*(4), 369-387.

Justi, R. & van Driel, J. (2005). A case study of the development of a beginning chemistry teacher's knowledge about models and modelling. *Research in Science Education, 35*, 197-219.

Keys, C. W., Hand, B., Prain, V. & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching, 36*(10), 1065-1084.

Krajcik, J., & Merritt, J. (2012). Engaging students in scientific practices: What does constructing and revising modelslook like in the science classroom? Understanding a framework for K-12 science education. *The Science Teacher, 79*(3), 38-41.

Knight, M., & Cunningham, C. M. (2004). *Draw an engineer test (DAET): Development of a tool to investigate student's ideas about engineers and engineering.* Paper presented at the ASEE Annual Conference and Exposition.

Langan, A. M., Dunleavy, P., & Fielding, A. (2013). Applying models to national surveys of undergraduate science students: What affects ratings of satisfaction?. *Education Sciences*, *3*, 193-207.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Ledreman (Eds.), *Handbook of research on science education* (pp. 831-879). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Lehrer, R., & Schauble, L. (2006). Cultivating model-based reasoning in science education. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*. New York, NY: Cambridge University Press.

Mahr, B. (2011). On the epistemology of models. *Rethinking Epistemology, 1*, 301-352.

McNeill, K. L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. *Journal of Research in Science Teahing, 48*(7), 793-823.

Mendonça, P. C. C., & Justi, R. (2013). The relationships between modelling and argumentation from the perspective of the model of modelling diagram. *International Journal of Science Education, 35*(14), 2407-2434.

National Research Council (NRC). (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

National Research Council (NRC). (2012). *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Nelson, M. M. & Davis, E. A. (2012). Preservice elementary teachers' evaluations of elementary students' scientific models: An aspect of pedagogical content knowledge for scientific modeling, *International Journal of Science Education, 34*(12), 1931-1959.

Nersessian, N. J. (2002). The cognitive basis of model-based reasoning in science. In P. Carruthers, S. Stich, & M. Siegal (Eds.), *The cognitive basis of science* (pp. 133-153). Cambridge: Cambridge niversity Press.

Nersessian, M. (2008). Model-based reasoning in scientific practice. In R. A. Duschl & R. E. Grandy (Eds.), *Teaching scientific inquiry. Recommendations for research and implementation* (pp. 57-79). Rotterdam: Sense Publishers.

Norton-Meier, L., Hand, B., Hockenberry, L., & Wise, K. (2008). *Ouestions, claims, and evidence: The important place of argument in children's science writing*. Portsmouth, NH: Heinemann.

Oh, P. S., & Oh, S. J. (2011). What teachers of science need to know about models. *International Journal of Science Education, 33*(8), 1109-1130.

Passmore, C., Stewart, J., & Cartier, J. (2009). Model-based inquiry and school science: creating connections. *School Science and Mathematics, 109*(7). 394-402.

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education*, *34*(10), 1535-1554.

Passmore, C., Gouvea, J. S., & Giere, R. (2014). Models in science and in learning science: Focusing scientific practice on sense-making. In M. R. Matthews (Eds.)., *International handbook of research in history, philosophy and science teaching* (pp. 1171-1202). Netherlands: Springer.

Reinisch, B. & Krüger, D. (2018). Preservice biology teachers' conceptions about the tentative nature of theories and models in biology. *Research in Science Education, 48*, 71-103.

Schwarz, C. V. (2002, April). *Using model-centered science instruction to foster students' epistemologies in learning with models*. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA.

Schwarz, C. V., & White, B. Y. (2005). Meta-modeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*(2), 165-205.

Sunyono, Leny, Y., & Muslimin, I. (2015). Supporting students in learning with multiple representation to improve student mental models on atomic structure concepts. *Science Education International, 26*(2), 104-125.

Tasquier, G., Levrini, O., & Dillon, J. (2016). Exploring students' epistemological knowledge of models and modelling in science: results from a teaching/learning experience on climate change. *International Journal of Science Education, 38*(4), 539-563.

Thomson, N., & Stewart, J. (2003). Genetics inquiry: strategies and knowledge geneticists use in solving transmission genetics problems. *Science Education, 87*(1), 161-180.

Tregidgo, D., & Ratcliffe, M. (2000). The use of modeling for improving pupils' learning about cells. *School Science Review, 81*, 53-59.

Ministry of Education (MoNE) (2018). Turkish Elementary Science Curriculum. Ankara: Education Board of Education. . [Online: http://mufredat.meb.gov.tr/Dosyalar], Date of access: 25.09.2018.

Ünal, G. & Ergin, Ö. (2006). Science education and models. *Millî Eğitim Dergisi (Journal of National Education), 171*, 188-196.

Weber, N., Duncan, D., Dyehouse, M., Strobel, J., & Diefes-Dux, H.A. (2011). The development of a systematic coding system for elemetary students' drawings of engineers. *Journal of Pre-College Engineering Education Research (J- PEER), 1*(1), 48-62.

White, B. Y. (1993). ThinkerTools: Causal models, conceptual change, and science education. *Cognition and Instruction, 10*(1), 1-100.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941-967.

Yang, H. T., & Wang, K. H. (2014). A teaching model for scaffolding 4th grade students' scientific explanation writing. *Research in Science Education, 44*, 531-548.

Yarker, Morgan Brown. (2013). *Teacher challenges, perceptions, and use of science models in middle school classrooms about climate, weather, and energy concepts* (Doctoral thesis). University of Iowa.

Yenilmez Türkoglu, A. & Öztekin, C. (2016) Science teacher candidates' perceptions about roles and nature of scientific models. *Research in Science & Technological Education, 34*(2), 219-236.

Yore, L., Bisanz, G.L., & Hand, B. M. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education, 25*(6), 689-725.

Citation:
Kara, S. & Kingir, S. (2019). Argument based inquiry approach accompanied by models in primary science teaching. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 144-162). ISRES Publishing, ISBN:978-605-698540-9.

Environmental Education in India: Constructing Environmental Citizens through Narratives of Optimism

Rebecca A. Johns
University of South Florida, United States

Rachelle Pontes
University of South Florida, United States

Indian Narratives of Environmental Citizenship

Environmental education (EE) programs, wherever they exist, create narratives of value and meaning. Through deliberate choice of topics, perspectives, and approaches to teaching, environmental educators construct a story about nature and human relations to it, presenting an ideal image of what it means to be an environmental citizen. Educators make choices about the intended audience for their programs, and they create expectations for behavioral change through program design. Narratives commonly aim to instruct, convey truths and values about a culture, encourage action, and legitimize behavior (Foss, 2009). By examining the rhetorical construction of the environmental citizen through an in-depth analysis of EE programs at key sites in India, we can better understand how the practitioners understand the process of social change required to ultimately address critical environmental challenges. Furthermore, patterns of both topical emphasis and pedagogical strategy can illuminate the extent to which programs in India fulfill the widely accepted four-point framework for effective EE. India's narrative of environmental citizenship can then be placed in the context of international critiques of EE.

India is the second largest country in the world in terms of population. With the second fastest growing economy in the world, India is expected to become one of the top three economic powers over the next several decades, positioning it as an economic powerhouse with mounting global influence. GDP in India increased 7.2% in 2017-18 and is expected to reach US $6 trillion by 2030. Currently, 30% of the country's energy is from non-fossil fuel sources and that is expected to rise to 40% in the next twelve years. India is also a major consumer economy due to the rise of a strong middle class and is expected to become the second largest economy in terms of purchasing power parity by 2040, according to Pricewaterhouse Coopers (India Brand Equity Foundation, 2019).

Despite positive economic growth and a central government pushing renewable energy, India is fraught with environmental woes. South Asia is home to four of the most polluted countries in the world, including India. India boasts eleven of the twelve cities with the highest amount of small particulate matter in the air, according to the World Health Organization. Air pollution in the Gangetic Plain is said to reduce life expectancy by more than 10 years (D'Ambrogio, 2019).Two-thirds of the population of India live in rural areas, and roughly 790 million people still use biomass (wood, charcoal, dung) for cooking fuel. India faces critical water shortages, with 600 million people experiencing severe water stress and 200,000 deaths from water related illness each year (D'Ambrogio, 2019).

India is also tasked with protecting some of the world's most iconic megafauna, such as the Bengal tiger and the Asian elephant. According to the United Nations Development Programme (UNDP), "India is one of 17 mega-biodiverse countries in the world. With only 2.4 percent of the earth's land area, it accounts for 7-8 percent of the world's recorded species. Home to 96,000 species of animals, 47,000 species of plants and nearly half the world's aquatic plants, India's management of its natural resources is crucial to protecting global biodiversity" (UNDP, 2018).

In tandem with these environmental problems, India faces the daunting task of providing sustainable development for its large population, eradicating hunger and poor health, providing livelihoods, education, shelter and healthcare to 1.3 billion people. It is this combination of pressing human needs with critical environmental challenges that makes India a particularly interesting and informative case study in EE. India cannot afford the myopic focus on species preservation or on affective connection with nature to the neglect of human systems and human-environment relationships that has characterized some western EE spheres (Cronon, 1996; Chapin, 2004). Since its inception, EE in India has been inseparably linked to development. Indeed, the Ahmedabad Declaration on Education for Sustainable Development was produced at an international conference hosted by the government of India in Gujarat. The declaration is the leading document inspiring the growth of education for sustainable development at the global scale.

Environmental Education Background

Environmental education's roots were established at 1972 at the UN Conference on the Human Environment, during which 24 principles were developed to facilitate environmental sustainability, with 19 principles highlighting the need for EE from all ages and all education levels (Stockholm, 1972). The major tenants of EE --promoting awareness, building understanding, improving skills and promoting behavior change to address environmental issues --were agreed upon in the Belgrade Charter, during the first International Workshop on Environmental Education (UNESCO-UNEP, 1976). Two years later, the Belgrade Charter was confirmed by, and built upon by the Tbilisi Declaration. Specifically, the declaration called for an increased focus on development of EE at non-formal locations such as zoos, parks and aquariums (McKeown & Hopkins, 2003; Authors, 2018).

While environmental educators as a whole agree that EE should lead to behavior change to alleviate environmental problems, scholars continue to debate how educators should engage individuals in EE (Lucas, 1980; Jickling & Spork, 1998; Robottom, 2007) and how change ought to be achieved. Part of the debate focuses on three threads of EE: education *in* the environment, education *about* the environment, and education *for* the environment (Palmer 1998). Education *about* the environment focuses on enhancing knowledge and skills required for understanding the nature of an environment. In contrast to education *about* the environment, education *for* the environment seeks to develop affective and cognitive dispositions toward the environmental issues to promote environmentally responsible behavior (Lucas, 1979). Education *in* the environment, also referred to as education *from* the environment, is a pedagogy in which all EE occurs in nature (Lucas, 1980). These threads of EE can be woven together into different combinations (Lucas, 1980).

There is disagreement about whether EE should include collective advocacy on behalf of the environment or a more individual approach based on developing environmental ethics and values (Kopnina, 2014) and strengthening scientific facts (Hart et al., 1999). Some scholars have argued that EE's focus on how individuals might alter their conduct to enhance the health of the environment, such as reducing water and energy use, avoiding littering, and recycling, does not go far enough. Clover et al. (2000) argue that EE programs have paid scant attention to large-scale, global systems that perpetuate an entrenched and destructive human and nature relationship, and to collective action to address environmental issues. One task for educators is to engage the complexities of a global consumer society more fully, and how individuals and communities might challenge its assumptions and values.

New opportunities for educators to engage human systems have arisen through a growing focus on both climate change education and education for sustainable development. Climate change education expands the scope of EE to a greater focus on human agency and human causes of degradation and often includes positive empowerment through building adaptive capacity and resilience in threatened communities. Similarly, education for sustainable development includes a focus on the intersection of socioeconomic and environmental issues, thus expanding EE's attention to complex systems (Ramadoss & Poyya Moli, 2011). Furthermore, scholars have emphasized that systemic thinking is indispensable in analysis of multifaceted environmental problems. Popularly labeled "wicked problems," challenges such as global climate change cannot be understood without a deep analysis of large scale economic and political processes which frame decision-making. Through programs incorporating governance, economic systems and the role of the individual and community in systemic change, individuals can be empowered to participate in decision making, and facilitate large scale change (Sauvé, 2005). Debates about how such change occurs continue in the field, however. Shove (2010) calls attention to the limitations of theories based on the triad of attitude, behavior, and choice (ABC) when she notes “the lexicon of ABC does not contain within it the terms and concepts required to discuss or debate significant societal transformation.” Uzzell (2008) suggests that ``an emphasis on individual behaviour change may not be the most effective way of tackling society’s relationship with climate change’’ (p. 4), and in a report of a study conducted for Department for Environment, Food and Rural Affairs (DEFRA), Darnton (2004) makes a very similar point, arguing that “some of the ends of sustainability…may be better reached not through behaviour change by individuals but through government-led interventions, the targeted delivery of public services or upstream solutions’’ (p. 9).

Environmental Education in India

Emphasis on living harmoniously with nature through protection of ecosystems is deeply rooted in Hindu philosophy (Almedia & Cutter-MacKenzie, 2011; Ravindranath, 2007) and enshrined in the Indian Constitution (Almedia & Cutter-MacKenzie, 2011). The Supreme Court of India ruled in 1991, and reaffirmed in 2003, the infusion of EE into school curricula. State governments were required to develop textbooks reflecting environmental problems and EE was made mandatory across all grades beginning in 2004 (Almedia & Cutter-MacKenzie, 2011). Nonetheless, rapid development, liberalization and industrialization have challenged ancient concepts of nature and devalued traditional rural livelihoods. The creation of a large consumer middle-class has perpetuated both Western lifestyle goals and notions of nature as separate from human beings (Jackson, 2004).

While academic evaluation of Indian attitudes toward nature generally, and wildlife specifically, has grown in recent years (Arjunan et. al, 2006; Karanth & Nepal, 2012) as has work on human-wildlife conflict (Madhusan, 2003: Ogra, 2009; Karanth et al., 2013), scholarly work on EE in the country is in its early stages. Jackson’s (2001, 2004) insightful work argues that the insertion of EE into school texts has resulted in an increase in confusion about the cause and potential solutions to environmental challenges. Specifically, he notes that causal explanations for big problems like riverine and industrial pollution are unclear and do not lend themselves to understanding and action by students. Similarly,

In the matter of land and forest degradation, the causation is more complex and textbook writers have apparently found it difficult to say who will restore them…Here questions of land ownership arise, and those of rights of use, rights to manage, conflicts over use between industry and local communities, bureaucratic inefficiency and corruption, disintegration of the village as a community…Unless these issues are gone into and clearly explained by textbook writers, it is difficult to see how EE can be more than a formality. (Jackson, 2001, p. 27)

Jackson also raises questions about how environmentalism itself is formulated in India, and argues that Western focus on the preservation of charismatic species and aesthetic landscapes diverts attention from the human dimension of environmental degradation. Ultimately, educators may "fail to see that at the heart of every environmental problem is a massive human livelihood issue" (Jackson, 2003). An emphasis on the environmental concerns of a "minority of affluent, powerful urban dwellers" has overshadowed the livelihood and resource-use concerns of the country's larger rural population (Jackson, 2004, p. 94).

Our evaluation of EE at zoos in southern India and through the Centre of Environment Education (CEE) attempts to update our understanding of the status of EE in India, placing its national efforts in the context of common concerns in the global field. Finally, we seek to illuminate the construction of the environmental citizen through EE narratives.

Environmental Education Framework

A lack of attention to systemic, structural processes that produce environmental ills has been a concern of scholars and evaluators in recent years. Conceptualizations of a process of environmental learning that would move students from awareness, through basic knowledge, to more complex understandings of the production and amelioration of environmental challenges, and finally, to meaningful action, have emerged from these discussions. Monroe et al. (2008) provides a widely accepted framework for evaluating the effectiveness of EE programs. The four primary foci of intervention are to 1) convey information, 2) build understanding, 3) improve skills, and 4) enable sustainable action. This framework can aid educators in determining program goals and environmental educational strategies to support their mission.

Convey Information

Providing foundational knowledge about key environmental processes and challenges is essential in increasing environmental literacy. This category identifies the one-way transmission of information to build awareness about specific topics, and supplement existing knowledge.

Build understanding

Building understanding expands foundational knowledge by engaging audiences in two-way or group communication in an effort to build an individual's conceptual models for examining and evaluating concepts, values, and attitudes. Programs that challenge participants to engage more deeply through group discussion, writing, oral communication, research or hands-on activities such as building models, creating projects such as composters or biogas machines, deepen their understanding through behavioral and cognitive engagement (Frederick et al., 2004).

Improve Skills

Improving skills, involves educators employing citizenship, critical thinking, and social marketing, encouraging personal responsibility and engagement while helping to improve upon skills required for behavior change. "Skills" in this context may range from cognitive abilities to social action skills, to more specific ecological monitoring skills (such as composting, or monitoring turtle nesting sites).

Enable Sustainable Action

Enabling sustainable action is an iterative process through which the educator and learner work together to address complex environmental issues through the definition of goals and possible solutions. This process places the participants in control of the outcome with educators providing support, enhancing opportunities for "transformation, empowerment and long-term problem solving" (Monroe et al., 2008, p. 214). While sustainable action is difficult to measure and track, educators affirm that the goal of EE is to equip and motivate participants to become active citizens for the environment, taking continued action to learn about and participate in solving critical problems.

Environmental Citizenship

Creating active environmental citizens can be seen as the ultimate goal of EE programming. While the notion of environmental citizenship has been debated and discussed at length in the EE literature, we adopt and expand on the practical environmental citizenship definition of Berkowitz:

[E]nvironmental citizenship can be defined as having the motivation, self-confidence, and awareness of one's values, and the practical wisdom and ability to put one's civics and ecological literacy into action. Environmental citizenship involves empowering people to have the knowledge, skills, and attitudes needed to identify their values and goals with respect to the environment and to act accordingly, based on the best knowledge of choices and consequences. (Berkowitz et al., 2005, p. 228)

Schild (2016) adds an important element to this definition, i.e., the need for collective action rather than a narrow focus on personal behavioral change. The emphasis in EE on the individual and on personal choices that impact the environment is recognized as problematic. Building programs that motivate citizens to engage collectively in facilitating wider structural and social changes (through revamping of public transportation systems, advocating for governments to aid in a transition from fossil fuels to renewable energy, pushing for policy change, etc.) is essential to the concept of an environmental citizen. Citizenship demands public participation and cannot be constituted merely through private actions and beliefs.

Thus, our working definition of the environmental citizen is one which combines knowledge, skill, commitment, and personal as well as collective action for the environment that moves beyond mere personal behavioral change. To understand if educational programs promote the development of environmental citizens, we first seek to identify specific activities and events at each of the four stages of Monroe's framework for effective EE (2008). In addition, we look for opportunities for both personal and collective action to address wide scale, complex problems, and we seek to identify opportunities for shared governance and policy intervention.

Environmental Education Programs in India

Centres of Environment Education

One of the most encouraging aspects of EE in India is the level of central government commitment exhibited through the creation of the Centre of Environment Education in 1984. Its mission is to provide educational programs across a wide range of sectors, from schools, to villages, government and industry. While the spark that led to the creation of CEE was the Intergovernmental Conference on Environmental Education in Tbilisi, Georgia in 1977, educational work about nature was already underway in India. Kartikey Sarabhai, one of the leading environmental educators in the country, opened Sundarvan, a nature education center funded by the Nehru Foundation for Development.

Environmental education in India is distinguished from EE in post-industrial countries in that it has always been linked to issues of development:

CEE's primary objective is to improve public awareness and understanding of environmental and developmental issues with a view to promoting action for the conservation and sustainable use of nature and natural resources. To this end, CEE develops innovative programmes and educational material, and builds capacity in the field of environmental education and education for sustainable development. It undertakes demonstration projects in education, communication and development that endorse environmentally sustainable attitudes, strategies and technologies.

The ability of India's central government to establish environmental goals is also significant. In 2003, the Supreme Court of India made EE a mandatory subject in schools. This ruling broke open the EE field and created a large demand for curricula, programs of training, and opportunities for innovative EE programs. Following the 2005 UN Declaration of the Decade of Education for Sustainable Development, CEE immediately moved forward by hosting an international conference on Education for Sustainable Development (ESD) in Ahmedabad. Ninety-seven countries and over 1,500 people participated in the conference, which led to the Ahmedabad Declaration on Education for Sustainable Development. The statement's emphasis is on a complex, systemic and integrated vision of how education can influence economic, political and ultimately, environmental decision-making:

Ever increasing human production and consumption is rapidly undermining Earth's life-support systems and the potential for all life to flourish. Assumptions about what constitutes an acceptable quality of life for some, often means deprivation for others. The gap between the rich and the poor is widening. The climate crisis, loss of biodiversity, increasing health risks and poverty are indicators of development models and lifestyles that are unsustainable…Human rights, gender equity, social justice and a healthy environment must become global imperatives.

The CEE has seven regional offices (south, north east, north, central, west, east, and Delhi), each of which covers multiple states or locales. For example, the CEE South region covers the states of Andra Pradesh, Karnataka, Kerala, Tamil Nadu, Lakshadweep as well as the Andaman and Nicobar Islands. While CEE was originally established and funded by the central government, funding has shifted to state governments, Non-governmental organizations (NGOs), grants and corporate sponsorships.

The types of programs offered, and the topics covered by CEE are startling in their breadth (Table 1; see also Appendix). The possible pros and cons of this wide approach will be discussed later. Below, we briefly describe some of the key programs offered by CEE. For a complete list of the activities and topics offered by CEE and identified through this research, see Appendix A.

Table 1. Education Programs Run by CEE, 6 months of 2017

Education Programs Run by CEE, 6 months of 2017
National Clean Ganga Mission
Jal Jeevan Hai – efficient use of water for agriculture
Permanent Exhibit installation at Kokrebellur Bird Sanctuary
Curriculum development in math, science, language and environment in Gujarat
Teacher training for sanitation and hygiene
DHaAL with Unicef – daily handwashing campaign
Cash-free, digital payment trainings
Children's Forest Programme in Uttar Pradesh, 1500 saplings planted
Learning Non-Violence
Establishing Eco-Clubs at 20 schools
Young Leader's Conference
Mari Shala/Reach to Teach, pedagogy on hygiene and health

Eco-mapping in Uttar Pradesh
Conference for Young Environmentalists on Smart Cities
Forests for Water Campaign, Karnataka
International Sustainability Exchange, Australia, Netherlands, Germany
Creating Green Campuses
Hosting Interns
Discovering Nature: 75,000 visitors to Sundarvan
Camping to Experience Nature
Turtle and Tortoise Conservation
Global Resilience Partners, SEWA Trust, USAID, Rockefeller to build climate resiliency of urban poor
Energy Conservation program for students
Training in managing biomedical waste
Multistakeholder dialogue for improve compliance with industry
Waste segregation clean up Kolkata
Student rally on plastics
National workshop on Waste Management rules to improve compliance
Sustainable Rural Development
Developed 4 permanent interpretive exhibits in four states
Grant making workshop
Earth Day Campaign and festival

Child Based Programming

CEE offers standard programs for school-age children, including school field trips to the CEE campuses. These day trips constitute a part of the school's regular curriculum. Schools are required to have a certain number of "outdoor field day" events. The precise number required depends on the individual school, ranging from one to five per year. During these programs, students are bussed to sites, where educational tours and activities (such as treasure hunts, worksheet exercises, etc.) are conducted. The purpose of these programs is primarily to reinforce scientific learning and is generally connected to the state or school's curricular standards and goals. Exposing urban children to nature is, however, also an important goal.

Nature camps, including sleep over events, are also common for school-age children at the sample sites with the Sundarvan discovery center hosting over 250 students from four states as part of a National Nature Camping Program 2017. Such camps seek to increase factual knowledge about local ecosystems and animals while providing the beneficial impacts of spending time outdoors in a relatively non-humanized landscape, in proximity to non-human living things. Such programs are based on the common theory that time in nature increases empathy and commitment to environmental goals. While the connection between "connection to nature" and action on behalf of the environment is debatable (Lieflander et al., 2013; Fletcher, 2017), this remains a common ideology in many countries.

Educator Programming

India's EE agenda has focused heavily on providing learning through the formal school system. In 1985, a National Environment Awareness Campaign was launched to develop and coordinate the implementation of programs at schools. While CEE staff may visit schools and run educational programs themselves, the greater initiative is on training teachers and providing curricula materials on the environment, or to assist teachers and other organizations in developing such materials. Programs at schools also involve developing field day activities that take place outdoors or off campus.

In Andhra Pradesh, for example, the state CEE office worked with the state government and 33 NGOs to bring EE materials, programs and activities into 1556 schools, in all districts of the state. Manuals were developed for teachers that contain instructional materials as well as activities for the students. Rather than delivering curricula and then leaving teachers to manage on their own, CEE offers ongoing support by visiting schools periodically and helping coordinate annual EE events. As a corollary of this project, a wall poster linking lessons in the science curriculum, called *Parisarallo Pathalu* (Learning from our Surroundings), was developed and distributed to about 13,500 primary schools in the state.

In Karnataka, the CEE runs school programs that focus on preserving forest habitats and wildlife. Approximately 10,000 students visited the 500-acre campus of the center to experience educational programs, such as day trips or camps. CEE Karnataka staff also focus on capacity building by training local teachers (Sutar, 2019). Recently, the organization has launched an online certificate program so that teachers may become proficient in EE.

Capacity Building

Capacity building, i.e. train the trainer type programs, are a major thrust of CEE. With staff at regional CEE offices limited to 5 to 15 people, training other professionals who will in turn, teach others, increasing educational impacts through a snowball effect, is imperative. Indeed, even working with children is seen as capacity building, in anticipation that children will share their new enthusiasm and knowledge with their parents, who will in turn share with co-workers and friends.

Nature Hikes/Nature Centers

Nature hikes are a common program at nature centers, zoos and CEE campuses across India. Approximately 75,000 people are estimated to have visited the Sundarvan CEE nature center in 2017. At this site, visitors participate in reptile awareness, hiking, bird watching, wildlife photography. CEE Karnataka also has an extensive natural area on its campus in north Bangalore, used for workshops, camps and educational activities. Additionally, CEE educators also make use of other natural areas, such as India's 50+ tiger preserves and bio-reserves.

Reducing Plastics/Reducing Waste

CEE's waste management programs focus on building awareness, training managers in applying principles of waste management and policy compliance, developing documents to assist in compliance, and tracking progress. Further, it develops "videos, toolkits, publications, games, posters, charts, etc.," and conducts demonstration projects of waste management practices and projects (such as biogas production, vermiculture composting, etc.). Finally, CEE engages in policy interventions in which its staff gives recommendations and suggestions at the city, state and national level on municipal waste handling and management.

Resource Conservation

Programs highlighting the need for resource conservation focused primarily on water scarcity and deforestation. Forest management was a common theme in CEE programs. Collective activities such as tree plantings were also executed. In rural areas, workshops on agroforestry aimed to assist rural farmers in developing more sustainable techniques to help maintain forest cover while not undermining livelihood. Conservation of water was also a frequent topic of CEE programs.

Hygiene and Sanitation

The most urgent effect of the lack of sanitation systems in much of the country is the detrimental impact on human health. CEE offers programs on hygiene which are designed to change personal behavior in order to prevent the spread of disease. While such educational efforts are no doubt helpful, we note the lack of focus on shared governance or policy intervention designed to actually solve the problem of poor sanitation.

Environmental Education at Zoos

Fieldwork was completed at three zoos in the southern Indian states of Tamil Nadu (Madras Crocodile Bank and Trust) and Karnataka (Mysore Zoo and Bannerghatta Wildlife Park). While all the facilities studied have conservation and research missions, the focus here is on educational programs.

Madras Crocodile Bank Trust and Center for Herpetology

Three species of indigenous crocodilians were listed as protected in India by the 1972 Wildlife Protection Act. All three species were near extinction due to centuries of hunting. The Madras Crocodile Bank Trust was established by Rom and Zai Whitaker in 1976 to focus on protecting these three important species, the mugger (*Crocodylus palustris),* the saltwater crocodile (*Crocodylus porosus*) and the rarest of all, the gharial (*Gavialis gangeticus*). Originally, the MCBT worked to multiply crocodiles and release them to the wild; however, with the loss of suitable habitat, this practice has now stopped.

Known today as the Madras Crocodile Bank Trust and Center for Herpetology (MCBT), the site houses seventeen species of crocodiles as well as turtles, lizards and snakes. While the focus remains on conservation, the staff of MCBT work closely with surrounding rural communities to increase knowledge and understanding of reptiles and decrease human-reptile conflict. Given that the public generally sees reptiles as dangerous or “nasty” animals, staff noted that their first task is to change public attitudes toward these maligned creatures. School field trips and nature camps, including sleep over events, are a regular part of their EE programming, but changing attitudes among diverse rural people is a critical function of the MCBT.

We cannot tell a rural family that their livelihood or their lives are somehow less important than the animals’ lives. That makes no sense. We have to be sensitive to their circumstances. It is not our job to tell a community that their traditional belief system is wrong…we are just trying to introduce a more tolerant way of interacting with these species, and a greater respect and understanding of them. (Srimathi, 2019)

Exposing children to reptiles and shifting the emotional response from one of fear or disgust to one of interest and acceptance, is a primary goal of the MCBT’s nature camps and programs for children.

Table 2. Education and Awareness Programs, MCBT 2017-2018

Education and Awareness Programs, Madras Crocodile Bank 2017-2018
The Junior Herpers for a Day (half day) camp - June 4th, 2017
Junior Herpers for a Day (full day) camp - August 20th, 2017
What’s That Reptile? Series
Snakes and Lizards – May 13th and 14th
Juniors – May 23rd and 24th
Crocodiles and Chelonians – May 27th and 28th
What’s that Lizard? – May 14th and 15th
What’s That Reptile? Junior Series – May 11th and 12th
Junior Keeper for a Day camps – April 30th, June 4th, July 30th, August 20th,

September 10th, October 22nd, December 24th
Zoo Snooze (Adults) – June 24th and 25th
Snake Walks – September 17th, November 5th
Vruksha Montessori 2 Day camp – September 1st and 2nd
George Washington University(GWU) workshop – July 25th
PRIST University workshop – July 21st
USV Pvt. Ltd. School workshop – August 29th
Orchid School camp – April 23rd and 24th, October 20th and 21st
Birthday celebrations – July 30th, September 10th, October 7th, December 3rd, December 27th
KFI school workshop – September 15th
Know Your Reptile sessions and Guided Tours

Junior Keeper for a Day camps – February 18th, 2018
Junior Herpers / Half-day camps – February 25^{th,}
Snake Walk – January 14th, February 11th, 2018

Mysore Zoo

Chamarajendra Zoological Gardens, also known as Mysore Zoo, was created in 1892 and named after its founder. Originally about 10 acres in size, the zoo is now almost 80 acres, and houses 1,450 animals representing 168 species, from more than 25 countries. Over 3 million people visit the zoo each year, with tens of thousands participate in its educational programming. The educational mission of the zoo is "to inspire local and global communities to protect, conserve and celebrate wildlife, and to provide a fun, unique and inspirational experience fostering appreciation, knowledge and care for the natural world."

The zoo's website lists special programs for physically challenged and special group children, literary competitions, celebration of wildlife week, World Environment Day, Youth Club activities, Summer Camp activities, signage, zoo keepers training, teacher training, internship and student programs, and publications as the primary educational outlets (Mysore Zoo, n.d.).Topics covered by zoo programs range from vermiculture production, human-leopard conflicts and co-existing with leopards, soil conservation trainings with local farmers, and training for mahoots (rural workers who train elephants).

Mysore Zoo is known for its biogas production facility and its elaborate demonstration vermiculture project. The zoo runs youth camps during the year and throughout the summer, which focus on the biology of animals, ecology and conservation issues such as climate change and urban waste (Kulkarni, 2019). An important feature of the education programs of this zoo are regular conservation speaker events, which are held every quarter and attract upwards of 800 people. Recent topics include agroforestry as a way to ameliorate climate change and drought, why otters matter, human-leopard conflict, and conservation of the lion-tailed macaque.

Bannerghatta Biological Park (BBP)

Bannerghatta is a biological park on the outskirts of Bengaluru. The park is currently 12 hectares and undergoing expansion. Approximately 2,000 animals and birds representing nearly 100 species are housed at the facility. Over 14,000 people visited the park in 2017. The facility's mission is "To educate and enlighten the public (visitors) by displaying wild animals that are equally important, interesting and essential for the ecosystem's support and thus create empathy towards wild animals in the public. To offer an excellent opportunity to the people to connect with nature and wildlife" (BBP, n.d.). One of the biggest attractions of this facility is its large carnivores; presently there are 26 regular Bengal tigers, 7 white tigers and 19 lions on site.

Of the three zoos visited in this research, Bannerghatta is the least developed. While the website claims educational programs on reptiles, snake bite protocols, animal management, urban-animal conflict, and the impact of plastic ingestion, little evidence of any such programs was seen during site visits. The only educational program in evidence was a school trip.

Research indicates that in late 2017, BBP began sponsoring student trips from government schools in the Human Wildlife Conflict (HWC) zone, aimed to increase awareness, knowledge, and tolerance of wild animals. From 2017 to 2018, over 1,000 students came to the park through this free program. Additional groups of students also came to the park under a Forest Department program. With assistance from Mysore Zoo, Bannerghatta launched a Youth Club in 2017. For over 15 Sundays from 10 am to 1pm, 60 children in the age category of 12 to 18 from schools in Bangalore attended the program in 2017 through 2018.

Bannerghatta's prime attraction is a popular series of jeep safaris through animal enclosures, in which passengers come in relatively close contact with elephants, gaurs, hippos, Bengal tigers and Asiatic lions. This type of emotional engagement (Frederick et al., 2004) is critical for effective learning. Up close and personal interactions with non-human animals are one of the most popular features of zoos, and educators agree that such interactions can foster compassion and concern for endangered species (Myers et al., 2009). The white Bengal Tiger photographed below (Figure 1), was one of four similar tigers in their enclosure at Bannerghatta.

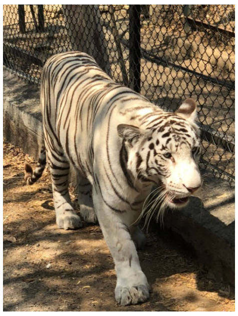


Figure 1. Up Close and Personal at Bannerghatta

As the jeep entered each animal enclosure, the driver stopped at a strategic location so passengers could take up close pictures of the animals. However, no commentary was provided by the driver about the animals, so other than a visceral experience of being only several meters from a large carnivore, no knowledge was conveyed to the participants.

Rural Livelihoods and Co-Existence

Environmental educators in India face a challenge unique to developing countries: the knowledge, needs and lived experience of urban Indians is quite different from that of the majority population who remain in rural areas. Indeed, Jackson (2004) notes a tension between programmatic differences arising from urban middle class and rural villages. The divergence in programming remains ironic: rural people, who have never left the land, are helped to live more sustainably while coexisting with wildlife, and urban residents are helped to "return" to nature, reduce waste and reduce consumption. Because Indian society is still in the process of urbanization and industrialization, the opportunity exists to slow the disconnect from nature evidenced in post-industrial societies. Similar to leap-frogging over some development failures (such as fossil fuel dependency), India has the opportunity to preserve sustainable attitudes and livelihoods in places where they still exist.

Livelihood in Human-Wildlife Conflict Zones

In rural India, many villagers live in areas shared with wildlife. Elephants, for example, destroy 14% of crops in India annually (Madhusan, 2003). Conflict with tigers, while not common, still results in over 100 human deaths per year (National Tiger Conservation Authority, 2019). In coastal areas of Tamil Nadu, an area designated as the Crocodile Conflict Zone is of particular concern to environmental educators at the MCBT. Educators demonstrated sensitivity to the constraints of rural life:

You cannot talk to rural people about the need to conserve non-human species without understanding their livelihood struggles. We give rural villagers our ears; we listen to their complaints and try to understand how they live. We try to work out a way for peaceable coexistence with wildlife (Srimathi, 2019)

Both Mysore Zoo and the MCBT focused on education about wildlife in the Human-Wildlife Contact zones in their regions. For example, Mysore Zoo dedicated one of its quarterly conservation speaker events to a discussion of human-leopard problems in the region.

Table 3. Rural v. Urban

	Rural	Urban
		Air pollution
		Water pollution/rivers
		Water scarcity
	Agroforestry	Sanitation/hygiene
	Water efficient agriculture	Plastic reduction
	Wildlife conflict	Waste management
Types of Programs	Sanitation	Digital payments
	Waste management	Tree plantings
	Biogas/vermiculture	E-waste clean up
	Eco-mapping	Green campus/schools
	Organic farming	Nature camps
		Workshops
		Conferences
		Certificate courses

Signage and Permanent Exhibits: The Missing Humans

Signs and permanent exhibits are critical components of zoos. While many zoos provide educators on the grounds and special programs to engage visitors in learning experiences, material artifacts that aide in learning are the primary way information is conveyed to the public. Photographs were taken during site visits to all three zoos (323 photos total) to facilitate visual analysis of permanent exhibits.

Signage at the three parks emphasized factual information about each species and was multilingual, reflecting the diversity of local populations. While all three facilities provide adequate information about resident species, the presentation of the information varied significantly between zoos in terms of the depth of information and quality of the signage. Two of the facilities have engaging signage, attempting to motivate visitors to care for wildlife, but lacked specific direction on how the public might assist in wildlife preservation. The physical space of all three facilities was suitable, with both the Mysore Zoo and the MCBT presenting very pleasant, large and well-maintained grounds. Some opportunities for participation in learning were provided, but these were minimal (safaris, listening to speakers, tram tours).

The MBCT had fairly new signage that was generally in good condition. Permanent exhibits included a scientific display of skulls of the many species of crocodilians resident at the park (Figure 2).

Figure 2. Permanent Exhibit at the MBCT

While emphasis on human interaction with non-human species did not feature strongly in the signage at all three parks, MCBT did have several large murals encouraging visitors to "treat them [muggers] with respect….and relearn how to live safely with crocodiles." The mural also emphasized that "sadly, most wild populations have disappeared. There is little habitat left because humans have taken over the spaces that used to be theirs." While this verbiage is helpful in linking human systems to the decline of the marsh crocodile species, there is no suggested action, personal or societal, to ameliorate the problem of habitat loss. Instead, it is merely presented as a sad problem with no apparent solution.

Figure 3. Cultural Interactions with Crocodiles at MBCT

MCBT also displayed a well-crafted mural depicting crocodilians in cultures across the globe. The mural signifies the importance of these animals, and the esteem with which they were held by different societies.

Mysore Zoo's signage was also generally in good condition. The factual information for each species was detailed and presented in several languages (Figure 4). There were no references to human behavior or specific actions that visitors could take to help the endangered animal species.

Figure 4. Typical Informational Signage at Mysore Zoo

Visitors were treated to inspirational messages along the walking path, such as "animals are true friends," "wild animals are great assets," "service to animal is service to God," and finally, "Go Green to get our Planet Clean." Signage using first person syntax (Figure 5), with the animal is speaking directly to the visitor, was innovative and engaging. Use of humor also made Mysore Zoo's signage appealing (Figure 6). Finally, signs included a reminder that zoos are for education as well as entertainment (Figure 7).

Figure 5. Engaging Visitors in First Person

Figure 6. Humorous Signage at Mysore Zoo

Figure 7. Reminder that Zoos are for Education

Older signage at BBP was in disrepair and was the least impressive of the three sites visited in this research (Figure 8). However, some upgrades had been recently conducted (between the researcher's preliminary site visit in 2017 and the field research in 2019). Signage is perfunctory and factual. Corporate sponsorships of the zoo were prominently noted around the grounds and on exhibit signs.

Figure 8. A typical Sign at an Animal Enclosure at BBP

Analyzing any narrative requires that we pay attention to silences and omissions (Foss, 2009). Signage at all three facilities, while using some innovation approaches such as humor, inspirational quotes, and first-person messages from animals, appears to replicate a persistent limitation seen at zoos elsewhere, with a lack of attention to human systems and the impact of humans on the species displayed. Ample opportunity exists in each of the facilities to elaborate on how urban sprawl, human hunger for resources, increased road traffic, encroachment on wild areas, and pollution impact resident species. The zoos in the sample focus on increasing awareness of endangered species and fostering a more empathetic connection between humans and non-human species – an "open the door" philosophy of EE, in which humans are essentially softened up to be receptive to additional cognitive information about animals, and eventually, one hopes, to a deeper understanding of how human actions impair the survivability of other species. The study facilities did offer occasional programs that were more active and required greater commitment and engagement by the public, such as workshops on identifying birds and butterflies (Figure 9) and creating compost with vermiculture (Figure 10).

Figure 9. Skill Building Permanent Exhibit at Mysore Zoo

Rhetorical Analysis: A complex EE for a complex country

Rhetorical analysis allows patterns of emphasis to appear in the discourse being provided by CEE and its regional offices to the public. Ideological rhetorical analysis (Foss, 2009) was applied to identify the beliefs and values of the organization as reflected in their public narratives. Since "description is the reality we experience" (Foss, 2009, p. 268), we interpret the narrative discourse created through CEE's ongoing communications with its audience. The objective of the EE narrative is to teach, to convey information and to encourage action. Specifically, Monroe's EE framework was applied to identify words that reflect either an emphasis on science/facts; an emphasis on affective connection/emotional or spiritual values of nature; an emphasis on skill-building; and an emphasis on action. The narrative that emerges from EE in India was analyzed for constructs of active citizenship, specifically, to identify where the emphasis on making change occurs. Are environmental citizens conceived as individuals, making personal choices about their behavior (recycling, reducing plastics) or are they, perhaps simultaneously, positioned as members of a collective (neighborhood, city, state, nation) tasked with working together to change larger structures which enable and sustain environmentally damaging practices?

Convey Information; Build Understanding; Improve Skills; Enable Sustainable Actions

Every person interviewed during fieldwork stated some version of “creating lifelong conservationists” as a primary goal of their work. Conveying information to participants in order to facilitate engagement with environmental challenges was clearly seen as the most important aspect of EE work; motivating citizens through increase in an affective connection to nature was also highly valued. Many programs encountered in the field and through document analysis are skill-based programs, and some were highly specialized, for example, how to build a vermiculture site (Figure 10) or create a biowaste system.

Figure 10. Solid Waste Management Program (Vermiculture) at Mysore Zoo

Breadth v. Depth

This evaluation of the programs of a select set of zoos and of the CEE indicates a wide range of topics covered. However, sporadic one-time events on multiple topics may lack the impact of a more consistent and deep focus on a singular issue. Over the period in which social media posts were tracked, CEE posted about conferences, workshops, teacher trainings, online courses, nature outings, etc. - a total of 29 different types of events. Over this time period, 49 different topics were covered by CEE events, ranging from events on plastics, water scarcity, and energy conservation to teacher trainings and environmentally friendly dyes for holiday celebrations.

The educational programing in sample zoos covered fewer topics and events, which was not unexpected. Zoos distribute their time and effort across three main categories: conservation, research and education. Indeed, the focus of zoos on animal welfare, habitat loss, and climate change impacts on animals is suitable. Expanding their educational reach to other issues not directly related to species health and survival may not be appropriate. The intense focus of MCBT, for example, on changing attitudes toward reptiles is consistent with their mission.

Table 4: The Four Rhetorical Signs

Environmental Education Focus, Key Words	Zoos	CEE
Signs of Awareness & Factual Knowledge	Zoo tours, animal exhibits, signage, zookeeper interpretation, safaris, nature camps, school day trips	Nature hikes, nature camps, workshops, teacher trainings, youth conferences, national conferences, climate change lectures, biodiversity lectures
Signs of Understanding & Analysis	Zookeeper interpretation, safaris, on-site lectures	Workshops, teacher trainings, courses, certification, youth conferences, national conferences, climate change lectures
Signs of Skill Building	Essays, art and photography exhibits, biogas workshops, vermiculture workshops, agroforestry workshops, bird identification	Handprint, hands-on learning, model building, stakeholder dialogue, empowerment of women and marginalized communities, rural sustainable development & livelihood, eco-mapping, cultural performances, student exchanges, experiential storytelling, organic farming, composting, digital payment, watershed management, research and writing for conservation, waste segregation
Signs of Action	Biogas workshops, vermiculture workshops, agroforestry workshops, internships, zookeeper training, plastics ban	Community clean ups, oath signing, reducing/banning plastics, waste segregation, hygiene and cleanliness, organic farming, Clean Ganga, research and writing for conservation, composting, digital payment, watershed management, non-violence training, energy conservation/ renewables, tree plantings, postcard campaigns

Scholars have noted the tendency of EE programs to focus primarily on building awareness and increasing fundamental knowledge about ecosystems. Programs that build skills, create the capacity for a deeper analysis of the production of environmental problems and their solutions, and facilitate action on behalf of environmental progress, are less common. The most challenging goal for environmental educators is creating citizens that are capable and committed to sustained action on behalf of the environment. In this regard, the CEE has programs that increase the skills of the participants, incorporating immediate action (tree planting, river clean ups) or creating conditions for long-term actions for nature (such as watershed management, organic farming, writing for the environment). However, the actions encouraged through EE programming are cemented in personal choice (the ABC theory of change) and rarely address larger scale structural change required to ameliorate the weighty environmental problems India faces.

Defining the Environmental Citizen in India

Who is India's environmental citizen? Visual analysis of the programs highlighted by CEE in social media reveal an urban, well-educated, middle-class target audience for environmental messages. Participants are always well-dressed or in school uniforms, appearing clean and contented. This image of the middle-class urbanite, employed in environmental management or caring for nature through green consumption and modification of personal behavior, is a familiar construction of the environmental citizen.

Interviewees were consistent in stating that the goal of education was to create lifelong "conservation citizens." One respondent explained that he hoped participants in EE would remain aware of environmental impacts of their own actions, and would become ambassadors for the environment in the workplace and community. He noted a few graduates who had gone on to have careers related to the environment, while also acknowledging that not everyone could work in a field related to conservation (Kulkarni, 2019).

Where India's programs diverge from this norm, however, is in the work being done in rural areas, in villages, with farmers and their children who live in daily contact with forests, rivers, swamps, deserts and the non-human inhabitants of these ecosystems. Because these citizens are less likely to fit the stereotype of the urban middle class environmentalist, they are rarely shown in images promoting CEE programs. In conversations with educators, environmental citizens in rural areas were constructed as hardworking individuals for whom livelihood demands may make conservation behavior difficult but not impossible (agroforestry, for example), and who can learn to live more harmoniously with wild animal neighbors.

The consistent tone of social media coverage of CEE events is one of success and optimism. Such words as "inspiration," "joyful", "take a bow," populate the brief textual annotations that accompany photographs on sites such as Facebook. The visual narrative created through social media emphasizes groups of well-dressed, smiling adults (Figure 11) or children.

Some images include children running or playing outdoors or engaging in model building (Figure 12). No images of destroyed landscapes, daunting piles of plastics, denuded hillsides or polluted rivers were displayed in the time period of the study. Hence, the visual story is one of active citizens, happily solving their community's environmental woes.

Figure 11. CEE Seminar on Environment and Development, Delhi

Posts tend to have a celebratory tone and convey pleasure and pride in the activities of the organization. While this may increase clicks, it is also true that environmental problems are often emotionally upsetting. Conveying the seriousness and the detrimental impact to life of oil spills, lack of water or food, plastic pollutants, etc., may be a useful strategy for gaining attention and commitment of the public, and one which CEE might want to consider. CEE rarely if ever engages this strategy. The overall feeling evoked by social media coverage of CEE is that of success: all sorts of environmental problems are being tackled and solved in a rather mysterious and somewhat haphazard manner by this omnipresent organization. While a benign feeling of "all is well" may emerge from this social media discourse, such a feeling does not match the urgency of environmental challenges and may have the unfortunate impact of dissuading some observers that any action on their part is necessary.

A noted accomplishment of CEE was the introduction of the Handprint measure in 2007. Handprint is a "tool to calculate the extent of ESD action being taken and the positive impact of our actions on Sustainable Development" and is licensed to CEE India.

Handprint is positive action, commitment, measurement; it also means connecting – joining hands, a symbol of care …Our lifestyle is directly connected with the consumption. It has become part of one's life and so there is a need to practice positive sustainable actions from now on. Actions are intentional and so is Handprint. Experiences and actions are very closely linked. (Handprint, n.d.)

Unlike the widely used notion of "ecological footprint," for which several common measures have been developed, *Handprint* allows one to estimate the positive gains made through one's actions, such as reducing water or energy consumption, or taking action through recycling or clean-ups.

Figure 12. Children create a model India

Emphasizing the Personal v. the Collective

While CEE programs do focus on changing individual behavior such as reducing the use of plastics, individual actions are most often situated within a collective action or carried out through a community organization or corporate entity. Rather than focusing on asking individuals to privately change their behavior, CEE programs take place in public spaces and in public view. Given the communal nature of Indian society, this approach might be expected, and contrasts with the dearth of collective approaches in countries such as the U.S., in which the individual citizen is paramount. Even when education targets individuals, the expectation of the educators interviewed here is a kind of "snowball theory of change," in which one person is fully expected to talk to and influence people in her immediate circle (friends, family, co-workers), who in turn will also influence others. In a kind of informal chat-based cultural diffusion process, ideas about the environment will spread through communities. As one interviewee noted, "laws can't solve everything – it has to be a grassroots effort" (Sutar, 2019).

Emphasizing the Structural

Environmental educators working with rural communities recognize structural elements that shape behavior. Rural people are seen by educators as constrained by the context of rural life, particularly the need to use resources for sustenance and living in close proximity to wildlife. Environmental educators do not seek to change the structure directly, recognizing little can be done about the villagers' need to use local resources or the steady sprawl of human settlements into crocodile and snake territory. Rather, their work with rural residents falls firmly within the realm of the ABC theory of change: in which information can change an individual's attitude, which will then impact their behavior. This process is seen as a choice made by individuals, rather than any collective effort to alter the circumstances in which such individuals live. For example, team members from MCBT visit rural areas when residents report an incident in which a person has been harmed by a crocodile or snake. By providing information about the species and their behaviors, helping rural people distinguish between venomous and non-venomous snakes, or how to avoid crocodiles in their habitats, educators hope to increase "peaceful co-existence" and reduce harm to both humans and reptiles.

Signs of Progress

Environmental education programs tend to emphasize awareness, experience of nature, and basic ecological knowledge. The challenge for educators is to move participants beyond these fundamentals, into deeper analytical understanding of how environmental problems are created through large-scale societal processes, equipping citizens to combat these ills through personal and collective action. Indian EE, as witnessed through this research, encompasses much within early stages of ecoliteracy, and has also begun to grapple with the tougher problems of skill building, systemic analysis and collective action for structural change.

CEE's website notes that policy intervention is an important part of its knowledge dissemination work for sustainable development. Specifically, it aims to inform decision and policy-makers on sustainable alternatives to conventional technologies (CEE, 2019). Evidence from interviews and document analysis suggests an awareness of the need to engage in "Policy formulation, public engagement and communication strategy development," (Menon, 2019). Educators in CEE's urban office in Pune work to increase participatory governance and public engagement with government programs and policy makers. Educators in the CEE Goa office also emphasize policy interventions and stakeholder consultations (CEE Goa). The primary form such actions take is through stakeholder dialogue and discussions between policymakers, educators and the public (Menon, 2019).

We have been trying to arrange public deliberations on street design and mobility, but *with very limited results. We are inspired by deliberative democracy and participatory budgeting work, as well as gram sabhas in rural India. Urban areas in India don't have analogous forums for public participation, and the urban context does pose several challenges (e.g. structural inequity, population density, time, scale). (Menon, 2019)*

CEE Pune staff note that they have been working to increase public consultations with local government, particularly in the area of transportation planning and urban design. "Our role was communication design, public outreach, stakeholder engagement and governance assessment, and then writing up the draft plan" (Menon, 2019). CEE has also arranged public consultations on issues related to coastal areas, commercial development, and state level climate action plans. The thrust of public governance work is relatively new and still in the development stages.

Conclusion

While India as a whole is making progress in several areas of large scale change, such as moving to renewable energy sources (The State of India's Environment, 2019), there is no evidence to connect this to the impact of EE directly. We can only infer that such programs have helped pave the way for public acceptance of policy changes, but without rigorous investigation of this connection, we cannot know for certain. Furthermore, the country continues to face monumental environmental problems, specifically in regard to air pollution, urban sprawl, solid waste and sanitation, and water pollution and scarcity (D'Ambrogio, 2019). The ability of EE to prompt the kind of wide-scale, infrastructural change needed remains uncertain.

Finally, discussions on environmental citizenship have noted that conflict is an inseparable part of systemic change (Barry, 2006). A vision of citizenship that excludes any kind of confrontational or conflictual interactions may risk being ineffectual in addressing the massive environmental issues facing India. While CEE's citizenship narrative includes community level activities such as "oath signing" and the occasional rally, no large-scale political actions were encouraged. For example, there are no references to engaging legislators, or building a grassroots movement to agitate for policy changes. Programs that engage local government or industry in conversation do occur, and several interviewees mentioned organizing policy interventions and working for participatory governance (i.e., stakeholder dialogues), but these were rare. Such strategies are also lacking in other countries' approaches to EE, as illustrated in the U.S., where lobbying for policy change and direct actions such as marches and protests are the purview of advocacy organizations (i.e., Sierra Club). A similar gap between India's long history of social movements on behalf of local ecosystems and the field of EE is apparent. However, given the severity of climate challenges and the scale of environmental problems in India, educators might benefit from rethinking environmental educations' aversion to advocacy, shifting the emphasis from education *in* and *of* the environment, to programs *for* the environment, including pushing for large scale, structural changes – even when such strategies cause conflict. Constructing EE as a happy and enjoyable pastime may not serve the interests of the environment or the people who depend upon it.

References

Almeida, S., & Cutter-Mackenzie, A. (2011). The historical, present and future ness of environmental education in India. *Australian Journal of Environmental Education, 27*(1), 122-133.

Arjunan, M., Holmes, C., Puyravaud, J. P., & Davidar, P. (2006). Do developmental initiatives influence local attitudes toward conservation? A case study from the Kalakad–Mundanthurai Tiger Reserve, India. *Journal of Environmental Management, 79*(2), 188-197.

Bannerghatta Biological Park. (n.d.). Retrieved from http://bannerghattabiologicalpark.org/about_park.html

Barry, J. (2006). Resistance is Fertile: From Environmental to Sustainability Citizenship. *Environmental Citizenship, 21.*

Berkowitz, A. R., Ford, M. E., & Brewer, C. A. (2005). A framework for integrating ecological literacy, civics literacy, and environmental citizenship in environmental education. *Environmental education and advocacy: Changing perspectives of ecology and education, 227*, 66.

Centre for Environmental Education. (n.d.). Thrust Areas > Knowledge Management for SD. Retrieved from https://www.ceeindia.org/knowledge-mngmnt-sd.html

CEE Delhi (2019).

CEE Goa (2019). https://www.ceeindia.org/goa.html

Chapin, M. (2004). A Challenge to Conservationists. *World Watch Institute Magazine*.

Clover, D. E., Follen, S., & Hall, B. (2000). *The nature of transformation, environmental adult and popular education (*2nd ed.). Toronto: Transformative Learning Centre, OISE/UT and International Council for Adult Education.

Cronon, W. (1996). The Trouble with Wilderness.” In Cronon, William, editor, 1996. *Uncommon Ground: Rethinking the Human Place in Nature*. W.W. Norton & Company: New York.

D'Ambrogio, E. (2019) India: Environmental Issues. European Parliamentary Research Service.

Darnton, A. (2004). Driving Public Behaviours for Sustainable Lifestyles Report 2 of Desk Research commissioned by COI on behalf of DEFRA. *Sustainable Development Unit of the Department for Environmental Food and Rural Affairs. The Government of United Kingdom.* Retrieved from http://www.sustainable-development.gov.uk/taking-it-on/pdf/desk-research2.pdf

DeWalt, K.M. & DeWalt, B.R. (2011). *Participant observation: A guide for fieldworkers*. United Kingdom: Altamira Press.

Fletcher, R. (2017). Connection with nature is an oxymoron: A political ecology of "nature-deficit disorder". *The Journal of Environmental Education, 48*(4), 226-233.

Foss, S. K. (2009). *Rhetorical criticism: Exploration and practice*. 4th edition. Waveland Press, Illinois.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59-109.

Handprint (n.d.). Retrieved from https://www.handprint.in/.

Hart, P., Jickling, B., & Kool, R. (1999). Starting points: Questions of quality in environmental education. *Canadian Journal of Environmental Education, 4*(1), 104-125.

India Brand Equity Foundation. (2019). About Indian economy growth rate & statistics. Retrieved from https://www.ibef.org/economy/indian-economy-overview.

Jackson, M.G. (2001). Environmental Education in India: What has been achieved*? Indian Educational Review*.37 (1).

Jackson, M. G. (2003). From practice to policy in environmental education. *Southern African Journal of Environmental Education, 20*, 97-110.

Jackson, M. G. (2004). Towards an authentic Indian environmentalism. *Southern African Journal of Environmental Education, 21,* 94-107.

Jickling, B., & Spork, H. (1998). Education for the environment: A critique. *Environmental Education Research, 4*(3), 309-328.

Authors. (2018). Building environmental literacy in Florida through non-formal environmental education: Challenges and opportunities. *Florida Geographer, 50*, 1–20.

Authors. (2019). Parks, rhetoric and environmental education: Challenges and opportunities for enhancing ecoliteracy. *Journal of Outdoor and Environmental Education, 22*(1), 1-19.

Johnson, L. R. (2017). *Community-based qualitative research: Approaches for education and the social sciences*. Thousand Oaks, CA: Sage Publications.

Karanth, K. K., & Nepal, S. K. (2012). Local residents perception of benefits and losses from protected areas in India and Nepal. *Environmental Management, 49*(2), 372-386.

Karanth, K. K., Naughton-Treves, L., DeFries, R., & Gopalaswamy, A. M. (2013). Living with wildlife and mitigating conflicts around three Indian protected areas. *Environmental Management, 52*(6), 1320-1332.

Kopnina, H. (2014). Future scenarios and environmental education. *Journal of Environmental Education,* 45(4), 217-231.

Kulkarni, Ajit, (2019). Executive Director, Mysore Zoo. Personal interview, February 8.

Liefländer, A. K., Fröhlich, G., Bogner, F. X., & Schultz, P. W. (2013). Promoting connectedness with nature through environmental education. *Environmental Education Research, 19*(3), 370-384.

Lucas, A. M. (1979). *Environment and education: Conceptual issues and curriculum implications.* Melbourne: Australian International Press and Publications.

Lucas, A. M. (1980). The role of science education in education for the environment*.* *Journal of Environmental Education, 12*(2), 33-37.

Madhusudan, M. D. (2003). Living amidst large wildlife: Livestock and crop depredation by large mammals in the interior villages of Bhadra Tiger Reserve, South India. *Environmental Management, 31*(4), 466-475.

McKeown, R. & C. Hopkins. (2003). EE ≠ ESD: Defusing the worry. *Environmental Education Research, 9*(1), 117-128.

Menon, S. (2019). Senior Programme Director, CEE Pune/Urban Programmes. Personal interview, June 13, 2019.

Monroe, M. C., Andrews, E., & Biedenweg, K. (2008). A framework for environmental education strategies. *Applied Environmental Education & Communication, 6*(3-4).

205-216.

Myers Jr, O. E., Saunders, C. D., & Bexell, S. M. (2009). Fostering empathy with wildlife: Factors affecting free-choice learning for conservation concern and behavior. *Free-choice Learning and the Environment*, 39-56.

Mysore Zoo (n.d.). Retrieved from http://mysorezoo.info/html/about.php.

National Tiger Conservation Authority (2010). https://projecttiger.nic.in/

Ogra, M. (2009). Attitudes toward resolution of human–wildlife conflict among forest-dependent agriculturalists near Rajaji National Park, India. *Human Ecology, 37*(2), 161-177.

Palmer, J. (1998). *Environmental education for the 21st century: Theory, practice, progress and promise.* Routledge: New York.

Quay, J. (2016). Outdoor education and school curriculum distinctiveness: More than content, more than process. *Journal of Outdoor & Environmental Education, 19*(2), 42-50.

Ramadoss, A., & Poyya Moli, G. (2011). Biodiversity conservation through environmental education for sustainable development--A case study from Puducherry, India. *International Electronic Journal of Environmental Education, 1*(2). 97-111.

Ravindranath, M. J. (2007). Environmental education in teacher education in India: Experiences and challenges in the United Nation's Decade of Education for Sustainable Development. *Journal of Education for Teaching, 33*(2), 191-206.

Report of the United Nations Conference on the Human Environment. Stockholm. 1972. United Nations.

Robottom, I. (2007). Rebadged environmental education: Is ESD more than just a slogan?. *Southern African Journal of Environmental Education, 24*, 90-96.

Sauvé, L. (2005). Currents in environmental education: Mapping a complex and evolving pedagogical field. *Canadian Journal of Environmental Education, 10*(1), 11-37.

Schild, R. (2016). Environmental citizenship: What can political theory contribute to environmental education practice?. *The Journal of Environmental Education, 47*(1), 19-34.

Shove, E. (2010). Beyond the ABC: climate change policy and theories of social change. *Environment and Planning A, 42*(6), 1273-1285.

Srimathi, A. (2019). Education Officer, Madras Crocodile Bank and Trust. Personal Interview, March 5.

State of India's Environment (2019*). Centre for Science and Environment, New Delhi.*

Sutar, S. (2019). Director, CEE South. Personal interview, Bengaluru, India, March 9.

UNDP. (2018). India Diodiversity Awards, 2018. Retrieved from http://www.in.undp.org/content/india/en/home/climate-and-disaster-reslience/successstories/IBA2018.html

UNESCO- UNEP. (1976). UNESCO/UNEP International Environmental Education Programme (IEEP). *Yearbook of International Organizations.*

Uzzell, D. (2008). The challenge of climate change: the challenge for psychology. *43rd Australian Psychological Society Annual Conference*. Hobart, Tasmania

Citation:
Johns, R.A. & Pontes, R. (2019). Environmental education in India: Constructing environmental citizens through narratives of optimism. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 163-194). ISRES Publishing, ISBN:978-605-698540-9.

10 Challenges for a Future Environmental Education

Fernando Echarri
University of Navarra, Spain

Víctor Echarri
University of Alicante, Spain

Introduction

Environmental Education (EE) is conceived as a discipline that tries to give an educational response to the “environmental crisis” (De Blas, Herrero y Pardo, 1991, p.8). This discipline has developed, since its inception in the so-called Stockholm Conference in 1972 (Calvo and Gutiérrez, 2007, p.26), in its more than 40 years of existence, numerous plans, strategies and programs that have developed various actions aimed to restore an adequate person-nature relationship, which allows to overcome this environmental crisis, addressing the main environmental problems that threaten the planetary ecosystem equilibrium, in local and global levels. During these years it has sought to achieve the intentions for which it was born (Declaration of the United Nations Conference on the Human Environment, 1972). But reality, perhaps because it constitutes a dynamic and immensely complex field of study and interpretation (Palmer, 1998, p.8), the difficulty of fulfilling its objectives is clear, as revealed by Gigliotti (1990) or the White Paper of Environmental Education in Spain (CENEAM, 1999, p.9).

At this moment, the environmental situation is very different from that intended by the EA, perhaps because there are no definitive answers or infallible advice (Palmer, 1998, p.8). Or maybe because of the strange paradox that most people agree to live sustainably, but formal education programs do not prioritise this intention. It seems that a battle is established, more than the EE is at the heart of this education (Palmer, 1998, p.8).

Environmental problems do not decline, but progress. There are several dangers that continue to threaten the complex biological processes settled on our planet: the global neoliberal economic system, where “environmental rationality confronts the fatal strategies of globalisation” (Leff, 1996), unique thinking, individualism, lack of participation in the community, loss of values , loss of biodiversity and human diversity (Novo, 2003, 2006), increasing and invasive pollution. The current pressing dimension of the old and the emergence of new environmental problems, such as global warming, places us in a still worrying-scenario that generates a perception of immobility or even regression in the achievement of the objectives intended by the EE. This reality invites us to ask ourselves: Has all the work done during these years being useful for anything, all this effort, made by so many people? Are the objectives of the EE really being achieved? Are the environmental sensitivities produced by your programs potent and lasting?

Are behavioural changes and new environmentally appropriate habits occurring? Are pro-environmental values held in people? Is the meaning and importance of the link between person-nature understood?

Despite the numerous actions carried out by the EE, the ecological alarm continues to be active, highlighting the difficulties that Redclift (1987) was already making in the ecologically sustainable development model. The current reality is that the world is advancing inexorably in a destructive direction; it advances towards a consumer globalisation, where the culture of discarding prevails at ease, with a growth that seems to have no limits (Meadows, Randers and Behrens, 1972); moves towards a solely utilitarian vision of natural resources, moves towards an excessive urban polarisation, towards an abandonment of traditional agro-systems; moves towards a loss of values of biological and cultural diversity; it advances towards a growing dehumanisation of the natural, towards an insane global person-environment relationship (Riechmann, 2004).

Therefore, due to the evolution and new dimension that environmental problems, including obviously social ones (Novo, 2003), acquire today, there is a need to give a boost to the EE, even to look for new ways for an alternative EE (Tsevreni 2011).

This EE must incorporate a reflection that includes the main challenges that must be faced in the s. XXI to continue advancing in the achievement of its proposed objectives.

10 challenges for the EA of the future

EE, in order to help focus their intentions on the reality of the 21st century and with the idea of emphasising aspects proposed since the beginning of the EA (UNESCO UNEP, 1994), but perhaps not yet sufficiently developed (Gigliotti, 1990). The aim is to influence already known or innovative proposals (Guruceaga, 2001, p.15) that deepen the awareness processes, the meaning of the contents, the learning methods, and the implementation of mechanisms of pro-environmental action. Following the recommendation of (Palmer, 1998, p. 10) that invites in each country to analyse, review and propose ways of progress of the EE, it is intended to advance this intention with the following challenges of the EE for the future:

1. Learn to be
2. Values education: value care
3. Adress complexity
4. Appropriate sequence: “think-decide-solve”
5. From local to global
6. Participation

7. Action Research
8. Emotional intelligence development
9. Natural intelligence development
10. Ecological spiritual intelligence development

Learn to be

Approximately in the last forty years people have gradually included in our lives the culture of "*having*" and we have lost in a general way many of the values that sustained the culture of "being," which curiously was very supported by the values of the populations rural areas, which maintain a much closer link with the natural. This culture of having unfortunately leads to a mistreatment of the land, because we see it as a commodity that belongs to us (Leopold, 2005). The market has created a culture of unbridled consumption, much more intense in urban populations. The desire to possess affects us, the competition to see who "owns" more, the social valuation towards the one that has the most has spread in our western societies. This possessive vision helps in no small measure the propaganda, which creates us continuous needs. We, using our freedom, focus our attention on them, often occupying much of our time.

How different is this other approach: the approach of trying to "*be*," to grow to be, to be formed to be, to focus our lives towards building ourselves in the best possible way, to try to reach our human plenitude of what we can reach to be, to develop our capabilities to the maximum, for ourselves and for others. This approach is the right one, because only being really gives meaning to our life and initiates new paths that the culture of having cannot provide.

The dangers of *having* are many. This culture is not harmless to the environment. The incessant demand for products and the consequent and wasteful "culture of discarding" (Santa Sede, 2015) does not cause a zero environmental cost. On the contrary, what causes is a continuous deterioration of the environment, a damage in the form of environmental impact that often reaches irreparable dimensions.

This aspect is not trivial. Novo (2003) includes it as one of the conceptual bases of the EE. Also Delors (1996) has included it as one of the four pillars that support education for the 21st century. *Learning to be* includes reconsidering the way we relate to the environment and the link we establish with it (Leopold, 2005). It is not necessary to delve more into the importance of this concept, but to emphasise that it can be key to the significant decrease in the footprint that each of us causes to the environment and in the way we understand our relationship with nature.

Learning to be (Delors, 1996) means, among other aspects, working to improve aspects that involve the development of multiple intelligences (Gardner, 2010) such as self-knowledge (intrapersonal intelligence), self-esteem, emotional intelligence (Goleman, 1996), adaptation, social skills (interpersonal intelligence), the relationship with the environment (natural and spiritual intelligence), the acquisition of values. Pope Francis believes that "buying is always a moral act and not just an economic one" (Holy See, p.64) and that we have to grow up with "sobriety" and not "be saddened by what we do not possess," since "You can need little and live long" (Holy See, page 68).

Values Education: Value Care

Directly related to learning to be, it is necessary to build an ethic that makes us relate adequately to the Earth, but this is not easy with today's lifestyles. Leopold (2005, p. 154) describes this difficulty well:

> The most serious obstacle that prevents the development of an ethic of the earth may be the fact that our educational and economic system has turned its back on a genuine awareness of the earth, instead of heading towards it. Modern man is separated from the earth by many intermediaries, and by innumerable contraptions. He does not have a vital relationship with her.

Therefore, education in values can be one of the pending subjects of the EE. Already in the publication "Trends in environmental education since the Tbilisi Conference" it was noted that:

> (...) The content of environmental education programs has turned too much around theoretical cognitive elements; the affective (values, attitudes) and technical problems still occupy a very small space, even marginal, in the contemporary practice of this education. (UNESCO UNEP, 1994, p.21)

This is a difficult, complicated challenge (Subirats, 1999, p.177), for many reasons, including because the values are long-term. Also, exactly what values do we have to promote? Although there are lists of the values that the EE proposes to promote (Caduto, 1992), we could say that the basic value that many others of the proposed ones disseminate is respect value (Carreras et al., 2003, page 199). Respect is the basis of many other values such as solidarity (respect for the needs of others) or responsibility (respect, not to what I want, but to what has to be done), but above all, when together with love, it gives rise to value "care", which goes beyond respect. Care value is key to EE because it implies a commitment, a concern, a responsibility with love towards what is cared.

How can we educate in values, for example in a key value such as care? Values are shaped as concrete attitudes are put into practice in a situation. In turn, putting concrete attitudes into practice helps reaffirm and shape that value. In addition, the value will allow its generalisation in other situations, putting into practice specific careful attitudes in different situations. That is why the conformation of a value system takes time. It occurs throughout the life of people and is associated with several contexts, such as family, school and social.

Perhaps it is the difficulty of designing specific programs of education in environmental values (EEV) (Caduto, 1992) and its character of long-term conformation, some of the reasons that have left a long way to go in this field. However, the education of values is fundamental because they intervene directly in our decision-making, trigger our actions that put into practice attitudes, which, by repetition, can shape our habits: "When attitudes become easy to execute we have a habit . (Carreras et al., 2003, p. 22). That is why the EE has the challenge of providing an education in environmental values that trigger pro-environmental behaviors that, once shaped into habits, favor an adequate person-environment relationship.

For example, if someone decides to turn off the light, it is because in their value system the value of respect for the environment and also the value of respect for others can be present. By turning off the light, that attitude helps to reaffirm the respect value in our value system. This more reaffirmed value will make it more likely that I turn off the light at other times, to create a habit, or to generalise respect in other situations, for example not lighting a fire when I go to the field because I can destroy the environment of people.

Discovering the values that intervene in our daily actions, for example through the value clarification methodology (Caduto, 1992), is a convenient exercise to discover the values that are behind our actions, so we make sense of them and we can improve the coherence of our acts. (Gutiérrez 1995, p. 153).

The reality is that it is not common to find these education programs in environmental values (EVA). However, this is a key purpose. Perhaps we have focused a lot on environmental programs focused on the concepts of environmental problems: knowing the species, the consequences of pollution, and obviously, this is necessary. But perhaps it is necessary to undertake in a more specific way the design of EVA programs. Specifically, the design of EVA programs that promote respect value.

Address Complexity

The environment is a complex system, more when considered at a planetary level. Complexity is an ecosystem characteristic that, in general, constitutes a measure of its maturity. The number of biotic and abiotic elements that an ecosystem includes and the multiple relationships that they include make complexity. Addressing complexity in the EE is a key aspect to understand that everything is related to the environment and that in the face of an environmental problem there are no simple solutions, but when there is an environmental mismatch that we can describe as damage or problem, solutions are also complex and usually require multidisciplinary actions. This is explicitly stated already from the Tbilisi Conference, where it is recommended:

> (...) that individuals and collectivities understand the complex nature of the natural and man-made environment resulting from the interaction of their biological, physical, social, economic and cultural aspects and acquire the knowledge, values, behaviors and practical skills to participate responsibly and effectively in the prevention and solution of environmental problems and in the management of the issue of the quality of the environment. (Intergovernmental Conference on Environmental Education, Tbilisi, USSR, Final Report, 1977, p.28)

It is about breaking with the idea that in front of a mechanism of environmental aggression there is a simple solution that "repairs" the damage. In no way is this the case. The solutions to environmental problems are also complex, as complex are the mechanisms that regulate the resilience of these ecosystems.

Obviously, due to the complexity, the precautionary principle should prevail in human performance. It is better not to touch what we do not know. It is not simple, but complex, to recover the initial situation or to minimize the damage. Better to know the complexity and then plan the actions in the middle, foreseeing their consequences.

Educating in the convenience of knowing the complexity is fundamental, among other things to be aware of this difficulty of "fixing" the imbalances that people are causing. It means knowing the importance of the environmental problems we cause, in all its multidimensionality. It means using a syncretic vision of reality. Humanity, in its eagerness to know everything and to control everything, still feels very far from being able to interpret the numerous and intricate relational processes that intervene both in the ecosystem life and in the intricate mechanisms of its regulation in the face of changes. We could consider, in the words of the Argentine genius, that "... the machine of the world is very complex for the simplicity of men" (Borges, 1960, p.185)

This is a paradox. The EE is facing a challenge here because it is not easy to explain and educate in something that we still do not understand in depth, such as complexity. This is a difficult concept to communicate for all ages, especially children. However, not introducing this content in environmental programs can favor a simplistic view of solutions to environmental problems and, therefore, not consider them in their entirety.

So we can find ourselves facing a situation of "whiffs that bite the tail": We have environmental problems. These problems are also addressed through educational measures, through EE programs. The concept of "complexity" is not included in EE programs. Therefore, we do not teach in complexity because it is still very unknown, difficult to understand and to explain, to teach and to learn. That is why people do not understand the value of complexity and its importance in the repercussions of environmental problems and their solutions. And that's why it's easier to continue causing environmental problems.

Education in complexity includes educating in a preventive vision, using syncretic methodologies and applying the precautionary principle before performing any significant action in the medium. To help educate in this idea we may use examples of not having contemplated the complexity of the environment. For example, the introduction of an allochthonous species such as the rabbit in Australia generated many other environmental problems. In these cases the complexity of that ecosystem was not foreseen, breaking the ecological balance between the species that made it up.

Appropriate Sequence:"Think-Decide-Solve"

Learn to Think

For EE, it is convenient for people to encourage competition to learn to think, formulated also as a critical spirit (Giordan, 1993), since they can be freer, less manipulable and can better understand the transcendence and consequences of their actions and causes of environmental problems and their possible solutions. This competence to learn to think is conceptualized as a key aspect in EE (Giordan, 1993; Novo, 2003), but its explicit programming in EE programs is infrequent. We are again faced with a programmatic difficulty. Programming actions and methodologies to develop competence learning to think is not easy. This competence is not explicit as a key competence in regulated education systems, although it can appear transversely in many educational instructions. The recommendation is to design specific programs that formulate the objective of developing this competence through specific activities. The challenge is to design educational instructions that develop aptitudes for obtaining truthful and reliable information, in order to analyze it, synthesize it and draw conclusions. It is intended that people adopt a critical attitude to encourage a precise analysis and an appropriate ordering of the different factors that intervene in each situation. We can mention here the correspondence of learning to think (McGuinness, 2012) with the learning to know proposed by Delors (1996) that includes cognitive skills such as being critical, informing oneself, interpreting, self-learning and creating knowledge.

Decision Making

Directly related to the previous point, this challenge is another of the key aspects of EE conceptualized at its inception (Giordan, 1993). But decision-making remains a pending issue in many environmental programs, mainly focused on environmental conceptual content, awareness raising through experiential education, but which do not end with a free decision-making exercise. The challenge is to include this decision competence in the EE programs, exercising and training this competence, integrating values such as respect and responsibility, together with the already exposed competence to learn to think. That is, the competition to learn to think should conclude with an appropriate decision-making process.

Problem Solving

The problem-solving is considered a key aspect since the beginning of the EA in the Tbilisi Conference. There, it is argued that EE should guide individuals towards solving problems "(...) through a global approach, based on ethics, rooted in a broad interdisciplinary base" (Novo, 2003, p.47). Reality, however, shows us that there is much left to advance in this "resolutive" ability. Normally it is advisable to program instructions that include methodologies of "role playing" in simulation games (Taylor, 1993), where it empathises with the different points of view of the various agents that appear in front of an environmental problem. In problem-solving (Camino and Calcagno, 1995), communication strategies, group dynamics techniques, emotional intelligence, creativity, truthful information management, etc., are put into play. The dynamic finally leads to the proposal of adequate solutions that take into account the multifactorial and complexity presented by environmental problems. To solve well you have to know well, think well and make correct decisions. The "think-decide" process is continued, ending the "think-decide-solve" cycle. It is this three-factorial educational process that can prepare the citizen to become an agent of change, active and participatory, of the environmental problems that occur in his community. This trinomial may correspond to another of the pillars that Delors (1996) proposes for 21st century education: "learning to do".

From Local to Global

Most people live in a specific place, so they usually live, develop their activity, in a specific community and space. This local dimension means that we can lose sight of the fact that many environmental problems are caused by the addition of local impacting actions (for example, water pollution, global warming). In these cases, the problems acquire a global dimension. That is why the environmental effects (both positive and negative) of our actions must be considered both at the local and global scales. And that is not easy, it requires a global perspective mind.

In order to achieve a global perspective, it is convenient to promote networking, to "get involved" with other proposals and improvements made in other geographical places that make us open our minds and focus our environmental improvement objectives both locally and globally. Seeing that our daily pro-environmental actions can favor the environment of our place, but also that of many other places can be a motivating factor, a reinforcement to be able to build personal habits that contain a background of global, planetary mentality. This promotes the acquisition of a holistic, global, planetary vision that favors the idea of a global village and the personal consideration of the world's citizen.

Already in the field of formal education, it is proposed that the perspective of environmental issues be worked from several scales, promoting local knowledge and universal knowledge: "(...) examine the main issues of the environment from a local perspective , regional, national and international, so that students can know the environmental conditions existing in other geographical areas. "(Glasgow, Robinson and Jacobson, 1995, p.17)

Participation

Despite the great advances that have been observed in recent years, participation remains one of the great challenges for the resolution of environmental problems:

> We have made little progress, if we think how far we still are from a society in which people actively participate in the solution and prevention of problems. However, the path traveled and the critical reflection are the best basis for future constructions. (CENEAM, 1999, p 4)

The cases of politicians and technicians who make decisions without counting the community, environmental conflicts resolved unilaterally or without taking into account all the people and agents involved are still a lot. Non-consensual solutions do not help meet the objectives of the EE or solve, especially in a long-term vision, the specific environmental problems at the local level. Participation means being serious with everyone, putting yourself in the shoes of others, understanding all the interests and needs that come into play in an action or environmental problem, taking them into account, so that among all of us we can find the best environmental management. Obviously, we are very far from this situation. Participation is related to learning to live in community, which includes skills and values such as: communication, respect, sociability, cooperation and solidarity. Participation is also educated (Ferreira and Davis, 2012) and it is convenient to include this competence among the intentions of EE programs, since it constitutes another of the pillars of 21st century education, formulated as "learning to live together" (Delors, 1996).

Action Research

Further progress should be made in this methodology, conceptualised as adequate for

EE (Giordan, 1993). The scientific method will help to know the scientific basis that intervenes in environmental problems and will provide accurate information about the specific problem. It is with this information that decisions must be made that generate concrete actions that help to restore or correct an environmental problem or, at least, minimise the environmental impacts generated. But in turn, we must not forget to include other forms of knowledge, especially humanistic, which do not use the scientific method, but other methodologies and which may be equally valid.

Emotional Intelligence Development

Emotions intervene directly in learning (Novak, 1978; Gowin, 1981), integrated in the trinomial "feeling, thought and action," making them more significant. That is why the emotional world is an aspect that plays a decisive role in environmental awareness, favoring the acquisition of pro-environmental behaviours and commitments. The development of people's emotional intelligence (Goleman, 1996) can be a determining factor in the need to achieve a more powerful and integral environmental awareness (Tsevreni, 2011).

Among the possible emotions, we want to highlight here the fear. Fear, generated by the catastrophic vision of environmental problems, is a widely used emotion and is usually spread by the media when dealing with environmental issues, possibly because generating fears and alarms can generate more audience. But fear is not convenient because it can cause us to lower our arms against the magnitude of environmental problems, which gives us a feeling that we cannot do anything in front of them. This sterile catastrophism (Morduchowicz, 2001) can contribute so that we do not react to environmental problems. That is why it is convenient to study the reality of environmental problems well, in its just dimension, promoting what each person can do to contribute to their solution.

Natural Intelligence Development

The EE aims for a comprehensive education of people. That is why it must include in its programs education in all types of intelligence proposed by the theory of multiple intelligences formulated by Gardner (2010). Many educational centers are currently incorporating the challenge of educating in the development of multiple intelligences. Among them, more specifically in EE, education in the so-called natural intelligence is convenient. This intelligence tries to foment the capacity of the person to relate and to know the natural environment. That is why it is a challenge for the EE to design specific educational instructions that aim to develop this intelligence. With its promotion, the knowledge of the environment and the person-nature relationship is made possible.

Ecological Spiritual Intelligence Development

As has been mentioned, the EE proposes the integral development of people, and does so by taking into account the holistic and interdisciplinary nature (Giordan, 1993) that presents reality. However, the inclusion of the spiritual dimension of people in this integral education is infrequent. Despite this reality, Gardner (2010) shows us the existence of a transcendent intelligence in his renewed theory of multiple intelligences. Other authors (Wolman, 2001, Torralba, 2011, Castro, 2012) call it spiritual intelligence. Wolman (2001, p.1) defines it as: "the human capacity to ask about the ultimate questions of the meaning of life and the simultaneous experience of the complete connection between each one of us and the world in which we live" (translation) de Castro, 2012, p.29). Pope Francis in his Encyclical Laudato si 'speaks of "ecological spirituality, for what could be more specifically called ecological spiritual intelligence.

Despite the advantages that this type of intelligence can provide (Keniger, Gaston, Irvine and Fuller, 2013, Kollmus and Agyeman, 2002), the values of neoliberalism and materialism / prevailing consumerism, do not favor the development of this type of intelligence, rather on the contrary, leading Occident into a spiritual desert. However, spiritual values have much to do with the conservation of nature (Mallarach, 2008). In general, areas of the planet that have preserved spiritual values have a better preserved environment. However, authors such as Keniger et al. (2013) recognize the scarcity of studies related to the nature-spirituality binomial (around 5% of the total of studies carried out on nature).

Spiritual intelligence can help in the environmental awareness of people in a powerful and lasting way, favoring the acquisition of environmental commitments, as occurs with environmental epiphanies (Vining and Merrick, 2012), which can be considered as a type of Significant life experiences (SLE) (Chawla, 1999; 2001, Tanner, 1980). These experiences, with a spiritual component, can provide a qualitative change that advances the EE in the achievement of its conservation and humanistic objectives. Aims, as proposed by Palmer (1998, p. 10).

Ecological spiritual intelligence can also influence the understanding and experience of the link between the person and nature (Abram, 1996, 2010, Barnhardt and Kawagley, 2010, Clayton and Myers, 2015, Williams ang Harvey, 2001). Design specific EE programs with concrete actions, the creation of EE facilities as centers of environmental meditation or centers of ecological spirituality that favor the contemplation of nature, renewing our sense of wonder (Carson, 1956, p.145) in the face of beauty and continuous wonder that nature presents us at every moment, can favor the valuation and conservation of our beloved environment. "We only become ethical in relation to something we can see, feel, understand, love, something in which we have faith in some way".

Conclusions

The EE of the 21st century must advance in the improvement of its educational strategies, focusing on the aspects that may be relevant in the fulfilment of its objectives. The 10 challenges presented intend to help to undertake this task.

To achieve the objectives of the EE it is convenient to influence the promotion of the culture of "being" as opposed to "having," promoting a life project based on the knowledge of the functioning of nature and the actions that can degrade it. A life project that conforms to a code of ethics, according to Leopold's criteria (2005, p.145): "We only become ethical in relation to something we can see, feel, understand, love, something we have faith in, somehow". Care value is configured as a key value for the conservation of the environment.

The challenges presented are intended to promote decision-making based on the truthful knowledge of environmental problems and natural dynamics, without using a catastrophic vision, carried out in a manner consistent with our value system (made up of environmental values). Decision-making that helps solve environmental problems in our community, integrating a local and global perspective and encouraging our participation and that of all the agents involved in the community.

The EE must promote the integral education of people, which includes an interdisciplinary vision of reality, including the emotional world. The more we educate in the complexity of reality, including the attitudinal, axiological and emotional contents that it presents, the more faithful we will be in understanding the world and intuiting the true dimension and repercussions of the environmental problems that people generate.

We cannot remain only in the utilitarian vision with nature. We cannot think only of nature as a resource to our service. It would be too reductionist, too poor. Nature and our relationship with her is much more than that. The development of intelligences that intervene directly in environmental conservation, such as natural intelligence and spiritual intelligence can help us to better understand that person-nature bond. Advancing the understanding of this link can help in achieving the objectives of the EE.

References

Abram, d. (1996). *The spell of the sensuous: perception and language in a more-than-human world*. New York: Vintage books.

Abram, d. (2010). *B*ecoming animal: an earthly cosmology. New York: Pantheon books.

Barnhardt, R., and Kawagley, O. (2010). *Alaska native education: views from within*. Fairbanks. Ak: University of Alaska press.

Borges, J. L. (2001). *Obras completas. 1952-1972. Vol. II*. Barcelona: Emecé Editores.

Caduto, M. (1992). *A Guide on Environmental Values Education,* Madrid: Libros de la Catarata (Environmental Education Series No. 13 of the Unesco-UNEP International Environmental Education Programme).

Calvo, S. y Gutiérrez, J. (2007). *El espejismo de la Educación Ambiental*. Madrid: Morata.

Camino, E. y Calcagno, C. (1995). An Interactive Methodology for 'Empowering' Students to Deal with Controversial Environmental Problems. *Environmental Education Research*, 1 (1), 59-74.

Carson, R. L. (2012). *El sentido del asombro*. Madrid: Ediciones Encuentro. (1ª ed. 1956).

Carreras, LL., Eijo, P., Estany, A., Gómez, Mª. T., Guich, R., Mir, V., Ojeda, F., Planas, T. y Serrats, Mª. G. (2003). *Cómo educar en valores*. Madrid: Narcea.

Castro, J. M.. (2012). *Aproximación a la inteligencia espiritual*. Gran Canaria: ISTIC Instituto superior de teología de las Islas Canarias-Sede Gran Canaria.

CENEAM. (1999). *El libro blanco de la educación ambiental en España*. Madrid: Ministerio de Medio Ambiente. http://www.magrama.gob.es/es/ceneam/recursos/documentos/blanco_tcm7-13510.pdf.

Chawla, L. (1999). Life paths into effective environmental action. *The Journal of Environmental Education,* 31 (1), 15–26.

Chawla, L. (2001). Significant Life Experiences Revisited Once Again: response to Vol. 5(4) 'Five Critical Commentaries on Significant Life Experience Research in Environmental Education'. *Environmental Education Research,* 7 (4), 451-461. 2001doi: 10.1080/13504620120081313.

Conferencia Intergubernamental sobre Educación Ambiental. Tbilisi (URSS). (1977). *Informe final*. http://unesdoc.unesco.org/ulis/cgi-bin/ExtractPDF.pl?catno=32763&look=default&ll=1&display=1&lang=sb&from=1&to=110.

De Blas, P., Herrero, C., y Pardo, A. (1991). *Respuesta educativa a la crisis ambiental*. Madrid: CIDE.

Declaration of the United Nations Conference on the Human Environment. (1972). http://www.unep.org/Documents.Multilingual/Default asp?DocumentID=97&ArticleID=1503&l=en.

Delors, J. (1996.). *Los cuatro pilares de la educación.* En: *La educación encierra* *un tesoro. Informe a la UNESCO de la Comisión internacional sobre la educación para el siglo XXI*. Madrid: Santillana/UNESCO. http://uom.uib.cat/digitalAssets/221/221918_9.pdf

Ferreira, J. A. y Davis, J. (2012). Problematizing the processes of participation in networks: working through the rhetoric. *Environmental Education Research*, 18 (5), 687-697.

Gardner, H. (2010). *La inteligencia reformulada.* Las *inteligencias múltiples en el siglo XXI*. Madrid: Paidós. (1ª ed. 2001).

Gigliotti, L. M. (1990). Environmental Education: What Went Wrong? What can be Done? *The Journal of Environmental Education,* 22 (1), 9-12.

DOI: 10.1080/00958964.1990.9943040

Giordan, A. (Coord.) (1993). Educación ambiental: principios de enseñanza y aprendizaje. (Serie de Educación Ambiental nº. 20, del Programa Internacional de Educación Ambiental UNESCOPNUMA). Bilbao: Libros de la Catarata.

Glasgow, J., Robinson, P. y Jacobson, W. J. (1995). *Programa de introducción a la educación ambiental para maestros e inspectores de Enseñanza Primaria*. (Serie Educación Ambiental, nº. 5 del Programa Internacional de Educación Ambiental UNESCOPNUMA). Madrid: Libros de la Catarata.

Goleman, D. (1996). *Inteligencia emocional*. Barcelona: Editorial Kairós,

Gowin, D. B. (1981). *Educating.* Ithaca (New.York): Cornell University Press.

Guruceaga, A. (2001). *Aprendizaje significativo y educación ambiental*. Tesis doctoral (Resumen en castellano). Pamplona: Universidad Pública de Navarra.

Gutiérrez, J. (1995). *La educación ambiental. Fundamentos teóricos, propuestas de transversalidad y orientaciones extracurriculares*. Madrid: La Muralla.

Keniger, L.E., K. J. Gaston, Irvine, K. N. y Fuller R. A. (2013). What are the benefits of interacting with nature?. *International Journal of Environmental Research and Public Health,* 10, 913-935. doi:10.3390/ijerph10030913.

Kollmuss, A. y Agyeman, J. (2002). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior?. *Environmental Education Research,* 8 (3), 239-260. doi.org/10.1080/13504620220145401.

Leff, E. (1996). La insoportable levedad de la globalización: la capitalización de la naturaleza y las estrategias fatales de la sustentabilidad. Foro de Economía Política-Tendencias.

Leopold, A. (2005). Una ética de la tierra. Madrid: Los libros de la catarata. (1ª ed. 1949).

Mallarach, J. Mª. (Coord.). (2008). *Valores Culturales y Espirituales de los Paisajes Protegidos.* Volumen 2 de la serie Valores de los Paisajes Terrestres y Marinos Protegidos. Sant Joan les Fonts: UICN, GTZ y Obra Social de Caixa Catalunya,.

McGuinness, C. (2012). The 1996 PSl Lecture Teaching Thinking: Learning to Think-Thinking to Learn. *Irish Journal of Psychology*, 17 (1), 1-12. doi: 10.1080/03033910.1996.10558082

Meadows, D., Randers, J. y Behrens, W. (1972). *Los límites del crecimiento*. Informe del Club de Roma sobre el predicamento de la humanidad. México: Fondo de Cultura económica.

Morduchowicz, R. (2001). Los medios de comunicación y la educación: un binomio posible. *Revista Iberoamericana de educación*, 26, 97-118.

Novak, J. D. (1978). *A Theory of Educaction as a Basis for Environmental Education*. En T. S. Bakshi, y Z. Naveh, (Eds.), *Environmental education, principles, methods and applications*. (pp. 129–138). New York and London: Plenum press.

Novo, Mª. (2003). *La educación ambiental. Bases éticas, conceptuales y metodológicas*, Madrid: UNESCO Universitas.

Novo, Mª. (2006). *El desarrollo sostenible. Su dimensión ambiental y educativa*. Madrid: Pearson educación.

Palmer, J. A. (1998). Environmental education in the 21st century: Theory, practice, progress and promise. London, England: Routledge.

Redclift, M. (1987). *Sustainable Development. Exploring the Contradíctions*. Londres: Routledge.

Riechmann, J. 2004. *Gente que no quiere viajar a Marte. Ensayos sobre ecología, ética y autolimitación*. Madrid: los libros de la catarata.

Santa Sede. (2015). *Carta Encíclica Laudato si' del Santo Padre Francisco sobre el cuidado de la casa común*. http://w2.vatican.va/content/francesco/es/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.pdf

Tanner, T. (1980). Significant life experiences: a new research area in environmental education. *Journal of Environmental Education,* 11 (4), 20-24.

Torralba, F. (2011). *Inteligencia espiritual*. Barcelona: Plataforma editorial.

Tsevreni, I. (2011). Towards an environmental education without scientific knowledge: an attempt to create an action model based on children's experiences, emotions and perceptions about their environment», *Environmental Education Research* 17 (1), 53-67. doi:10.1080/13504621003637029.

UNESCOPNUMA. (1994). *Tendencias de la educación ambiental a partir de la conferencia de Tbilisi*. (Serie de Educación Ambiental nº. 1, del Programa Internacional de Educación Ambiental UNESCOPNUMA). Bilbao: Libros de la Catarata.

Vining, J. y M. S. Merrick. (2012). Environmental Epiphanies: Theoretical Foundations and Practical Applications. En S. D. Clayton, (Ed.), *The Oxford Handbook of Environmental and Conservation Psychology,* (pp. 485-508). New York: Oxford University Press. doi:10.1093/oxfordhb/9780199733026.001.0001.

Williams, K. y Harvey, D. (2001). Transcendent experience in forest environments. *Journal of Environmental Psychology,* 21 (2001), 249–260.

Wolman, R. (2001). *Thinking with your soul. Spiritual intelligence and why it matters*. New York: Harmony books.

Citation:
Echarri, F. & Echarri, V. (2019). 10 challenges for a future environmental education. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 195-210). ISRES Publishing, ISBN:978-605-698540-9.

An Analysis of the Impact of Forest School Provision on Early Years Foundation Stage Outcomes Using CASEY

Graham Arnold
Cambridgeshire County Council, United Kingdom

Sara Knight
Cambridgeshire County Council, United Kingdom

Introduction

In 2016 Cambridgeshire County Council's Early Years and Childcare Team formed a multi-agency steering group to promote the further development of Forest School provision in the county. This initiative was to enable a continuation of the work already done by the team, and in particular by the lead advisor for Forest School, Heather Jebb, and her predecessor, in the face of cuts to public spending. The steering group includes head teachers from primary schools across the county, teachers, early years and childcare practitioners, forest school leaders, local authority employees and Sara Knight, co-author of this paper and a well-known expert and author about Forest School. In the first year we undertook a series of consultation events with schools and settings. From this we formed the 'Cambridgeshire Forest School vision' which is that all children in early years and primary education settings should have access to Forest School provision. The group meets on a termly basis and has set up working sub-groups to look at specific strands of work, one of which is the research sub-group, committed to investigating the validity of our intuitions, namely that this vision will be of benefit to the children and future of Cambridgeshire.

This paper presents the findings from our initial analysis of such data that we could easily access and with due regard for the ethics of confidentiality. We intend to use this to direct our development of larger studies. We are fortunate to have attracted the interest of Dr Janine Coates and Dr Helena Pimlott-Wilson from Loughborough University to help us with our next steps. Their recent paper (Coates & Pimlott-Wilson, 2018) drew to our attention their work in this area.

To start, we will consider the constituent elements of the paper; what is Forest School, what is CASEY, what is the Early Years Foundation Stage and why are they all useful in this context.

Forest School

Forest School has been delivered in the UK for over twenty years, spreading inexorably since the mid-1990s. The history of the movement is accessible on the website of the Forest School Association (Cree & McCree, 2014). In Knight 2016, I argued that Forest School exemplifies ways of being in and with nature that are essential for the health of the individual, society and the planet. In the UK, as elsewhere in the developed world, the strains of modern life are having deleterious effects on the health and well-being of many people. Forest School offers benefits that all can access, and at all ages.

The largest group participating in Forest School in the UK is often thought to be the preschool sector, where the roots of Forest School lie. However, it is clear that it is the 4–7-year-olds in primary schools who make up the largest group participating in Forest School sessions (Knight, 2016:3). Forest School is not the only way to get outside but the unique combination of the six principles ensure that it holds unique benefits for participants:

- FS is a long-term process of regular sessions, rather than a one-off or infrequent visits; the cycle of planning, observation, adaptation and review links each session.
- FS takes place in a woodland or natural environment to support the development of a relationship between the learner and the natural world.
- FS uses a range of learner-centred processes to create a community for being, development and learning.
- FS aims to promote the holistic development of all those involved, fostering resilient, confident, independent and creative learners.
- FS offers learners the opportunity to take supported risks appropriate to the environment and to themselves.
- FS is run by qualified Forest School practitioners who continuously maintain and develop their professional practice. (FSA 2012)

The most obvious reasons for providing regular and protracted outdoor learning opportunities are the physical ones. Increased opportunities for fresh air and for vigorous outdoor exercise stimulate increases in bone and muscle development. More physical reasons to establish habits of going outside include the rise across the wealthier nations of childhood obesity. Figures from the Health Survey for England (HSE) for 2013 revealed that among children aged 2–15, 16 per cent of boys and 15 per cent of girls were classed as obese, and 14 per cent of both boys and girls were classed as overweight. Overall, 30 per cent of boys and 29 per cent of girls were classed as either overweight or obese (Boodhna, 2013). Undoubtedly, this is a major national concern as an obese child is at double the risk of becoming an overweight or obese adult.

However, the earliest research outcomes from the beginning of the century (Murray and O'Brien, 2005) showed clear benefits to children in the areas of confidence, social skills, language and communication, and motivation and concentration. This reflects findings in the Northern European countries where nature preschools are more common, although even here there is a need for more research evidence (Lysklett, 2017: 250). In these countries children do not start school education at such a young age as in England, the emphasis being on developing strong social and emotional foundations before the pressures of formal education start.

The regularity of Forest School sessions in crucial. Establishing habits of exercise and being in the fresh air are achieved by *being* active and *being* outside on a regular basis. As I have stated before (Knight, 2013: 19), neural pathways are established in the brain in response to activity and the myelinisation of those pathways – the process that makes that activity a part of the child's way of being – occurs in response to repetitions of that activity. Being outside regularly and being free to stretch and grow makes a child *want* to be outside regularly and be free to stretch and grow. It is much easier to create these healthy ways of being while the brain is young and plastic.

Risk taking is an important element of Forest School. In 2003, Jennie Lindon warned of the dangers from over-protection in the preschool years (Lindon, 2003: 10), and suggested that children need to take age-appropriate risks in order to learn to stay safe. Gill (2007) followed this up by focusing on the same issues around the needs of school-aged children. He considered the demise of adventure playgrounds in inner cities during the 1970s and 1980s, and asked us to consider what this says about our attitudes to children. Are they 'fragile, incompetent, accident-prone, unable to deal with adversity and incapable of learning how to look after themselves' (ibid.: 38)? In Forest School, the attitude is one of mutual trust and shared learning, which is why tool use and fire lighting are common activities, regardless of the ages of the children.

Casey

CASEY is a shared computer system which helps early years settings in Cambridgeshire to manage their information on children's progress. The Early Years Service has developed the system with Sentinel Partners Limited, and with input from providers, to draw together information on children's development and progress, and facilitate information sharing between settings and the local authority. Whilst it relates to the Early Years Foundation Stage, its scope is wider and it is offered to private, voluntary and independent (PVI) settings as well as local authority maintained early years settings in schools. A secure online portal is pre-populated with details of settings and funded children. Other features enable non-funded children to be added, and a specially designed dashboard automatically summarises children's data. Reports in the system enable the progress of key target groups to be measured against their peers. There is ***no charge*** for access for one user per setting.

The CASEY screens provide settings with the ability to maintain details for all the children at their setting (referred to as the Child register), as well as enter specific information for each child. Managers / owners of more than one setting can track data for each specific setting within a single view. Assessment schedules can be set up for all children, with tabs for both Early Years Foundation Stage (EYFS) and Every Child a Talker (ECaT) options. Children are scored according to whether their level of development is 'emerging' (the child is just developing in this area), developing (the expected stage of development at this age) and secure (exceeds the expectation for this age). This differs in nomenclature slightly from the EYFS, see below. To ensure data security there is a dual factor authentication system as well as the standard password protection. Parents and settings also agree the level at which their child's data can be shared. There are three options:

1. Detail anonymised: Data for this child, such as level of development, and progress, will be included in data visible to the local authority. However, the child's name and address will be suppressed.

2. Setting level: Individual data for this child will not be shared with the local authority. However, it will be included in aggregate data for the setting.

3. Full: Data for this child may be shared in full with the local authority in support of its statutory duties. The child's name and address will be visible alongside their assessments, level of development and progress.

This conforms to the County policy: Cambridgeshire Information Sharing Framework (http://www.cambridgeshire.gov.uk/info/20044/data_protection_and_foi/148/information_and_data_sharing/3)

The data can then be analysed by the settings using a range of attributes and parameters. It can also be used by the County Council, suitably anonymised and with access restricted by the senior team, for research tasks such as described in this paper. More information can be found at https://www.cambslearntogether.co.uk/early-years/business-support/cambridgeshire-assessment-system-for-early-years-casey/

Figure 1 is a screen shot of the page where settings can record their EYFS assessments and more, as can be seen. This record then forms part of the data that can be interrogated.

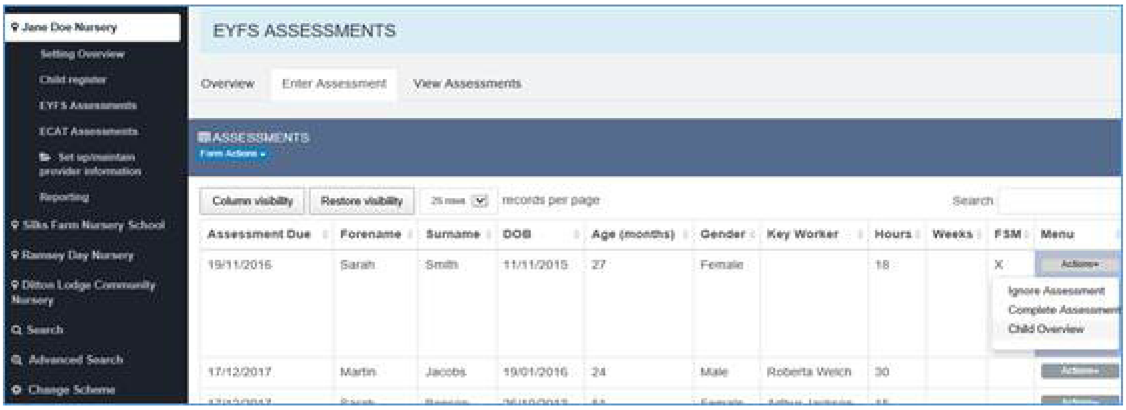


Figure 1. CASEY Page for EYFS Assessment Recording

Early Years Foundation Stage

All early years settings in England are required to follow the Foundation Stage framework as a condition of their registration with the Government. This includes): maintained schools; non-maintained schools; independent schools (including free schools and academies); all providers on the Early Years Register; and all providers registered with an early years childminder agency (CMA). It provides the standards by which Ofsted (the Office for Standards in Education, Children's Services and Skills, https://www.gov.uk/government/organisations/ofsted) frame their inspections, and the assessments at the end of the Foundation Stage are used to inform the teachers who will lead them into formal schooling.

The Statutory Framework for the Early Years Foundation Stage 2017 (Department for Education, 2017) identifies seven areas of learning and development that settings must encourage. They state that three areas are crucial building blocks for future learning, namely communication and language; physical development; and personal, social and emotional development (PSED). These broadly match to the 'dispositions to learning' identified by Guy Claxton (2013), namely Reciprocity (interdependence, collaboration, empathy and listening, imitation), Reflectiveness (meta-learning, planning, distilling, revising) Resourcefulness (making links, questioning, capitalizing, imagining, reasoning) and Resilience (perseverance, managing distractions, absorption, noticing). These are the skills that make for happy and successful learners at any age.

Settings are required, alongside their continuous assessment and monitoring of the children in their care, to review their progress when the children are between two and three and provide parents and carers with a short written summary of the child's development in the prime areas. In the final term of the year in which the child reaches the age of five they must complete an EYFS Profile that will provide parents, carers and the Year 1 teachers they will progress to with a snapshot of their readiness for starting their formal school career. Children are scored according to whether their overall level of development is 'emerging' (the child is just developing in this area; this is the same as CASEY), or the child is at the expected stage of development at this age (described by CASEY as developing) or they exceed the expectation for this age (described by CASEY as secure).

Our Proposed Data Review

With this useful data set available to the Cambridgeshire County Council's Early Years and Childcare Team, it provides an invaluable resource for the initial investigations reported below. As stated above, the aim was to use this study to direct our development of larger future research projects. We wanted to see if Forest School provision was having an effect on the assessment scores for preschool children in the county. We focused on PSED as previous studies (Knight 2013: 42-49, 118-124) had indicated that the effects were most marked in this area.

Arnold analysed data from settings using CASEY who offered Forest School provision. From a list of 18 settings provided by the team, 13 had used CASEY, and 7 had pre-school children on CASEY in the summer term 2018. These 7 settings provided the data for the analysis, comparing with the county data as a whole.

Pre-school children	Number	Cohort size (estimated)	Percentage
On CASEY	1,335	7,500	18%
Attended Forest School setting	109	*7,500* *1,335*	*1.5% of all children* *8% of children in CASEY*

Figure 2. Chart Showing Numbers of Children in Cohorts

Setting names have been removed from the paper to anonymize the findings. Children's assessed level of development was compared against the results for the wider sample of children on CASEY who are not accessing Forest School through their setting. The specific areas of the Early Years Foundation Stage analysed were those relating to Personal, Social and Emotional Development (PSED), namely

- Managing Feelings
- Making relationships
- Self-confidence

Personal, Social and Emotional Development data:

The chart below shows the initial snapshot of the CASEY data. The highlighted areas indicate significant results for our analysis. Whilst not statistically outstanding, they highlighted for us differences that warranted further analysis. Using a crude numerical equivalent for each sub-stage of development, the sample data suggests children are around 0.5 of a sub-stage ahead of their peers in Managing Feelings (4.73 to 4.16) and Self-confidence (5.04 to 4.50), and around 0.25 in Making Relationships (4.84 to 4.60). From the overall data profile it is not entirely clear whether these children are developmentally ahead of their peers, or more likely to be secure at their assessed level (which is an interesting finding in itself).

Arnold followed this up by looking at the profile of assessment outcomes across the two groups by each of the three areas; managing feelings, making relationships and self-confidence. The results are shown below.

CASEY data, Summer 2018, children aged 48-60 months at assessment										
Assessed stage of development for Personal, Social and Emotional development specific areas										
			30-50 months			40-60 months				
Managing feelings		Below 30-50	Emerging	Developing	Secure	Emerging	Developing	Secure	above 40-60	Total
Numbers	Forest School	5	2	8	42	18	15	17	2	10
	Others	52	119	233	283	288	194	57	0	122
Managing feelings		Below 30-50	Emerging	Developing	Secure	Emerging	Developing	Secure	above 40-60	
Percentages	Forest School	5%	2%	7%	39%	17%	14%	16%	2%	100
	Others	4%	10%	19%	23%	23%	16%	5%	0%	100
Making relationships		Below 30-50	Emerging	Developing	Secure	Emerging	Developing	Secure	above 40-60	
Numbers	Forest School	4	2	3	46	17	19	16	2	10
	Others	35	49	159	291	359	264	69	0	122
Making relationships		Below 30-50	Emerging	Developing	Secure	Emerging	Developing	Secure	above 40-60	
Percentages	Forest School	4%	2%	3%	42%	16%	17%	15%	2%	100
	Others	3%	4%	13%	24%	29%	22%	6%	0%	100
Self-confidence		Below 30-50	Emerging	Developing	Secure	Emerging	Developing	Secure	above 40-60	
	Forest School	3	3	5	36	19	17	24	2	10
	Others	19	57	220	315	311	218	86	0	122
		Below 30-50	Emerging	Developing	Secure	Emerging	Developing	Secure	above 40-60	
Self-confidence	Forest School	3%	3%	5%	33%	17%	16%	22%	2%	100
	Others	2%	5%	18%	26%	25%	18%	7%	0%	100

Figure 3. CASEY data for EYFS PSED Assessments Summer 2018

Below are the three charts for each area of the PSED data tabulated above:

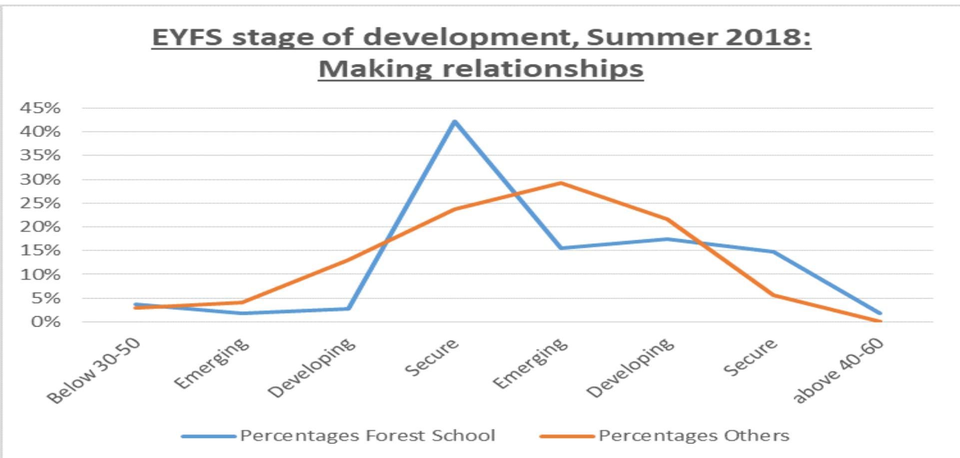


Figure 4. CASEY data for Making Relationships Summer 2018

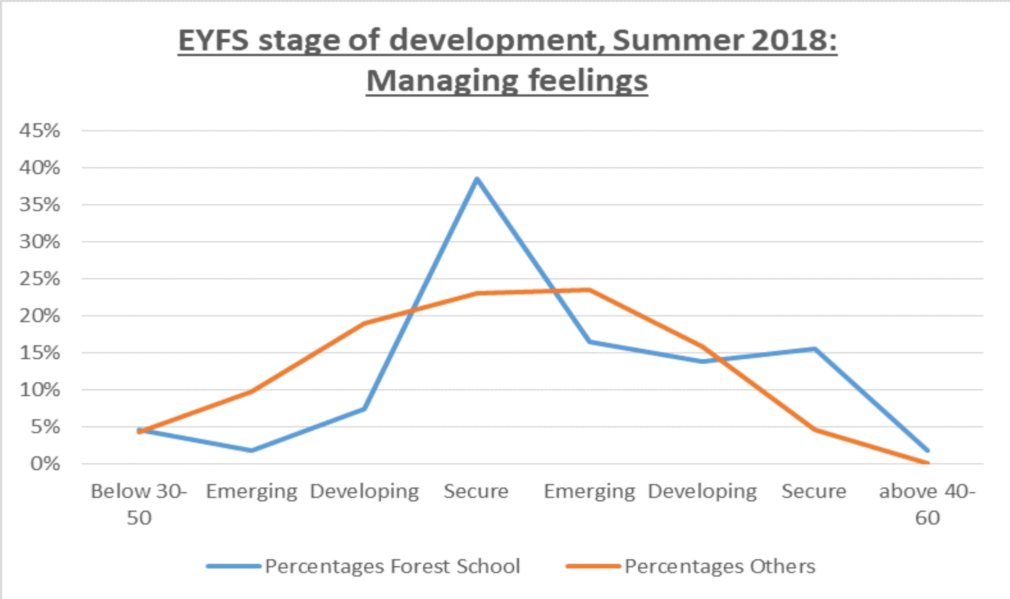


Figure 5. CASEY data for Managing Feelings Summer 2018

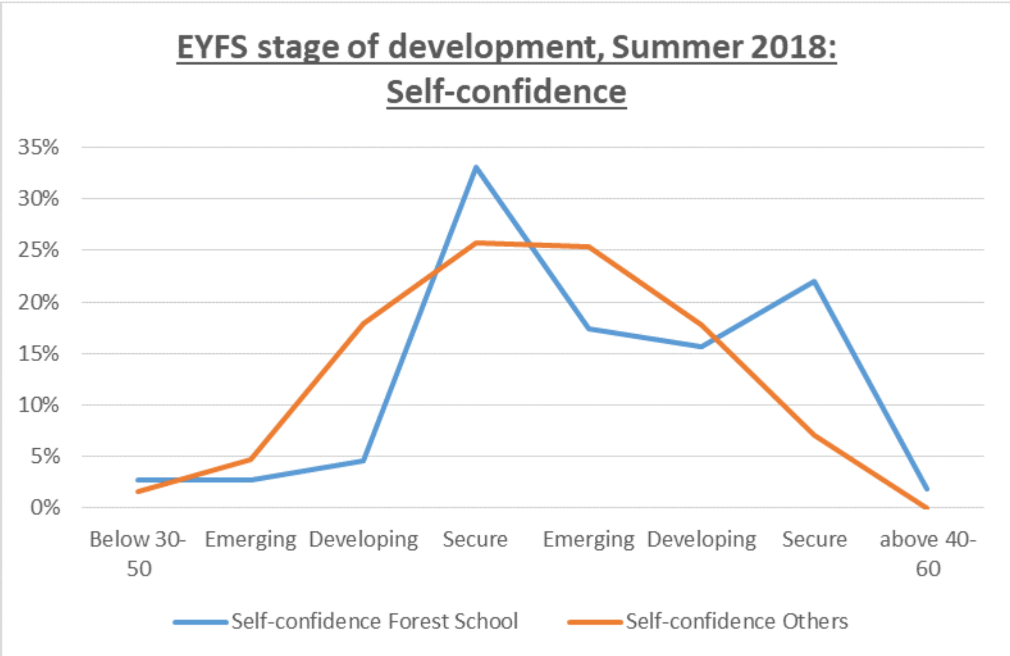


Figure 6: CASEY data for Self-confidence Summer 2018

An examination of the curves on the three charts illustrates the findings we found interesting. As can be seen from the shapes of the two lines in each chart, the profile of the two sets of children is slightly different. Whereas the main population of children follows a standard "bell curve", the Forest School children are more clustered around the "secure" judgement at 30-50 and at 40-60 months. The difference is perhaps most evident in "Managing Feelings". This is an interesting finding which has sparked further discussion within the group.

Discussion focused on the following areas:

- Whether the differences between the Forest School sample and the CASEY population were significant, and if so, what conclusions might be drawn to test in further research

- What the reasons for the differences might be.

On the first point, the sample of children in CASEY has a strong likelihood to be representative of the population in Cambridgeshire as a whole. The Forest School sample is small, but if taken as a percentage of the children in CASEY, is large enough on which to draw conclusions**.**

In looking at reasons for differences, the group discussed the following aspects:

a) Characteristics of settings (and self-selecting parents/children)

b) Characteristics of practitioners

c) Context provided by Forest School activity as a direct and indirect influence on children's demonstrated stage of development

d) Genuine differences in stage of development

A) Characteristics of settings: the argument that the sample is biased because settings offering Forest School will market themselves more confidently, attracting self-confident parents with high aspirations for their children, who potentially bring other factors into the home environment which would support a more advanced stage of development in this area. Whilst this is possible, the geographical and social spread of the settings in relation to other settings using CASEY seems broadly comparable, **though this could be tested further**.

B) Characteristics of practitioners: children were assessed as confident because the Forest School practitioners themselves were more confident, and projected this onto the children. This might be **cross-checked by looking at the assessment profile for these settings for other areas of the EYFS**. It should also be stated that the assessment for Forest School settings are likely to have been **completed by different practitioners** acting as the child's lead worker.

C) Context of FS activity: the idea that Forest School activity itself offers more opportunities for children to demonstrate the skills and behaviours to evidence a judgement of "secure" than their peers in other settings, making it more likely for their settings to make a judgement at that stage (direct influence); or that behaviour observed in the Forest School environment allows practitioners to gain more insight into other behaviour observed elsewhere (indirect). In either case, Forest School activity could be argued to support children's development effectively in these areas.

D) Genuine differences in development: the idea that Forest School activity genuinely promotes children's growth and development in such a way as to be visible in these areas of the Early Years Foundation stage by the end of the pre-school year. Such a finding, if validated, would support the anecdotal and individual case study evidence, as well as the convictions of many practitioners.

Conclusion

In the light of this data analysis, Arnold and Knight believe that it may be possible to demonstrate that Forest School activity in early years settings is having an impact on children's development in the personal, social and emotional domain. Whilst this current analysis can only be regarded as a starting point, this is a promising area for research, particularly as much of the previous research in the area has been qualitative in nature and therefore perceived by policy makers and budget holders as being of less significance. In times of budgetary constraint, all evidence of effective educational interventions and strategies is to be welcomed, particularly when there are potential health benefits to be had as well.

Recommendations

Our discussions are now how we should set this finding in a proper research context, to form a research question that can be explored and scaled up in such a way as to have wider validity and credibility. **A significance test can be done on the mean scores to determine the probability that the difference is significant**. However, the main purpose in this initial analysis was to identify potential lines of enquiry for high level data. The data underpinning the analysis should be further tested (see areas in bold above) and peer reviewed within the Council to minimise the chances of the findings being invalid. Further investigations would benefit from matching settings that do and do not offer FS opportunities according to set criteria such as urban/rural location, numbers of children in each group, numbers of children eligible for free school meals, and numbers of children with identified additional requirements. Balancing the sizer of the two comparable cohorts and making a clear differentiation between the two sets of data should produce more robust findings.

Acknowledgements

The team would like to thank the settings who gave permission for their CASEY data for

summer 2018 to be used for the purposes of this analysis and paper.

References

Boodhna, G. (2013) *Children's Body Mass Index, Overweight and Obesity.* Retrieved from https://files.digital.nhs.uk/publicationimport/pub16xxx/pub16076/hse2013-ch11-child-bmi.pdf

Cambridgeshire County Council Early Years and Childcare Team (2018, April). *Cambridgeshire Assessment System for Early Years (CASEY).* Retrieved from https://www.cambslearntogether.co.uk/earlyyears/business-support/cambridgeshire-assessment-system-for-early-years-casey/

Claxton, G. (2013). *Building Learning Power.* Bristol: TLO Ltd

Coates, J.K. & Pimlott-Wilson, H. (2018). *Learning while Playing: Children's Forest School experiences in the United Kingdom.* British Educational Research Journal, (in press).

Cree, J. & McCree, M. (2014). *History of Forest School.* Retrieved from https://www.forestschoolassociation.org/history-of-forest-school/

Department for Education, 2017. *Statutory framework for the early years foundation stage.* Retrieved from www.gov.uk/government/publications

Forest School Association (FSA) (2012). *What is Forest School?* Retrieved from https://www.forestschoolassociation.org/what-is-forest-school/

Gill, T. (2007). No Fear: Growing Up in a Risk Averse Society. London: Caloustie Gulbenkian Foundation

Knight, S. (2013). *Forest School and Outdoor Play in the Early Years, 2nd edt.* London: Sage

Knight, S. (2016). *Forest School in Practice.* London: Sage

Lindon, J. (2003). Too Safe for Their Own Good? London: National Children's Bureau

Lysklett, O. (2017). *Nature Preschools in Denmark, Sweden, Germany and Norway.* In Waller, T., Ärlemalm-Hagsér, E., Hansen Sandseter, E. B., Lee-Hammond, L., Lekies, K. & Wyver, S. (Eds.), *The Sage Handbook of Outdoor Play and Learning* (242 – 250). London: Sage

Murray, R. & O'Brien, L. (2005) *Such Enthusiasm – A Joy to See: an evaluation of Forest School in England.* London: New Economics Foundation.

Citation:
Arnold, G. & Knight, S. (2019). An analysis of the impact of forest school provision on early years foundation stage outcomes using CASEY. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 211-221). ISRES Publishing, ISBN:978-605-698540-9.

SECTION 3
EDUCATIONAL TECHNOLOGY

The Functions of each Discipline in STEM Practices

Rabia Nur Ondes
Atatürk University, Turkey

Engin Kursun
Atatürk University, Turkey

Alper Ciltas
Atatürk University, Turkey

Introduction

Establishing connections between different disciplines have received increased attention in business world. Individuals from different professions, for instance a computer engineer, an industrial engineer, a physicist and a business manager have been coming together to organize a team when carrying on a project in various areas. Without teamworks, individuals can also face some real world problems that require various disciplines to be used in order to make a decision or solve the complex problems (Mansilla, 2005). However, they may have difficulty in integrating their knowledge and skills acquired in a meaningful way since the mathematics, science, history and other disciplines are considered as isolated subjects in schools although they are related to each other in reality, which leads to the need to an integrated education (Berland, 2013). At this point, it is important to differentiate the terms of multidisciplinary approach and interdisciplinary approach. *Multidisciplinary* has been defined as individuals from different disciplines working independently on different aspects of a project (Mallon, & Burnton, 2005) or subject-specific concepts and skills are learned separately in each discipline and students are expected to connect the content, taught in different classrooms, on their own (Thibaut, et al., 2018). *Interdisciplinary* refers to the capacity to integrate knowledge and modes of thinking drawn from two or more disciplines to produce a cognitive advancement in ways that would have been unlikely through single disciplinary means (Mansilla, 2005). So, the integration attempts in schools have increased in order to raise qualitative and productive individuals by providing learning environments where students gain experience on integrating different disciplines and making practical applications of the abstract theories in mathematics and science (Carlson, & Sullivan, 1999; Estapa, & Tank, 2017; Kaleci, & Korkmaz, 2018; Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, & Kimmel, 2010; Stohlmann, Moore, McClelland, & Roehrig, 2011). In this sense, STEM that is the acronym of science, technology, engineering and mathematics disciplines has emerged as an integrated education and become widespread in the K-12 education (Johnson, 2013).

The integration of STEM disciplines in education can traced back to the integration of two disciplines to make teaching better. There exist several efforts about integrating technology, history and engineering into mathematics and science instructions and integrating mathematics and science (Alpaslan,& Haser, 2012; Furner, & Kumar, 2007; Khosrow-Pour, Clarke, Becker, & Anttiroiko, 2015; Ondes, & Ciltas, 2018). Yet, according to STEM Roadmap book (as cited in English, 2017), STEM education is not simply integrating two disciplines for teaching something that many educators are already doing this. By contrast, STEM is a holistic approach that links the disciplines so the learning becomes connected, focused, meaningful and relevant to learners as an interdisciplinary curriculum (Smith & Karr-Kidwell, 2000). In addition to these, Johnson (2013) defines STEM as "*an instructional approach, which integrates the teaching of science and mathematics disciplines through the infusion of the practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st century interdisciplinary themes and skills*".

In addition to the various definitions of the STEM education that is still on the development process, there is no common understanding of STEM integration on practices (English, 2017; Holmlund, Lesseig, & Slavit, 2018; Johnson, 2013; Pellas, Kazanidis, Konstantinou, & Georgiou, 2017; Stohlmann, 2018; Thibaut, et al., 2018). In some researches, it can be seen that mathematics and science are on the central when technology and engineering are considered as the supporting vehicle (Corlu, Capraro, & Capraro, 2014; Rockland, et al., 2010; Stohlmann, 201), while in some researches the priority were given to science and engineering rather than mathematics and technology (Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018; So, Zhan, Chow & Leung, 2017). At this point, it is important to define two main models for the implementation of the STEM, which are content and context integration. *Content integration* focuses on the merging of more than one discipline into a single curricular activity or unit to highlight "big ideas" from multiple content areas, while *context integration* is putting one discipline into the center and teaching it in a meaningful way by selecting relevant contexts from other disciplines without ignoring the unique characteristics, depth, and rigor of the main discipline (Thibaut, et al., 2018).

Although STEM implementations vary with different models, perspectives or frameworks addressed, they mostly start from a problem, follow engineering design process and end with a product as a solution of the problem. At the beginning, the problems introduced should be open-ended, real-world, authentic and ill-structured in the context of meaningful, engaging and motivating (Holmlund, et al., 2018; Thibaut, et al., 2018). Since the structure of these problems are similar to the mathematical modeling problems, it can be seen that Model Eliciting Activities (MEAs) which have multiple entry and exit points within the client-driven, real life context have been using in science, mathematics and engineering lessons (Moore, 2008). MEAs, especially engineering design based MEAs can be considered as a bridge for STEM integration since they enables to enhancing the constructed mathematical representations/

models as equation, graph and diagram at the end to hands-on products (Baker, & Galanti, 2017; Baker, Galanti, & Birkhead, 2017; Hamilton, Lesh, Lester, & Brilleslyper, 2008; Kertil, & Gurel, 2016; Stohlmann, 2018). During the process of STEM practices, engineering design process (EDP) including the iterative steps of asking, imagining, planning, creating and improving is used (DiFrancesca, Lee, & McIntyre, 2014; English, 2017; Hamilton, et al., 2008; Hill-Cunningham, Mott, & Hunt, 2018). The definitions of the each EDP steps are in the following:

1. Ask: The problem is defined and constraints are identified
2. Imagine: The best idea is chosen after the brainstorming of the ideas
3. Plan: A model or diagram is drawn and materials are collected
4. Create: The plan is followed and tested
5. Improve: Possible improvements are discussed and all steps are repeated

At the end of the STEM practices, prototypes, products or models were designed and constructed. Yet, it is important to address that creating something or designing models does not always mean doing STEM products. Although mathematics/science principles and concepts can be implicitly used in construction of any physical/digital models in Do It Yourself (DIY), thinkering/maker activities, hacking, creative arts and creation with client designed without math/science based knowledge, it is important to applying math and science concepts/principles when designing or constructing a prototype in STEM challenge (Berland, 2013; Marshall, & Harron, 2018). Since engineering represents the application of science and mathematics concepts to meet human needs and make life better for them, engineering design provides students an opportunity to use math and science concepts in real life to solve the problem (Carlson, & Sullivan, 1999; Chien, & Chu, 2018; Harrison, 2011; National Research Council, 2010; Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, & Kimmel, 2010). Thus, EDP is not just the process of constructing products through hands-on activities as it plays an important role as connecting glue for STEM integration (Brophy, Klein, Portsmore, & Rogers, 2008; Stohlmann, 2018).

By the growing and developing STEM literature, there is still no common agreement on the implementations of STEM activities. With respect to the content and context integration, it can be seen that science, technology, engineering and mathematics are used as a main focus, supporting tool or context in STEM practices, which are the general categorization of their usage (Coad, 2016; Corlu, Capraro, & Capraro, 2014; Stohlmann, 2018; Stohlmann, et al., 2011). However, more detailed categorization can be seen in the integration of technology into instructions since the classification includes different purposes of the supporting tool as communication, exploration, evaluation, management and motivation (Sherman, 2014). In this sense, the functions of each STEM discipline explicitly in practices can be identified. On the other hand, there exist some claims that T, M or E do not receive same attention as S (Fitzallen, 2015; Guzey, Moore, & Harwell, 2016; Harrison, 2011; Rockland, et al., 2010; Stohlmann, 2018). So, it is important to address in which ways STEM disciplines are used in integrated applications. As a result, researchers, educators and teachers from different fields can choose the best STEM integration from multiple ways with respect to their purposes. Also, it can offer a framework that illustrates the various usages of the disciplines in integrated activities and provide an opportunity to see the different approaches and improve implementation plan in a more constructivist way. In this sense, the aim of the study is to identify the function of each STEM discipline in integrated practices. So, the research questions are as follows:

- In which roles science from the components of STEM is used in integrated STEM education?
- In which roles technology from the components of STEM is used in integrated STEM education?
- In which roles engineering from the components of STEM is used in integrated STEM education?
- In which roles mathematics from the components of STEM is used in integrated STEM education?

Meta-synthesis was used as a research design in this study. Meta-synthesis is the systematic synthesis of the qualitative studies conducted on the same subject through a process of identifying patterns and forming common themes by comparing their similarities and differences with a critical insight and a holistic approach (Calık and Sözbilir, 2014; Glesne, 2013). Since the aim of the study is to identify the roles of each component in STEM, it is appropriate to use meta-synthesis that enables to examine the previous studies on STEM critically; compare the roles of each discipline in STEM by systematically identifying the similarities and differences of them and provide a framework involving the common categories of the each role.

Since STEM is the abbreviation of science, technology, engineering and mathematics, the keywords are determined as “stem”, “stem education”, “stem integration”, “integrated stem”, “science technology engineering mathematics”, “model eliciting activities and stem", "integrated education", "stem approaches", "mathematics and engineering", "engineering integration in stem", "science and mathematics integration", "technology integration", "stem learning", "stem implementation".

By using these keywords, articles were searched in the databases of Web of Science, ERIC and Google Scholar. At this point, the abstracts of the articles were examined whether they are appropriate for the purpose of this meta-synthesis study or not. Here, the quantitative studies (the effects of STEM in students' achievement, attitudes etc.) and phenomenological studies (only focus on the views of participants) were extracted. The papers contain the examination of the application and process of the activity were collected in order to analyse the usage of the disciplines. After finding appropriate studies, those that use STEM disciplines in different ways were selected to synthesise various functions of them with respect to our purpose. Briefly, they are examined in detail according to the inclusion and exclusion criteria given below. At this point, the main criteria is that the article should have contain the description of an activity covering more than one STEM disciplines in order to identify the roles of science, technology, engineering and mathematics.

Exclusion Criteria:

- Quantitative researches (studies having only quantitative results)
- Researches focusing only the effect of STEM on students' achievement/ motivation/skills without presenting STEM activities in the process
- Researches focusing only the investigation of the participants' views/attitudes/ perceptions qualitatively
- Reviews/Meta analysis/ Concept Analysis that discuss the concepts without presenting an application about STEM

Inclusion Criteria:

- Researches including the description of an activity that is related to more than one STEM disciplines (S-M, E-M-T, S-T-E-M, S-E-T etc.)
- Researches having different perspectives on STEM integration practices

At the end of the application of the exclusion and inclusion criteria, researches were analyzed by considering the roles of STEM components. Then, researches offering variety for the components' roles were selected since the sample of the meta-synthesis study can be determined purposely. Thus, 15 researches were obtained as given in Table 1. (Aquino, Caliguid, Buan, Magsayod, & Lahoylahoy, 2018; Baker & Galanti, 2017;

Baker, Galanti, & Birkhead, 2017; Berland, 2013; Bryant-Davis, & Hardin, 2013; Ceylan & Ozdilek, 2015; Chien & Chu, 2018; English, 2017; English & Mousoulides, 2015; Kern, Howard, Brasch, Fiedler & Cadwell , 2015; Kertil & Gurel, 2016; Nemorin & Selwyn, 2016; Ring-Whalen, Dare, Roehrig, Titu & Crotty, 2018; So, Zhan, Chow & Leung, 2018; Sumrall, 2015).

Table 1. The Sample of the Researches and Their Demographic Features

Authors	Primary Focus	Activity Names
Aquino, et al., 2018	Engineering	Rocket Building
Baker and Galanti, 2017	Mathematics	Survivor/Packing a Truck/ Creating a Mosaic/A day at the Zoo
Baker, et al., 2017	Mathematics	Pelican Colonies
Berland, 2013	Engineering	Pinhole to Pixels
Bryant-Davis and Hardin, 2013	Engineering	Rocket Launches/ Card Building/ Simulators/ Egg Drop/ Skyscraper
Ceylan and Ozdilek, 2015	Science	Acids and Basis
Chien and Chu, 2018	Engineering	Racing Cars
English, 2017	Mathematics & Engineering	Similar findings related to the codes
English and Mousoulides, 2015	Engineering	Bridge Design
Kern, et al., 2015	Engineering	The Fish Weir
Kertil and Gurel, 2016	Mathematics & Engineering	Rocket Project/The Cassette Player MEA
Nemorin and Selwyn, 2016	Engineering	Race Car Design
Ring-Whalen, et al., 2018	Engineering	Soccer Stadium / Cross Pollination of GMOs / Improving the Mechanical Claw
So, et al.,, 2018	Science	Homemade food waste enzyme cleanser/ Combustion efficiency
Sumrall, 2015	Engineering	Recycling Metallic Elements

Since the present study seeks to identify the characteristics of each discipline in STEM, the main categories have been already formed as science, technology, engineering and mathematics. However, the codes representing the different roles were constructed by constantly comparing-contrasting the roles of the science, technology, engineering and mathematics in each research. The code names are chosen from the literature to make them familiar and they are decided by the agreement of the authors with an expert opinion. Furthermore, some activities included in researches have more than one role for one discipline; hence they were assigned under the each code that they match up with. Also, in coding process, it was beneficial to use the explanations or discussions about the activities, processes or implementation practices in studies if exists when making classification of the research and deciding which code they belong to.

The findings obtained through the analysis of the researches defined were presented under four sections that are related to the research questions focusing on the different usage forms of the disciplines in implementations.

The Roles of "S" in STEM

Scientific knowledge, principles and concepts can be used in STEM based approaches, which gives an opportunity for linking and applying science in real life. Also, the science discipline has been considered as main focus in content integrated STEM education. However, there exist many ways of integrating science with different disciplines, and hence its role has been changing in different implementations. According to the examined articles in this study, science plays roles as a tool for providing information, as a tool for contextualizing the problem situation and as a context for applying science process skills (SPS) and scientific inquiry as given in Table 2.

Table 2. The Roles of Science in STEM Education

	Science	Descriptions
As a tool	For providing information	Scientific knowledge is necessary for constructing a model as a solution of the problem or completing the activity.
	For contextualizing the problem situation	Scientific ideas are covered in problem situation to make them more meaningful for real life.
As a context for applying science process skills (SPS) and scientific inquiry		SPS and scientific inquiry used within the science standards and curriculum objectives in the integrated implementations.

The descriptions of the each role as follows:

- *Science as a tool for providing information* refers to that scientific knowledge is necessary for constructing a model as a solution of the problem or completing the activity. In other words, activities require using scientific principles and concepts that are already known and making research for unknown scientific knowledge and for further information. So, it is observed that science has been using in the part of extending information. For example, when recycling metals, the information of the properties and qualities of the metals; when building a rocket, the principle of Newton's Law 3; when constructing ph metre, the information of ph degrees in acid and bases are required.

- *Science as a tool for contextualizing the problem situation* refers to that scientific ideas are covered in problem situation to make them more meaningful for real life. Mathematical problems can be extended by integrating science ideas as they are not isolated in real world situations. For instance, the model eliciting activity that focuses on mathematics and does not focus on the scientific principles includes scientific information as speed and velocity in the context of problem.

- *Science as a context for applying science process skills (SPS) and scientific inquiry* refers to that science process skills (e.g., posing questions, planning investigations, analysing and interpreting data, providing explanations, and making predictions) and scientific inquiry used within the science standards and curriculum objectives in the integrated implementations. It was considered that science is used in activities when analysing and interpreting data since scientific inquiry and science process skills provide an environment for students to think like a scientist.

The Roles of "T" in STEM

As mentioned in literature review, technology can be used as a goal and as management tool, communication tool, motivational tool and cognitive tool for discovery in teaching. By taking into account them, technology usage in STEM related activities was categorized by examining the researches. The findings indicates that technology plays roles as a supporting tool for researching, collecting data, analysing data, graphing data, sketching 3D models, creating simulation and animation video, checking data and producing prototypes, and technology plays a role as a practical context for end product as given in Table 3.

The descriptions of the each role as follows:

- *Technology as a supporting tool for researching* refers to that the Internet, presentations, informative videos are used as a tool when gathering information that is required in an activity.

- *Technology as a supporting tool for collecting data* refers to that Internet or other useful programs are used when collecting data from real life situations that is required for an activity.

- *Technology as a supporting tool for analysing data* refers to that analysing programs are used as a tool when collected, existed data needs to be analysed.

- *Technology as a supporting tool for graphing data* refers to that some software programs are used to represent the data in terms of graph, table and figures.

- *Technology as a supporting tool for sketching 3D models* refers to that some dynamic geometry software and sketching programs are used to design 3D model that is required to be constructed in activity with appropriate sizes.

- *Technology as a supporting tool for creating simulation and animation video* refers to that some programs are used to make simulations and design an animation video within the activity.

- *Technology as a supporting tool for checking data* refers to that some technological devices and software programs are used to test the solution and measure the quantities that are found in the process of activity.

- *Technology as a supporting tool for producing prototypes* refers to that vehicles like LEGO, maker kits, robots, 3D printer and hands-on materials are used to make hands-on constructions that enable to design a prototype.

- *Technology as a practical context for end-product* refers to that

produced products, crafts and designed models at the end of the activities are considered as technological tools.

Table 3**.** The roles of Technology in STEM Education

Technology		Descriptions
As a supporting tool	For researching	Technology is used when gathering information that is required in an activity.
	For collecting data	Technology is used when collecting data from real life situations that is required for an activity.
	For analysing data	Technology is used when collected, existed data needs to be analysed.
	For graphing data	Technology is used when representing the data in different forms.
	For sketching 3D models	Technology is used when designing 3D model that is required to be constructed in activity with appropriate sizes.
	For creating simulation/animation video	Technology is used when making simulations and designing an animation video within the activity.
	For checking data	Technology is used when testing the solution and measuring the quantities.
	For producing prototypes	Technology is used when designing hands-on constructions.
As a practical context for end product		Produced products, crafts and designed models at the end of the activities are considered as technological tools.

The Roles of "E" in STEM

According to the findings obtained from identified researches, there exist different types of engineering integration into activities. As stated in Table 4., engineering has roles as a tool for application of math/science knowledge, as a tool for generating hands-on solution and as a context for application of engineering design process.

Table 4. The Roles of Engineering in STEM Education

Engineering	Descriptions
As a tool for application of science/math knowledge	Observing, testing and learning the scientific/mathematical knowledge.
As a tool for generating hands-on solution	Designing, prototyping and modelling products for the solution of real life problem.
As a context for application of engineering design process	Applying the iterative steps of asking, imagining, planning, creating and improving.

The explanations of the each role as follows:

- *Engineering as a tool for application of science/math knowledge* refers to that science and math concepts, principles are applied in real life by the help of engineering which offer an opportunity to observe, test and learn the scientific/mathematical knowledge (formulas, laws, etc.).
- *Engineering as a tool for generating hands-on solution* refers to that engineering enables to find solutions to real life problems by designing, prototyping, modelling a craft or product in the range of hands-on practices.
- *Engineering as a context for application of engineering design process* refers to that engineering provides an environment for using engineering design process in activities by applying the iterative steps of asking, imagining, planning, creating and improving.

The Roles of "M" in STEM

The findings that were obtained from examined researches by considering the mathematics component were presented in Table 5. According to them, mathematics has roles as a supporting tool for calculation, measurement, data analysing, data representation and variable analysing; and a context for the application of mathematical modelling process; quantitative and proportional reasoning; and geometry.

The explanations of the each role as follows:

- *Mathematics as a supporting tool for calculation* refers that mathematics is used when using number operations and algebra to work out the answer required in the activity process. These calculations include simple operations like addition, subtraction, multiplication and division of natural, rational numbers and integers or advanced operations like differentiation, trigonometry (sin,cos etc.).

- *Mathematics as a supporting tool for measurement* refers that mathematics is used when measuring *angles,* length, area and volume of the objects or figures.

- *Mathematics as a supporting tool for data analysing* refers that mathematics is used in the process of examining, transforming and arranging raw data for inferring information from it.

- *Mathematics as a supporting tool for data representation* refers that mathematics is used when demonstrating data in algebraic expressions and the visual forms like tables, graphs and models.

- *Mathematics as a supporting tool for variable analysing* refers that mathematics is used when interpreting the variables in the formulas and equations.

- *Mathematics as a context for the application of mathematical modelling process* refers that mathematics is used within the context of model eliciting that provides an environment to solve problems in mathematics world by following the iterative process of mathematizing, interpreting, verifying, revising and generalizing the mathematical model.

- *Mathematics as a context for the application of quantitative & proportional reasoning* refers that mathematics is used within the context of quantitative reasoning that enables converting verbal, graphical, numeric and symbolic representations to each other; interpreting measured data and models by connecting it to physical phenomena; and proportional reasoning that enables making comparisons between quantities in multiplicative terms in the range of problem situation.

- *Mathematics as a context for application of geometry* refers that mathematics is used when working with hands-on physical objects and digital designs in the context of geometry (circles, geometric shapes, triangles, polygons, etc.). It is also related to the art (A in STEAM).

Table 5. The Roles of Mathematics in STEM

Mathematics		Descriptions
As a supporting tool	For Calculation	When number operations and algebra to work out the answer required.
	For Measurement	When measuring length, area and volume of the objects or figures.
	For Data Analysing	The process of examining, transforming and arranging raw data for inferring information from it
	For Data Representation	When demonstrating data in algebraic expressions and the visual forms like tables, graphs and models.
	For variable analysing	When interpreting the variables in the formulas and equations.
As a context	For the application of mathematical modelling process	Model eliciting that provides an environment to solve problems in mathematics world by following the iterative process.
	For the application of quantitative & proportional reasoning	Converting verbal, graphical, numeric and symbolic representations to each other; interpreting measured data and models by connecting it to physical phenomena; making comparisons between quantities in multiplicative terms.
	For the application of geometry	When working with hands-on physical objects and digital designs in the context of geometry

The nature of the real life problems are composed of different disciplines, which leads to integrating various disciplines to each other in order to raise qualitative and productive individuals who can apply the abstract knowledge of science, technology, mathematics for solving problems and meeting their needs. The widespread integration approach in education is STEM (Science, Technology, Engineering, Mathematics) which can be implemented by using two main models as content and context integration. However, there is still no common agreement on the implementations of STEM activities due to different perspectives, approaches, and models about the integration, which causes to use each discipline in STEM differently. Thus, this study aiming to identify the roles of the disciplines in STEM was conducted by synthesizing of 15 researches containing STEM related practices and explanations inside. The findings of the current study were presented under four categories corresponding to the research questions as the roles of S, T, E and M in STEM.

The first research question of the study is regard to the identification of the roles of science in integrated STEM education. According to the findings, science plays roles as a tool for providing information, as a tool for contextualizing the problem situation and as a context for applying science process skills (SPS) and scientific inquiry. The findings are consistent with the idea that science is an integral part of STEM integration and science is mostly positioned as central point rather than mathematics, technology and engineering (Corlu, et.al., 2014; Rockland, et al., 2010; Ring-Whalen, et al., 2018; So, et al., 2017 Stohlmann, 2018). This may be result from the fact that scientific knowledge, principles and concepts are related to the real life contexts and constructed products contain scientific knowledge inside in some way. When considering the beginning of the STEM related activities that generally start with a problem from real life context, the problem situations contain the discipline of science as explicitly or implicitly since it cannot be considered as an isolated discipline from the real world (Baker, et al., 2017; Holmlund, et al., 2018; Kern, 2015; Kertil, & Gurel, 2016; Sumrall, 2015; Thibaut, et al., 2018) That means, scientific ideas may be covered in problems in order to make them more meaningful for students, or scientific knowledge may appear explicitly in problems. So, the possible explanation of this might be that science can be used as a tool for contextualizing the problem situation for making sense of them. When considering the end of the STEM related activities that generally require designing a model for the solution of the problem addressed, scientific knowledge is used in some way when designing and constructing products, models or crafts (Carlson, & Sullivan, 1999; Chien, & Chu, 2018; Harrison, 2011; Rockland, et al., 2010; Marshall, & Harron, 2018). This may be result from the fact that scientific knowledge takes place in a wide range of interval from determining the materials by considering the properties of them to building products by considering the physical phenomena (Aquino, et al., 2018; Kertil, & Gurel, 2016; Sumrall, 2015). Therefore, it can be inferred that science can be used as a tool for providing information to complete the activity. When considering the process of the STEM related activities that use the engineering design process (asking, imagining, planning, creating and improving), it can be seen that scientific process skills and scientific inquiry may be involved in the process. This may be result from the fact that both engineering design and scientific process have related iterative steps in common (Dillivan, & Dillivan, 2014; Rockland, et al., 2010; Kelley, 2010; Koretsky, 2018; Lewis, 2006). Questions can be posed, investigations can be planned, data can be analysed and interpreted, possible explanations can be presented and predictions can be done in which a problem and constraints are defined, the best solution is chosen among possible solutions, model is drawn, materials are collected, the plan was implemented, prototype is built and tested, improvements are done if needed. So, science can be used as a context for applying science process skills (SPS) and scientific inquiry during the activity.

The second research question of the study is about the identification of the roles of technology in integrated STEM education. Based on the findings it was observed that technology has different roles as a supporting tool for researching, collecting data, analysing data, graphing data, sketching 3D models, creating simulations and animation videos, checking data and producing prototypes, and technology plays a role as a practical context for the end product. These findings are consistent with the previous study that technology can be used in different purposes as a goal and as tool for management, communication, motivational, and cognitive (exploration) in terms of the diversity of the usages (Sherman, 2014). This may be result from the fact that technology can make the procedures easier and possible. So, technological software programs and technological tools can be used as an assistant and supporting tool when researching something on Internet to get information about the problem, materials or solutions; collecting data for the solution of the problem; analysing data to see the patterns and make inferences; graphing data to make conclusion from the representations that seem more systematic; sketching 3D models besides 2D or paper-pencil drawings to prototype the design before constructed; creating and designing simulations and animation video to present the solution of the problem; checking data to control the measurements when determining their appropriateness; and producing prototypes to demonstrate the model as a solution. In other words, technology can take place in every part of the procedure from searching about the problem to designing a model. Also, the finding that the technology is used as a practical context for the end product may be results from the fact that produced products, crafts and designed models at the end of the activities can be considered as technological tools, which can be supported by the idea that technology also means innovations such as pencils, aspirin and microscopes that used for various types of human activities such as farming, agriculture, manufacturing, industrial, military, and so on (National Research Council, 2010).

The third research question of the study is about the identification of the roles of engineering in integrated STEM education. Based on the findings, engineering has roles as a tool for application of math/science knowledge, as a tool for generating hands-on solution and as a context for application of engineering design process. The findings are parallel with the previous studies that integrate the engineering into math, science and engineering courses to show that it provides an environment for applying theoretical knowledge in real life to allow students make sense of them. Also, as seen in the literature, at the end of the engineering design-based and project-based instructions, students are expected to construct, build or design a craft, which consistent with the idea of engineering as a tool for generating hands-on solution (Carlson, & Sullivan, 1999;

Chien, & Chu, 2018; Harrison, 2011; Rockland, et al., 2010). The possible explanation of this may be that engineers try to meet human needs and make their lives better by designing products. However, constructing something is not always making engineering since without scientific/mathematical knowledge it can be any craft like DIY and puzzle robots that depend on only creativity or guidance of someone (Marshall, & Harron, 2018). At this point, it is important to implement engineering design process which enables STEM based activities to be integrated with engineering and allow students to think like an engineer (Berland, 2013; Brophy, et al., 2008; Stohlmann, 2018). This may be result in that engineering is used as a context for applying engineering design process in STEM integrated practices since without systematic process creating something by trial and error cannot be related to engineering.

The forth research question of the study is related the identification of the roles of mathematics in integrated STEM education. The findings indicate that mathematics has roles as a supporting tool for calculation, measurement, data analysing, data representation and variable analysing; and a context for the application of mathematical modelling process; quantitative and proportional reasoning; and geometry. The results are consistent with the studies claimed that mathematics within STEM has not received the focus it deserves in integrated practices although the theoretical knowledge in mathematics can find an application area by STEM (Berland, 2013; Stohlmann, 2018**).** Also, it was stated that mathematics has already been using in science courses in the terms of calculation, graphing data, analysing variables and quantitative reasoning. The possible explanation of that may be that science and math are connected to each other since science requires using such types of mathematical processes when dealing with problems (Moore, 2008). However, it can be seen that mathematics supports science and other disciplines when making calculations, measuring *angles,* length, area and volume of the objects, analysing the given data, converting the findings into the different representations like graph, table and model, interpreting the formulas by considering the relationships of the variables and their coefficients, determining the sizes of the models to be drawn, constructing mathematical models like equations and graphs. Besides its supporting role, it was observed that mathematics enables to apply mathematical modelling process, quantitative and proportional reasoning and geometry (Koretsky, et al., 2018). This may be result from the fact that model eliciting activities that used in mathematics, engineering and science courses can build a bridge between the mathematics and STEM and allow to use mathematics more explicitly (Baker, & Galanti, 2017; Baker, et al., 2017; Hamilton, et al., 2008; Kertil, & Gurel, 2016; Stohlmann, 2018). Also, quantitative and proportional reasoning used implicitly in STEM have found an application environment in real life. Moreover, STEAM in which A (art) integrated may result in the using geometry as a context since the geometrical shapes, physical sizes are related to the geometry.

To sum up, integrated STEM practices can be different from one instruction to the other due the approaches and models followed. However, it can be seen that similarities and differences of the implementations exist and the roles of each discipline can be identified. At this point, it can be suggested that researchers, educators and teachers can consider the STEM roles determined in this study in order to develop better STEM activities and construct rubrics that assess the teachers' STEM instructions and their lesson plans. Also, the framework can be extended by examining the learning methods, materials used and the process followed.

References

Alpaslan, M., & Haser, Ç. (2012). History of mathematics" course for pre-service mathematics teachers: A case study. In *12th international congress on mathematical education pre-proceedings* (pp. 4180-4189).

Aquino, J. G., Caliguid, M. P., Buan, A. T., Magsayod, J. R., & Lahoylahoy, M. E. (2018, January). Teaching Newton's 3rd law of motion using learning by design approach. In *AIP Conference Proceedings* (Vol. 1923, No. 1, p. 030075). AIP Publishing.

Baker, C. K., & Galanti, T. M. (2017). Integrating STEM in elementary classrooms using model-eliciting activities: responsive professional development for mathematics coaches and teachers. *International Journal of STEM Education*, *4*(1), 10.

Baker, C., Galanti, T., & Birkhead, S. (2017). STEM and model-eliciting activities: Responsive professional development for K-8 mathematics coaches. *North American Chapter of the International Group for the Psychology of Mathematics Education*

Berland, L. K. (2013). Designing for STEM integration. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(1), 3.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369-387.

Calik, M., & Sözbilir, M. (2014). Parameters of content analysis. *Egitim ve Bilim*, *39*(174).

Carlson, L. E., & Sullivan, J. F. (1999). Hands-on engineering: learning by doing in the integrated teaching and learning program. *International Journal of Engineering Education*, *15*(1), 20-31.

Ceylan, S., & Ozdilek, Z. (2015). Improving a sample lesson plan for secondary science courses within the STEM education. *Procedia-Social and Behavioral Sciences*, *177*, 223-228.

Chien, Y. H., & Chu, P. Y. (2018). The different learning outcomes of high school and college students on a 3D-Printing STEAM engineering design curriculum. *International Journal of Science and Mathematics Education*, *16*(6), 1047-1064.

Coad, L. (2016). The M in STEM what is it really?. *Australian Mathematics Teacher, The*, *72*(2), 3.

Corlu, M. S, Capraro R. M, Capraro M. M. (2014). Introducing Stem education: implication for educating our teachers for the age of innovation. *Education and Science, 39*, 171.

Davis, K. E. B., & Hardin, S. E. (2013). Making STEM fun: How to organize a STEM camp. *Teaching Exceptional Children*, *45*(4), 60-67.

DiFrancesca, D., Lee, C., & McIntyre, E. (2014). Where is the" E" in STEM for young children? Engineering design education in an elementary teacher preparation Program. *Issues in Teacher Education*, *23*(1), 49-64.

Dillivan, K. D., & Dillivan, M. N. (2014). Student interest in STEM disciplines: results from a summer day camp. *Journal of Extension*, *52*(1), n1.

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, *15*(1), 5-24.

English, L. D., & Mousoulides, N. G. (2015). Bridging STEM in a real-world problem. *Mathematics Teaching in the Middle School*, *20*(9), 532-539.

Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: a professional development approach centered on an engineering design challenge. *International Journal of STEM education*, *4*(1), 6.

Fitzallen, N. (2015). STEM Education: What does mathematics have to offer?. *Mathematics Education Research Group of Australasia*.

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: a stand for teacher education. *Eurasia journal of mathematics, science & technology education*, *3*(3).

Glesne, C. (2013). *Nitel araştırmaya giriş (3. Basım). A. Ersoy ve P. Yalçınoğlu (Çev. Edt.).* Ankara: Anı Yayıncılık.

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research (J-PEER)*, *6*(1), 2.

Hamilton, E., Lesh, R., Lester, F., & Brilleslyper, M. (2008). Model-eliciting activities (MEAs) as a bridge between engineering education research and mathematics education research. *Advances in Engineering Education*, *1*(2), n2.

Harrison, M. (2011). Supporting the T and the E in STEM: 2004-2010. *Design and Technology Education: An International Journal*, *16*(1).

Hill-Cunningham, P. R., Mott, M. S., & Hunt, A. B. (2018). Facilitating an elementary engineering design process module. *School Science and Mathematics*, *118*(1-2), 53-60.

Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of “STEM education” in K-12 contexts. *International Journal of STEM Education*, *5*(1), 32.

Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science and Mathematics, 113*(8), 367–368. doi:10.1111/ssm.12043.

Kaleci, D., & Korkmaz, Ö. (2018). STEM education research: content analysis. *Universal Journal of Educational Research*, *6*(11), 2404-2412.

Kelley, T. (2010). Staking the claim for the “T” in STEM. *Journal of Technology Studies*, *36*(1), 2-11.

Kern, A., Howard, M. A., Brasch, A. N., Fiedler, F., & Cadwell, J. (2015). The fish weir: A culturally relevant STEM activity. *Science scope*, *38*(9).

Kertil, M., & Gurel, C. (2016). Mathematical modeling: A bridge to STEM education. *International Journal of Education in mathematics, science and Technology*, *4*(1), 44-55.

Khosrow-Pour, M., Clarke, S., Becker, A., & Anttiroiko, A. (Eds.) (2015). *STEM education: Concepts, methodologies, tools, and applications*. IGI Global.

Koretsky, M., Keeler, J., Ivanovitch, J., & Cao, Y. (2018). The role of pedagogical tools in active learning: a case for sense-making. *International Journal of STEM Education*, *5*(1), 18.

Mallon, W. T., & Burnton, S. (2005, June). The functions of centers and institutes in academic bio- medical research. *Analysis in Brief 5*(1), 1-2.

Mansilla, V. B. (2005). Assessing student work at disciplinary crossroads. *Change, 37*(1) 14-21

Marshall, J. A., & Harron, J. R. (2018). Making learners: A framework for evaluating making in STEM education. *Interdisciplinary Journal of Problem-Based Learning*, *12*(2), 3.

Moore, T. J. (2008). Model-eliciting activities: A case-based approach for getting students interested in material science and engineering. *Journal of Materials Education*, *30*(5-6), 295-310.

National Research Council. (2010). *Standards for K-12 engineering education?* National Academies Press.

Nemorin, S., & Selwyn, N. (2017). Making the best of it? Exploring the realities of 3D printing in school. *Research Papers in Education*, *32*(5), 578-595.

Ondes, R. N., & Ciltas, A. (2018). Using theoretical framework with sample activities to enlighten prospective elementary mathematics teachers about technological pedagogical content knowledge (TPACK). *International Journal of Educational Studies in Mathematics*, *5*(3), 98-108.

Pellas, N., Kazanidis, I., Konstantinou, N., & Georgiou, G. (2017). Exploring the educational potential of three-dimensional multi-user virtual worlds for STEM education: A mixed-method systematic literature review. *Education and Information Technologies*, *22*(5), 2235-2279.

Ring-Whalen, E., Dare, E., Roehrig, G., Titu, P., & Crotty, E. (2018). From conception to curricula: The role of science, technology, engineering, and mathematics in integrated STEM units. *International Journal of Education in Mathematics, Science and Technology*, *6*(4), 343-362.

Rockland, R., Bloom, D. S., Carpinelli, J., Burr-Alexander, L., Hirsch, L. S., & Kimmel, H. (2010). Advancing the “E” in K-12 STEM education. *Journal of Technology Studies*, *36*(1), 53-64.

Sherman, M. (2014). The role of technology in supporting students’ mathematical thinking: Extending the metaphors of amplifier and reorganizer. *Contemporary Issues in Technology and Teacher Education*, *14*(3), 220-246.

Smith, J., & Karr-Kidwell, P. (2000). *The interdisciplinary curriculum: A literary review and a manual for administrators and teachers*. Retrieved from https://eric.ed.gov/?id=ED443172

So, W. W. M., Zhan, Y., Chow, S. C. F., & Leung, C. F. (2017). Analysis of STEM activities in primary students' science projects in an informal learning environment. *International Journal of Science and Mathematics Education*, 1-21.

Stohlmann, M. (2018). A vision for future work to focus on the "M" in integrated STEM. *School Science and Mathematics*, *118*(7), 310-319.

Stohlmann, M., Moore, T. J., McClelland, J., & Roehrig, G. H. (2011). Impressions of a middle grades STEM integration program: Educators share lessons learned from the implementation of a middle grades STEM curriculum model. *Middle School Journal*, *43*(1), 32-40.

Sumrall, W. (2015). Using a STEM-Based approach to make recycling metallic elements relevant. *Science Scope*, *39*(2), 55.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., ... & Hellinckx, L. (2018). Integrated STEM Education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2.

Citation:
Ondes, R.N., Kursun, E. & Ciltas, A. (2019). The functions of each discipline in STEM practices. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 223-242). ISRES Publishing, ISBN:978-605-698540-9.

Good Practices Using Digital Technologies in STEM Education with a Focus on Mathematics

Jenny Sendova
Bulgarian Academy of Sciences, Bulgaria

Introduction

When Dudley Herschbach, a Nobel laureate in Chemistry for 1986, delivered a lecture to high school students with a potential for doing science, he surprised them with his opinion about the difference between the scientists and the students. Here is what he said (I am quoting by memory): *The difference between the scientists and the students is in fact very small – it consists in the way they react to a question they don't know the answer to. Whereas the students feel embarrassed and miserable thinking of a possible failure on a test, the scientists feel enthusiastic – they see food for reflection and explorations!*

Enstein, in a classical humble brag, once remarked (as quoted in Ryan, J., 2017, p. 41): "I have no special talents. I am only passionately curious." … "The important thing", the great physicist observed, "is to not stop questioning. Never lose a holy curiosity". Then Ryan continues: *Curiosity begins with asking "I wonder why?"* and he further suggests that we should take the time to look around us and remember to ask "I wonder why?" – a question that launches discoveries and leads to remarkable insights.

One of the most important aspects of education towards a creativity-based society deals with provoking teachers to become authentic co-learners joining their students in creative explorations. Such a goal requires for the education (traditionally teacher-centered in Bulgaria) to provide appropriate strategies, methods and environments, which nurture, enrich, and stimulate learner's creativity (Henriksen, Henderson, Creely, et al., pp. 418-419)

Supporting the inborn curiosity of children and encouraging them to act like scientists during all the stages of the school system has been the motivation behind the development of learning environments in support of the inquiry-based STEM education by a research team at the Institute of Mathematics and Informatics at the Bulgarian Academy of Sciences (IMI-BAS).

There exist various interpretations of STEM but in our further considerations we shall stick to the one in (Ackay, 2018, p.138), which is in harmony with our understanding:

> STEM education is the intentional integration of science, technology, engineering, and mathematics, and their associated practices to create a student-centered learning environment in which students investigate and engineer solutions to

problems, and construct evidence-based explanations of real-world phenomena with a focus on a student's social, emotional, physical, and academic needs through shared contributions of schools, families, and community partners.

Our focus will be on mathematics education by an intensive use of digital technologies as laboratories for experiments – a phenomenon typical for the natural sciences but not for mathematics some decades ago…

The inquiry-based learning in a digital setting in Bulgaria has been closely related to the principles of an experimental Research Group on Education (RGE) functioning in the period of 1978-1989 (Sendov, Bl., 1987; Sendova, 2017) and has recently being developed within a series of recent European educational projects dealing with innovative education. Among these projects it is worth mentioning InnoMathEd – *Innovations in Mathematics Education on European Level* (Chehlarova et al., 2011), Fibonacci - *Disseminating Inquiry-Based Science and Mathematics Education in Europe* (Sendova, Chehlarova, 2012; Kenderov, Sendova, Chehlarova, 2012), KeyCoMath - *Developing Key Competences by Mathematics Education* (Zehetmeier et al. (2015), MaSciL – *Mathematics and Science for Life*, Scientix – *The community for Science Education in Europe* (Kenderov, Sendova, Chehlarova, 2015), STEM PD Net - *The Network of **S**cience* (Maass et al., 2019; Maass & Engeln, 2019).

Research Group on Education – an educational experiment launched 40 years ago

The Research Group on Education (RGE) experiment was launched jointly by the Bulgarian Academy of Sciences and the Ministry of Education. It comprised 2% of the Bulgarian K-12 schools, the main goal being to design and implement a novel, ICT-prompted curriculum (Sendova, 2013). The guiding principles of RGE were *learning by doing*, *guided discovery* and *integration of the school subjects*. During the first four years, Informatics was introduced as a part of an encyclopedic education.

The educational materials developed specially for the experimental schools included textbooks, teacher guide-books, a bulletin Informatics and mathematics for teachers, and unified (Logo-based) computer environments tuned to specific subject domains and still allowing exploratory activities in a broader context.

One of the main integrated disciplines in the primary cycle was "I read, write and calculate". A good example of activities under this subject would be creating a situation in which children would decode a letter (matching numbers with letters), read, write, and code a return message in a context of interest to them.

An innovative idea for integrating the study of Mathematics, natural languages (Bulgarian, English and Russian), and computer language (Logo in this case) was launched in 1984 with the publication of the textbook *Language and Mathematics* (for 5th and 6th grades). Designed to show the intersection of language study with mathematical thinking in the context of Informatics, this experimental textbook included problems of translating from a natural to a formal language, of algorithmic description of basic grammar rules, and of ways to extend the Logo vocabulary to several languages. Informatics notions, such as *coding, decoding, tree-graphs, algorithms, variables, tables, procedures, recursion, data*, etc. were applied in the context of playing, editing and creating linguistic games, coding and decoding secret texts, describing and executing algorithms in the subjects of Mathematics, Language and Music (Figure. 1).

Figure 1. The *Language and Mathematics* Textbooks for the RGE 5- and 6-graders

Specifically designed microworlds were provided for students to deal with these new notions from a procedural rather than a declarative point of view. This has already had an impact on the way we started teaching Mathematics, Literature, Science, Art and Music (Nikolov, 1987).

Building *Geomland*, a microworld for explorations in Euclidean geometry (Sendov, Dicheva, 1988), was another important step toward inquiry-based learning. It was launched in 1986 as a language-based computer laboratory enabling students to construct and experiment with Euclidean objects, to investigate their properties, and to formulate and verify conjectures, i.e. to *act as mathematicians rather than learn about mathematics* (to paraphrase Papert, 1971).

Our experience showed that students mastered their mathematical language; they looked for patterns, formulated hypotheses, posed problems and were highly motivated to prove their own theorems.

As far as the teachers are concerned, Geomland empowered them to a great extent to act like researchers, something they would hardly dare to do otherwise.

Expanding the RGE positive results beyond the pilot schools turned out to be difficult not only for economic and political reasons but also due to the fact that the assessment instruments (for students and teachers alike) were not relevant to its basic principles. Still, some of the main constructionists' ideas (Sendova, 2014) that outlasted the RGE experiment and were reborn in EU projects on STEM education, are as follows:

- IT are a means for self-expression, not an object of education;
- When learning by doing students construct something meaningful to them which could be shared.

Furthermore, the lesson learned was that the learners' and teachers' creativity potential can be stimulated by developing specific ICT-enhanced methodologies and educational resources in support of the inquiry-based learning and creativity.

Examples of Good STEAM Practices in Support of IBL in Mathematics

The current activities of the Institute of Mathematics and Informatics at the Bulgarian Academy of sciences (IMI-BAS) as a center for inquiry-based learning (IBL) include developing and providing an open access to learning environments related to STEAM (the letter **A** standing for art in our case) as well as delivering various types of PD courses for primary and STEM teachers.

A good repository of such educational resources is the *Virtual School Mathematics Laboratory* (VirMathLab, http://www.math.bas.bg/omi/cabinet) being developed by IMI-BAS which contains over 1200 scenarios with dynamic files transparent for the users (Kenderov, Chehlarova, 2016).

Mathematical notions such as *rotation, translation, reflection and compositions of those* are presented in the context of modeling natural phenomena and artifacts (Chehlarova, Sendova, 2010). Some examples are given in Fig. 1. The design and the implementation of these scenarios are just elements of a more ambitious goal – we expect our students to look for manifestations of geometric congruences, discover them and use them in various activities, and thus – to be able to find patterns and relationships deepening their knowledge and understanding of the world around them.

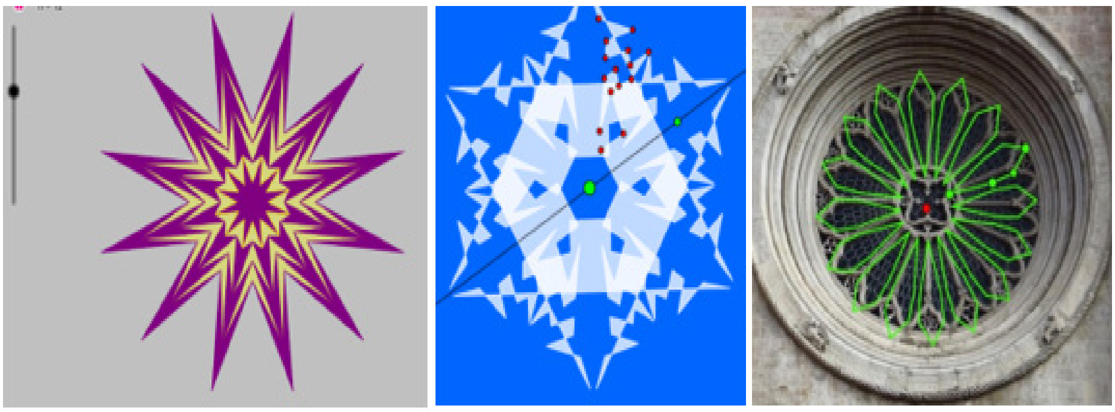


Figure 2. VirMathLab: Dynamic Files for Rotational Symmetry

The Art component of STEAM is considered by providing dynamic applets for: studying fine-art compositions (Sendova, Chehlarova, 2013); facilitating the creation of virtual models in the style of Mondrian, Warhol, Escher (Chehlarova, Sendova, Stefanova, 2012); adding special effects to photographs by artistic explorations based on play with mathematics functions (Chehlarova, T., Chehlarova, K., 2014). Examples are shown in Figure. 2-5.

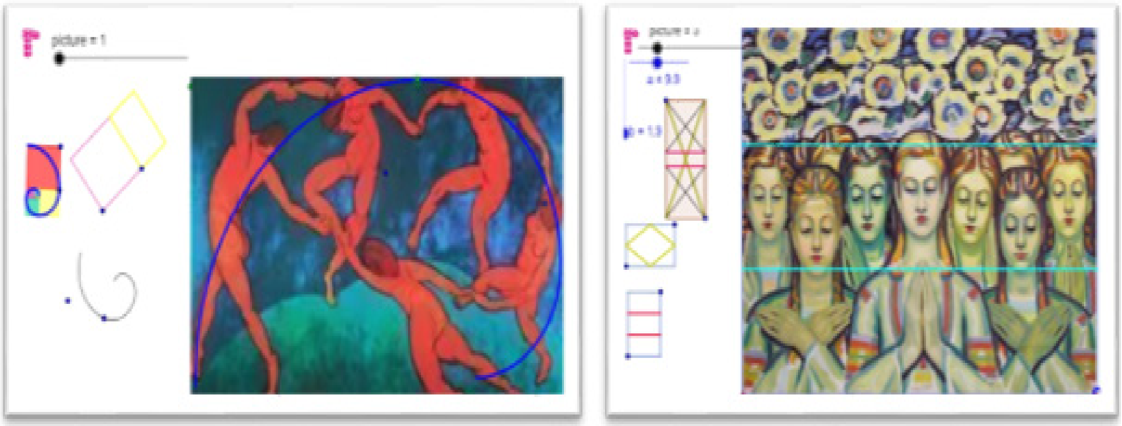


Figure 3. Dynamic Geometric Constructions for Studying Art Compositions

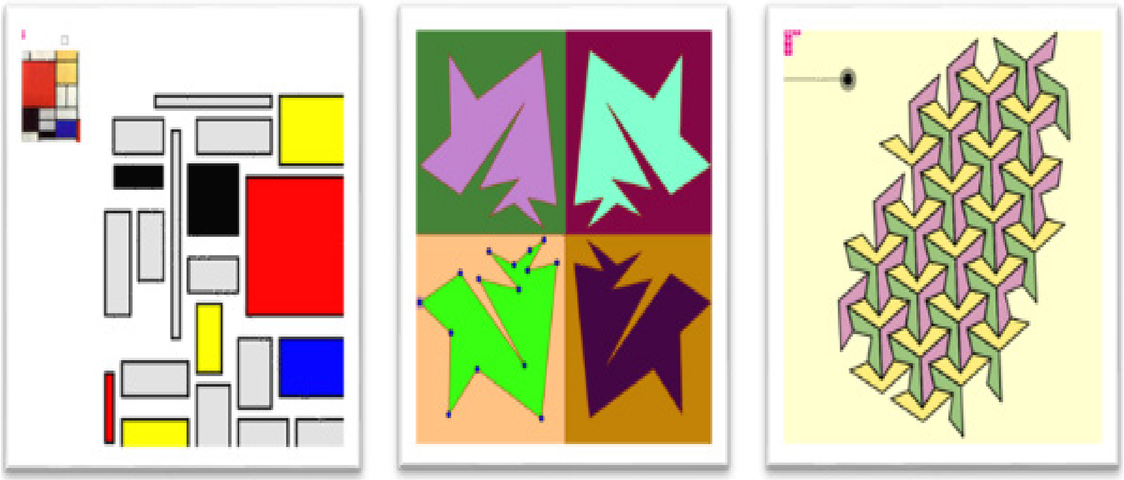


Figure 4. Dynamic Files for Modeling in the Style of Mondrian, Warhol, Escher

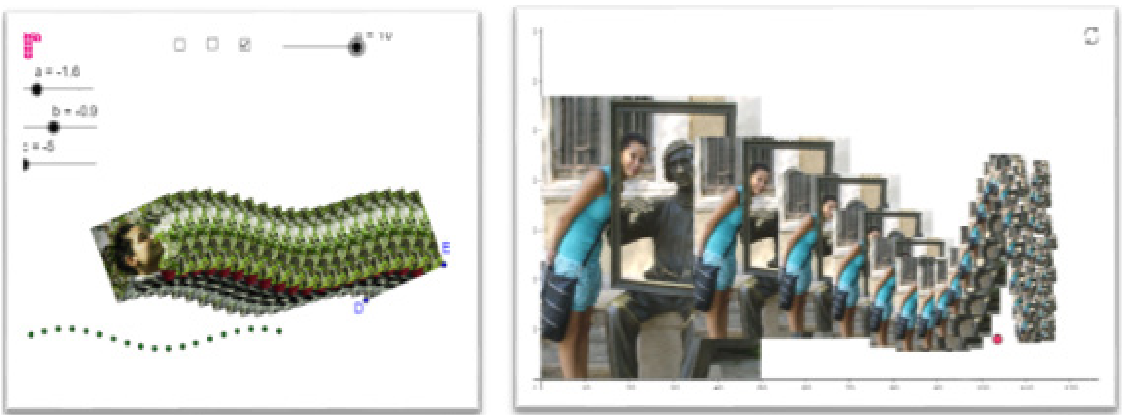


Figure 5. Art Photos Based on Mathematics Functions

Professional Development (PD) Courses for Teachers in Mathematics and IT

The inquiry-based learning, its connection with the world of work, good practices and problems in its implementation in a class- and out-of-class setting have been the focus of our work with teachers.

This approach requires experienced scientific reasoning and domain competences from students, which in turn poses specific challenges for the teachers and the teacher educators.

We encourage teachers to use the VirMathLab resources so as to stimulate students to behave like working mathematicians: to make experiments, to look for patterns, to make conjectures, to verify them experimentally, to apply "what-if" strategies so as to modify/generalize the problem, and even to use them as a preparation for a rigorous proof. To do this without leaving their comfort zone, the teachers enter the role of their students and experience the same type of activities during our courses, and when working on their own. Thus, it would hopefully become quite natural for them to work jointly with the students as a research team.

With this in mind a team of IMI-BAS scientists (including the author) has been involved in organizing novel PD courses in support of such an approach. These PD courses are being organized by IMI-BAS in the frames of European projects (InnoMathEd, Fibonacci, Mascil, KeyCoMath, STEM PD Net and Scientix), as well as by the Union of Bulgarian Mathematicians (UBM), by the Ministry of Education and Science, by publishing houses for educational literature, and by PD centers. The main goal of the courses is in harmony with the most recent educational strategies for updating the math and science education in the EC countries: the development of key-competences by implementing the inquiry-based learning in integration with the world of work. The courses are based on a team work (of the lecturers and the participants alike) and implement educational models adaptable to various school settings. The crucial part of the courses is for the participants to experience different stages and levels of IBL. They first use the dynamic files supporting the scenarios as a ground for explorations. The next step for them is to propose appropriate modification of the files for similar problems, or to use them as a model for creating one of their own from scratch. Typically, the teachers work on pedagogical problems related with: reformulating of math problems in IBL style so as to enhance the development of specific key competences; formulating their own math problems reflecting real-life situations, not solvable with the current math knowledge of the students but allowing for explorations (by means of dynamic geometry models) leading to a good enough approximation of the solution; studying and proposing methods for tackling problems which are unstructured, or whose solutions are insufficient or redundant; solving "traditional problems" with "non-traditional" data, for which the use of a computing device is necessary; applying game-design thinking so as to engage better the students in the problem solving; formulating more relevant evaluation criteria for the students' achievements; assessment of learning resources in terms of formation and development of IBL skills and key competences; project-based work with presentation of the results (Chehlarova, Kenderov, Sendova, 2015).

The key feature of these PD courses is that the teachers do act as partners in a research team −they enter the shoes of their students in an IBL environment. They work in groups, use brainstorming technique to generate ideas for solving specific tasks and present their ideas to the rest of the participants.

New Types of Mathematics Contests

Changing the very character of the learning process by implementing an inquiry-based education and taking into account the new realities in the world of work is not easy in the context of a relatively conservative educational system. To challenge and motivate students on a larger scale to *see through the eyes of professional mathematicians* by exploring problems of mathematical nature with tools available in out-of-class setting, a two novel contests have been launched a couple of years ago (Chehlarova, Kenderov, 2015; Kenderov, Chehlarova, Sendova, 2015). These are *Mathematics with a computer* and *Theme of the month*, based on the *VivaCognita* computer platform (Figure 6).

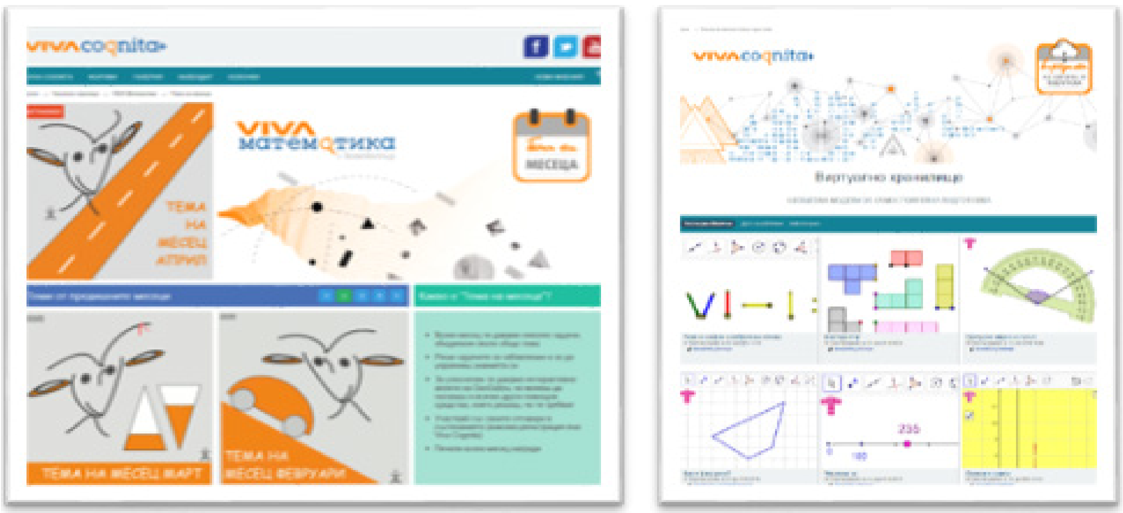


Figure 6. *Theme of the Month*: (Left) and *Virtual Repository* of Math Problems (Right)

Students (3-K12) are invited to work on a chain of problems in increasing difficulty and based on a unifying mathematical idea. Some of the problems in both competitions are accompanied by auxiliary dynamic geometry files (*GeoGebra* files in our case) so that the students could explore a specific mathematics situation, discover relevant properties, try out various strategies and find (possibly an approximate but practically acceptable) solution. Thus, the digital competence the students are developing is expected to go beyond the one of traditional IT users, and to reach its most crucial part – *algorithmic thinking and programing.* Furthermore, the students are expected to develop new mathematical competences thanks to their explorations of mathematical constructions, and observations of mathematical phenomena

The students work on the problems on-line. The data they are expected to enter as solutions are related with essential characteristics of the mathematical objects involved and are acceptable within certain error bounds. Grading the submitted solutions is automatic and the points for every solution depend on its closeness to the correct solution (Gachev, 2015).

On regular basis, the IMI-BAS delivers courses and seminars with teachers got preparing their students for these contests.

Conclusions

With all our efforts we have been trying to help teachers create an atmosphere where the students would experience the excitements of the genuine learning: *How interesting, I wonder what will happen if… I wonder why… I am ready to try something nobody has tried before…*

Our impressions of the work with teachers so far make us optimists about the future of education. One of the main achievements is the organization of communities of teachers who implement and spread the inquiry-based learning of mathematics and informatics. They participate in pedagogical experiments not only as a reality-proof of researchers but as members of a research team. These teachers implement, modify and develop from scratch educational resources in support of IBL, share their good practices at seminars, conferences and in professional journals. Some of them organize public events at a school and regional level for popularizing the inquiry-based mathematics education. Teachers are also key figures in organizing the new contests *Mathematics with a computer* and *Theme of the month*, in making them known to a broader audience. A significant number of teachers already are serving as multipliers of implementing the IBL with the world of work at a school level. These multipliers are further educating new groups of teachers by the cascade method. Some of the multipliers have already developed resources at a level high enough to be included in the repository of the VirMathLab. Others have suggested problems which were included in the contests *Mathematics with a computer* and *Theme of the month* and published on the Viva Cognita portal.

In conclusion, instead of complaining that the STEM (and particularly the math) education is in crisis, let us, the people who care about its destiny (researchers, educators, policy makers), join our efforts to identify, implement and disseminate styles and practices of learning which makes the teachers and students enjoy the explorations on their own right.

References

Akcay, H. (2018). Promoting STEM Education for All Students, in Research Highlights in STEM Education, ISRES Publishing, 2018, 135-145

Chehlarova, T., Kenderov, P., Sendova, E. (2015). Achievements and Problems in the In-service Teacher Education in Inquiry Based Style. Proceedings of the National Conference on "Education and Research in the Information Society", Plovdiv, 2015, ISSN:1314-0752, 21-30

Chehlarova T., Kenderov, P. (2015). Mathematics with a computer—a contest enhancing the digital and mathematical competences of the students. In: Kovatcheva, E., Sendova, E. (Eds.). UNESCO International Workshop: Quality of Education and Challenges in a Digitally Networked World. Za Bukvite, O'Pismeneh. Sofia, 2015, 50–62.

Chehlarova, T., Chehlarova, К. (2014). Photo-pictures and dynamic software or about the motivation of the art-oriented students. In International Journal for Technology in Mathematics Education. vol.21, n1, Plymouth, England, ISSN 1744-2710

Chehlarova, T., Sendova, E., Stefanova, E. (2012). Dynamic tessellations in support of the inquiry-based learning of mathematics and arts, in Theory, Practice and Impact - Proceedings of Cosntructionism 2012, Athens, Kynigos, C., Clayson, J., Yiannoutsou, N. (Eds.) August 21-25, pp.570-574.

Chehlarova et al. (2011). Seeing the innovations as an opportunity, not a threat: lessons from the InnoMathEd European project. 40th Spring Conference of UBM, pp. 347-355, ISSN 1313-3330

Chehlarova, T., Sendova, E. (2010). Stimulating different intelligences in a congruence context. In: Constructionist approaches to creative learning, thinking and education: Lessons for the 21st century. Proceedings for Constructionism 2010. The 12th EuroLogo conference. 16-20 August, Paris, France. ISBN 978-80-89186-65-5 (Proc) ISBN 978-80-89186-66-2

Gachev, G. (2015). Online system for assessing of mathematical knowledge, in Kovatcheva, E. and Sendova. E. (eds.), UNESCO International Workshop:Quality of Education and Challenges in a Digitally Networked World, Za Bukvite, O'Pismeneh, Sofia, Bulgaria, pp. 117-122.

Henriksen, D., Henderson, M., Creely, E. et al. (2018). Tech Know Learn 23: 409. https://doi.org/10.1007/s10758-018-9380-1, pp. 409-424

Kenderov, P., Chehlarova, T. (2016). Extending the class of mathematical problems solvable in school, Serdica Journal of Computing, Volume 9, No. 3-4, 2015, pp 191-206, ISSN 1312-6555

Kenderov, P., Chehlarova, T., Sendova, E. (2015). A Web-based Mathematical Theme of the Month, Mathematics Today, vol. 51, no. 6, pp. 305-309 ISSN 1361-2042

Kenderov, P., Sendova, E., Chehlarova, T. (2015). Communities within the European projects Mascil and Scientix, 44th Spring Conference of the UBM, Sofia, pp. 151-154

Kenderov, P., Sendova, E., Chehlarova, T. (2012). IBME and ICT – the experience in Bulgaria. In Baptist, P. and Raab, D. (Eds.): Implementing Inquiry in Mathematics Education, Bayreuth 2012. pp. 47-54

Maass, K., Doorman, M., Jonker, V. & Wijers, M. (2019). Promoting active citizenship in mathematics teaching. *ZDM Mathematics Education*, 51(7). DOI 10.1007/s11858-019-01048-6

Maass, K. & Engeln, K. (2019). Professional development on connections to the world of work in mathematics and science education. *ZDM Mathematics Education*, 51(7). DOI 10.1007/s11858-019-01047-7.

Nikolov, R. (1987). Integrating Informatics into the Curriculum, in Education & Computing, North-Holland, 1987, pp. 369-374

Papert, S. (1971). Teaching Children to be Mathematicians vs. Teaching About Mathematics, Artificial Intelligence Memo. Number 249, https://files.eric.ed.gov/fulltext/ED077243.pdf (attended November, 2019)

Ryan, J. (2017). *Wait, What? And Life's Other Essential Questions*, HarperCollins Publishers, New York, ISBN 978-0-06-266457-0

Sendov, B., Dicheva, D. (1988). A Mathematical Laboratory in Logo Style, in Lovis, F. and Tagg E.D. (Eds.), Computers in Education – Proceedings of the ECCE'88, Lausanne, Switzerland, North Holland, p. 213

Sendov, Bl. (1987). Education for an Information Age, in Impact of Science on Society, v37, n2, 1987, pp. 193-201

Sendova, E. (2017). Inquiry based learning as a natural vehicle for cross-curricular integration: the Bulgarian experience, in 3. mednarodna konferenca o uˇcenju in pouˇcevanju matematike KUPM 2016, Zbornik izbranih prispevkov, Brdo pri Kranju, 16. in 17. november 2016 / Suban, Mojca; Bone, Jerneja; Rajh, Sonja;

Sirnik, Mateja (ur.). Ljubljana: Zavod RS za solstvo, 2017, pp. 38-47

Sendova, E. (2014). You do – you understand, you explore – you invent: the fourth level of the inquiry-based learning, in Futschek, G., Kynigos, C. (Eds.) Constructionism and Creativity, Proceedings of the 3d International Constructionism Conference, August 19-23, Vienna, Austria, pp. 103 – 112

Sendova, E., (2013). Assisting the Art of Discovery at School Age - a Bulgarian Experience, Third Chapter of Talent Development Around the World, Coordinator Pedro Sanchez-Escobedo, Merida, Yucatan, pp. 39-98

Sendova, E., T. Chehlarova (2013). Studying fine-art compositions by means of dynamic geometry constructions. Scientia iuvenis, Book of Scientific Papers, Scientific guarantee: prof. RNDr. Ľubomír Zelenický, CSc. Slovak republic, Constantine the Philosopher University in Nitra, pp. 495-502 ISBN 978-80-558-0390-6

Sendova, E., Chehlarova, T. (2012). The specifics of teacher education within the Fibonacci project in Bulgaria, in: Baptist, P., D. Raab (eds.): Implementing Inquiry in Mathematics Education, Bayreuth, 2012, pp. 114-124, ISBN 978-3-00-040752-9

Zehetmeier, S. et al. (2015). Concepts for In-Service Mathematics Teacher Education: Examples from Europe. In: Gehring, C., Ulm, F. (Eds.) Developing Key Competences by Mathematics Education. ISBN 978-3-00-051067-0 University of Bayreuth, Germany pp. 23-33

Citation:
Sendova, J. (2019). Good practices using digital technologies in STEM education with a focus on mathematics. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 243-253). ISRES Publishing, ISBN:978-605-698540-9.

Distance Learners' Expactations and Concerns about Educational Social Software

Adem Akbiyik
Sakarya University, Turkey

Introduction

The excessive information movement brought about by the information age leads to a shortening of the information life process, which necessitates the continuation of training activities in order to continuously improve the knowledge and skills (Smit, 2002). The popularity of social software, especially among younger generations (Lenhart, Pew / Internet Research Center, 2011), has been questioning the usability of these technologies in recent years (Williams and Jacobs, 2004; Anderson T., 2005; Alexander, 2006; Anderson P., Mason and Rennie, 2008; Minocha, 2009; Hartshorne and Ajjan, 2009; Brady, Holcomb and Smith, 2010; Poellhuber and Anderson, 2011).

"Social software" used in the study refers to educational social software defined by Terry Anderson (2005). Educational social software is network-based tools that encourage and encourage individuals to learn together- by maintaining control over the times, areas, assets, activities, identities and relationships of individuals (Anderson, 2005: 4).

Social software - especially in distance education - will reduce the loneliness of students (Anderson T., 2005; Kamel Boulos and Wheeler, 2007), and also it will increase motivation by facilitating student-teacher and student-student interaction with active learning (Minocha, 2009). Anderson and Garrison (1998) mentioned the importance of communication technologies supporting continuous interaction in both campus and distance education environments and stated that the quality of learning would increase with the interaction between distance education actors (teacher, student, content). Garrett, Thoms, Soffer, and Ryan (2007), as a result of the design research project carried out in order to increase the online interaction between graduate students and to increase the use of the social software (Elgg Platform) they use for this purpose; that educational social software helps students learn together by reaching each other's work and strengthens the relationships between students; They concluded that this situation increased the social presence and student motivation. Lee and McLoughlin (2010) stated that social software offers excellent opportunities for the possibility of establishing connections and collaborations for distance education programs. Poellhuber and Anderson (2011), in their study about distance education students' readiness to use social media, have reached the conclusion that students are interested in cooperating with their classmates - by age and gender.

In spite of the intensity of the studies aimed at the adoption of social media tools, the inadequacy of studies for the use of educational purposes constitutes an essential gap in this area. In addition, the technology adopted models require the development of educational technology acceptance models due to the fact that they are generally market-oriented and the social aspects of the information system acceptance (Legris, Ingham and Collerette, 2003). At the point; In terms of the acceptance and continuity of the use of social software in distance education, students' expectations and concerns need to be defined.

This study examines concerns and expectations in the context of the adoption of educational social software, which is presumed to fill an important gap in distance education. At this point, it is thought that the study will contribute to the literature in the context of the theory. Theoretically, the study aims to fill the gap in a specific area such as the use of social media in distance education by defining the expectations and concerns of distance education students for the acceptance of the use of educational communication technologies. The findings in this study were obtained from two open-ended questions directed to 574 distance education students studying at the University of Athabasca in Canada and were reported in this study under the groups of concerns and expectations.

Distance Education

Distance education is all educational processes in which all or most of the learning is realized by means of electronic or print, artificial means, allowing for the difference of space and / or time between the student and the teacher (UNESCO, 2002). Distance learning differs from other educational settings and formats due to some basic qualities. Keegan (1986), which is generally accepted in the literature and also referred to by other definitions, list the characteristics that distinguish distance education from other education as follows:

1) the so-called continuous separation of the teacher and the student during the learning period (this distinguishes distance education from traditional education),

2) the impact of an educational institution on the preparation of both planning and learning materials and the provision of student support services (which distinguishes distance education from private study and self-study programs),

3) to utilize technical environments (print, sound, video or computer) to bring together the teacher, the student and the content of the course,

4) to provide a two-way communication environment which the student can use or even start (This situation separates distance education from the use of technology in other education),

5) the pseudo-continuous absence of learning groups during the learning period -

with the possibility of rarely meeting educational and social purposes - so people are considered not at the level of individuals, but at the level of individuals (This article is criticized for not taking into account the many practices (video conferencing technologies, etc.) carried out on a group basis. (Garrison and Shale, 1987; Verduin and Clark, 1991).

Media, which is the tool of interaction between teacher, student, and content in distance education activities, has shown changes in parallel with technological developments up to now and has been the main factor in the development process of distance education. Today, distance education is mainly carried out via internet based systems. Online learning is a branch of distance education, computer-based learning, Internet-based learning, virtual classrooms and digital collaborations, such as a wide range of technological applications and learning processes (Urdan and Weggen, 2000).

Online Learning

The development and diffusion of the Internet provide the possibility of eliminating the dependence of time and space on the communication of information transmitted to the electronic environment by digitizing. In the 90s, computer and communication technologies, which are used as educational tools (multimedia tools), are seen as the environments where all the elements of education are provided with the opportunities offered by the internet (Odabaş, 2004). These systems, called online learning, provide students with: Internet-based educational environments that allow access to course materials, classmates, and faculty via online communication tools (Bonk and Reynolds, 1997).

Hybrid Education

Although the hybrid teaching approach covers many different applications, it is generally defined as the combination of face-to-face learning and online resources (Mason and Rennie, 2008). The hybrid teaching approach offers students more interaction with their classmates and faculty members in online or offline types (Allen and Seaman, 2003).

The assumption underlying hybrid teaching is the advantages of using online methods as well as the nature of face-to-face interaction (Clark and James, 2005). At this point, they try to create the most appropriate learning environment by using internet technologies according to the structures and requirements of the courses by going to the differences in the level of utilization of internet technologies in the academic activities of universities.

Table 1. Types of Courses According to Utilization Rates from Internet Technologies

Internet Technologies Benefit Rate	Course Type	Description
%0	Traditional	The courses where the traditional contents are delivered verbally and textually.
%1-%29	Internet Assisted	Internet-based technologies are used in order to relieve face-to-face lessons. Students carry out their activities such as course program and homework submission via a learning management system (LMS).
%30-%79	Hybrid / Mixed	Face-to-face training and online education are combined. An important part of the content is delivered over the Internet. Includes partial online meetings and partial face-to-face meetings.
%80	Online	Courses where the content is delivered entirely online and generally does not hold face-to-face meetings.

Source: Allen, E., Seaman, J., & Garret, R. (2007). Blending In:The Extent and Promise of Blended Education in the United States. p. 5.

In accordance with the learning styles of educational institutions with a student-centered approach, the learning environment, which they try to design by using many different areas of distance education, is the concept of distributed education which is frequently mentioned together with the concept of distance education. In hybrid education, learning activities can be in a campus environment (geographic distribution is not a must), in distributed education, from face to face education to distance education, all educational applications can be used, face to face training is not a must (Mason and Rennie, 2008).

Distributed Education

Distributed education can be defined as a combination of some face-to-face learning interactions simultaneously (synchronous) or asynchronously (asynchronously) through technologies aimed at creating a student-centered learning environment (Lefoe, 2003). Distributed education aims at providing learning environments that enhance interaction and collaboration by changing the learning environment to best suit the learning styles, whether or not students are in the campus environment (Mason and Rennie, 2008: 25).

Student-Centered Learning

In the literature, it is stated that highly flexible course designs should be developed with a student-centered approach rather than an instructive-centered approach (Motschnig-Pitrik and Holzinger, 2002; Gudmundsson and Mathiasdottir, 2004).

The teaching-centered approach, also known as the traditional paradigm and the most dominant approach to the present, is to offer an educational institution teaching (Barr and Tagg, 2000) and in this context, 50 to 75-minute course deliveries are carried out to carry out the teaching. Finally, the mission of the educational institution is the delivery of the course (Saulnier et al., 2008). In this structure, the instructor and institution that determine the limits of what to learn are at the center of the learning environment.

A student-centered approach is an approach based on individual or solidarity (team-based) learning that gives students responsibility for their learning, rather than active learning for teachers (Felder and Brent, 1996). In a student-centered approach, it is not about transferring knowledge from educational institutions, but for students to discover and create events and environments so that they can access the information they will configure properly (Saulnier et al., 2008). The role of the instructor in this structure is to set up an interaction environment infrastructure for students and help them in their individual or collective sense of meaning (Mason and Rennie, 2008).

John Tagg (2003) focused on time and learning dimensions to reveal the difference between these two paradigms. Tagg (2003) states that in the instructional paradigm, time is fixed, but learning is variable, that is, a course hour spent in the classroom is fixed, but at this time, how much students learn is variable. In the student-centered paradigm, it is stated that learning is fixed and time is changing. This shows that the student-centered approach values individuals and individual differences, cooperation, and teamwork as opposed to the instructional approach, and puts learning in the center of all decisions rather than knowledge (Harris & Cullen, 2010).

Education and Social Software

Social software concept, although the idea of supporting the group interaction was based on earlier, was put forward by Clay Shirky in 2002 at the Social Software Summit in order to cover all software intended for this purpose (Allen C., 2004). Despite the expressions available for the software that supports the aforementioned group interaction (group software - groupware, computer-mediated communication, social programming - social computing, etc.), Despite the expressions available for the aforementioned group interaction software (group software - groupware, computer-mediated communication, social programming - social computing, etc.), Shirky claims that these older terms are insufficient to express existing new technologies and cause pollution, and that the term social software includes new generation technologies even though interaction is offline (Boyd, 2006).

Educational Social Software

The popularity of social software, especially among younger generations (Lenhart, 2011), leads to questioning the usability of these technologies for educational purposes in recent years. Ferdig (2007) stated that although social software is not designed for educational purposes, it has features that make them useful for teaching and learning environments. Especially Internet 2.0 based applications; It is seen as quite suitable as educational tools with its features like accessibility, ease of use (Schofield, 2003), functionality and flexibility (Chen et al., 2005). Kamel Boulos and Wheeler (2007: 3-4) stated that the collaborative, flexible, participatory, and interactive structure of Internet 2.0 applications is suitable for educational purposes.

The concept of educational social software was first introduced by Terry Anderson (2005). Anderson (2005: 4) describes educational social software as; network-based tools that support and encourage individuals to learn together - maintaining control over their own times, areas, assets, activities, identities and relationships.

Ajjan and Hartshorne (2009: 72) in response to the question "why internet 2.0 for the educational environment?" indicated that:

1) New generations known as digital natives have already adapted to these systems (Leslie and Landon, 2008) that changing internet structure offers opportunities for higher education to produce, acquire and share information (Maloney, 2007),

2) Internet 2.0 is a social process that takes place through the exchange of interactions and mutual knowledge (Vygotsky, 1978), and constitutes a suitable infrastructure for the social learning approach (Ferdig, 2007), which envisages a structuralist education approach and active participation,

3) Finally, through internet 2.0, students stated that they would be able to publish their work in a global environment, thus gaining many educational achievements as well as motivation.

Studies to demonstrate the suitability of social software tools for educational use show that social software tools, which the new generations are mostly familiar with, have the potential to reduce the time and space barriers in education, as well as to complement the social aspect of education by providing a working environment.

Educational Social Software in Distance Education

In today's higher education institutions, having the best possible performance with fewer resources obliges universities to be governed by basic business principles (Kozeracki, 1998: 1). The intensely competitive environment in the higher education system, where students are now perceived as some kind of consumer, also requires a meeting or exceeding the needs (Coates, James and Baldwin, 2005). Different communication channels in education and training programs are emerging. All these financial and social constraints lead universities to integrate more flexible and more effective learning processes worldwide (Beller and Or, 2003). In recent years, distance education has come to the fore to respond to the needs of society and universities at this point.

Media, which is the tool of interaction between teacher, student, and content in distance education activities, has shown changes in parallel with technological developments up to now and has been the main factor in the development process of distance education. Today, distance education is mainly carried out via internet based systems. However, the developments on Internet 2.0 technologies force the technologies used in the distance education environment to update once again.

Armstrong and Franklin (2008: 12) base the two main reasons why internet 2.0 is vital for higher education: 1) students are increasingly benefiting from these technologies in their business and social lives, and they expect the educational institutions to have the vision to provide the same opportunities in virtual learning environments, 2) The Internet 2.0 environment provides functions and tools that strongly support the next generation of educational approaches.

The popularity of social software, especially among younger generations and the high potential of educational use in the literature, raises the question of how to integrate this software into educational environments. When considered with a student-centered approach, the adaptation of students to these technologies becomes the primary focus. Therefore, it is necessary to reveal the expectations and expectations of the students about educational social software.

Expectations and Concerns for Educational Social Software

Expectations represent the lower expectations that the individual believes will achieve with the use of social software. The belief in expectation determines attitude towards a particular behavior (Fishbein and Ajzen, 1975). Students' expectations for educational social software are categorized in the table below.

Concerns represent the negative expectations or concerns that a person believes will arise with the use of social software.

Table 2. Expectations for Educational Social Software

Category	Sub-category	Description
Interaction	Student - Stıdent	Students want to share information and documents with their classmates and be more involved.
Interaction	Student - Teacher	The students want the faculty members to be more accessible, more interacting.
Social Software Usage	Simplicity	Students want to make the use of social software easy and understandable.
Time Management	Effective Time Management	Students will be able to use homework, exams, etc. they want to accelerate the deliveries and feedbacks of the activities and thus save time in their educational processes.
Time Management	Effective Time Management	The students want the use of social software to offer flexibility in time and space in the training calendar they prepare in accordance with their lifestyle.
Course Quality	Technology Contribution	Students want the use of social software to facilitate learning processes and help them to improve their success.
Course Quality	Technology Contribution	Students want the use of social software to help the distance education environment to achieve the quality of face-to-face education environment and enrich the educational environment.

Source: Akbıyık, A. (2012). *A study on determining the factors affecting the use of social software in distance education*. (Doctoral Dissertation). Sakarya University.

Student-student interaction is a measure of the expectation that the student will increase the possibility of meeting with classmates through social software, changing information, or changing documents. Moore (1989) stated that interaction between the students considered in distance education in the 1990s is sometimes an essential resource for education and sometimes even a necessity. Anderson and Garrison (1998) stated that student-student interaction and cooperative learning should be included in distance education in order to improve the quality of education. According to the results of the qualitative analysis, one of the expectations of students from social software tools is that they offer more interaction with their classmates.

The student-teacher interaction is a measure of the expectation that the student will be able to get in touch with the lecturers through social software, to get advice and support. A student-teacher interaction in which the influence of faculty members on students is frequent and intense is better than the student's interaction with content

(Moore, 1989). However, due to the structure of distance education, the interaction between students and teachers in separate spaces requires an intermediary (Anderson and Garrison, 1998). Social software tools have the potential to see this agent role. According to the results of the qualitative analysis, the students are expected to have more interaction with the faculty members who take their courses from the expectations of social software tools.

The contribution of technology is the measure of the expectation that the educational environment will be enriched by the student through social software, thus improving the learning process and the current success. According to the results of qualitative analysis, students' expectations from social software tools are to enhance the educational environment and to increase the ease of learning and success.

Table 3. Concerns for Educational Social Software

	Category	Sub-category	Description
CONCERNS	Interaction	Perceived Student Obstacle	Students are concerned that the interaction environment with their classmates will delay or prevent their education.
	Interaction	Perceived Student Obstacle	Students are concerned that the use of social software will threaten their personal information and privacy.
	Interaction	Perceived Teacher Obstacle	Students are concerned that they will have more difficulty in reaching the faculty member with the use of social software.
	Social Software Usage	Complexity	Students may find the use of social software difficult and complicated and worry that this situation will delay or prevent their education.
	Time Management	Waste of Time	Students are concerned that more time is needed to keep track of a large number of information flows.
	Course Quality	Intensive Technology Obstacle	Students may be satisfied with the existing structure in distance education and may not want them to change.
	Course Quality	Intensive Technology Obstacle	Students are concerned that the use of social software and the intensive technology in the future will lead to an out-of-class goal and quality.

Source: Akbıyık, A. (2012). *A study on determining the factors affecting the use of social software in distance education*. (Doctoral Dissertation). Sakarya University.

The perceived student disability is a measure of the student's concern about delaying /

blocking the education of the interaction environment due to social software. Coppola, Hiltz and Rotter (2004) stated that it is crucial for successful online interactions but that virtual classes contain more uncertainty, risk, and expectation than traditional education environment.

According to the qualitative research findings; the interaction environment that will occur as a result of the use of social software may cause problems in the confidentiality of personal information, unauthorized information and document sharing, and this may result in delayed or blocked training.

The perceived teacher disability is the measure of the student's concern about the indifference of faculty members to the interactive environment that will arise due to social software. Heckman and Annabi (2005), in their study on interaction in face-to-face and online learning environments, found that the teacher presence was more common in face-to-face discussion sessions and that the teaching process in the timeless learning networks such as discussion forums was mostly carried out by students rather than teachers.

According to the qualitative research findings, students are concerned that the interactive environment that will be formed as a result of the use of social software will not show enough interest for technical skills or other reasons. Therefore, they will not be able to use the fast return opportunities provided by social software tools.

The intense technology dimension refers to the extent to which the student will be exposed to a high technology environment due to social software and that this situation will harm the quality of education. Brown (2009) stated that the focus group work with students from different educational institutions is that the idea that too much or unfettered technology is terrible and that it directly interferes with the education is frequently mentioned by the students. According to the qualitative study findings, there is a concern that a technology environment, which is too much for students, will hinder education.

As a result of the changes and updates, basic categories and subcategories have been reached. The thematic structure is divided into two as expectations (positive / negative) for the output of the system and for the use of the system. These positive and negative expectations are expressed as expectations and concerns.,

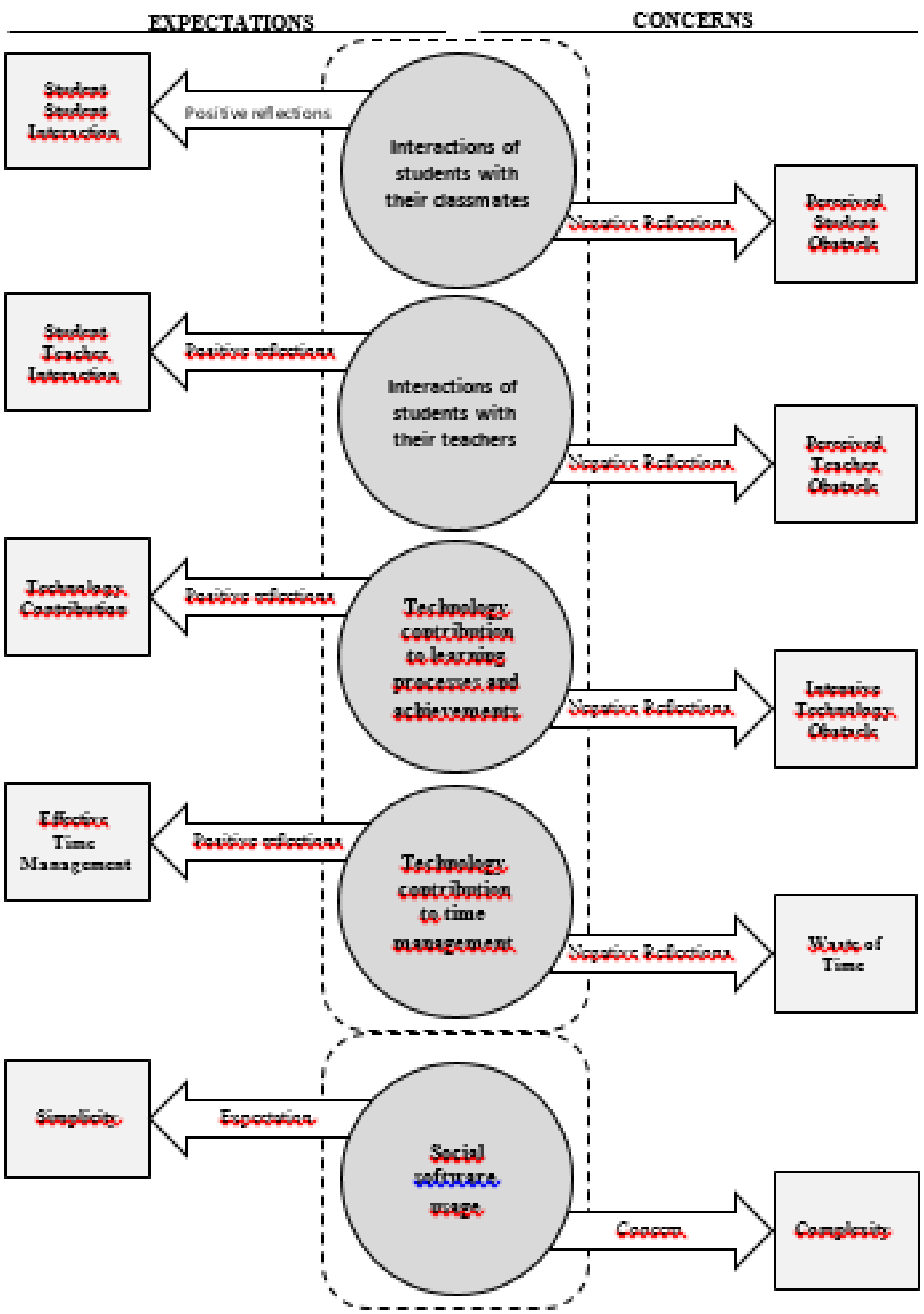


Figure 1. Thematic Structure for Expectations and Concerns

Source: Akbıyık, A. (2012). *A study on determining the factors affecting the use of social software in distance education.* (Doctoral Dissertation). Sakarya University.

Conclusion

The developments in communication technologies and their reflections on daily life have made the Internet one of the most important needs of human beings. One of the most common uses of internet technologies, which offers many different service options, is realized through social software tools. The popularity of social software, especially among young generations, has been questioning the usability of these technologies for educational purposes in recent years. This study aims to answer the expectations and concerns of distance education students.

Students who use social software in distance education programs expect;

- To share information and documents with classmates and to have more interaction (student - student interaction),
- more accessible, more interaction of faculty members (student - teacher interaction),
- Easy and understandable use of social software (simplicity),
- Use of social software, homework, exam, etc. speeding up deliveries of the activities and their feedback, thus saving time in their academic processes (processing speed),
- To offer flexibility in time and space in the training calendar prepared by the use of social software in accordance with their lifestyles (flexibility),
- To help the use of social software to facilitate learning processes and to increase their success (easy learning and success),
- The use of social software to help the distance education environment to achieve the quality of face-to-face education environment, enrich the educational environment (enrichment).

In general, students; It is concluded that they have more expectations to be more interacting with their classmates and faculty members, easy and comprehensible software to be used, gaining time and flexibility in their academic processes, increasing the ease and success in learning processes, and enriching the educational environment in terms of content.

On the other hand, students are anxious about;

- that the interaction environment that will occur with classmates will delay or prevent the education (perceived student disability),
- they will have more difficulty in reaching the lecturer (perceived teacher disability) with the use of social software,
- The use of social software may find it difficult and complex and will delay or prevent its education (complexity),
- the fact that this situation will leave behind them because of the lack of

knowledge and experience about the use of social software,

- The technical competence and reliability of social software tools may be insufficient and will delay or prevent their education (technical problems),
- Students need to spend more time to track a large number of information flows (loss of time),
- Students will reduce the flexibility of time and space using social software (flexibility),
- Students may be satisfied with the current structure of distance education and change (satisfaction),
- With the use of social software and the intensive technology environment that will occur after the course, the quality of the lessons can go beyond the target (intensive technology),
- the use of social software to threaten personal information and privacy (private life and privacy),
- Compulsory use of social software

In general, students; It has been concluded that the instructors cannot delay their education and that they do not have enough knowledge about these technologies and that they can be irrelevant and that the intensive technology environment can harm the quality of education.

References

Ajjan, H., & Hartshone, R. (2009). Investigating Faculty Decisions to Adopt Web 2.0 Technologies: Theory and Empirical Tests. *The Internet and Higher Education, 11*(2), s. 71-80.

Akbıyık, A. (2012). *Uzaktan Eğitim Ortamlarinda Sosyal Yazilim Kullaniminin Kabulünü Etkileyen Faktörlerin Belirlenmesine Yönelik Bir Çalışma*. (Doctoral Dissertation). Sakarya University.

Alexander, B. (2006). Web 2.0: a new wave of innovation for teaching and learning? *EDUCASE Review, 41*(2), 32-44.

Allen, C. (2004). Tracing the Evolution of Social Software. Life With Alacrity (Blog).

Allen, E., & Seaman, J. (2003). *Sizing The Opportunity: The Quality and Extend of Online Education in the United States, 2012 and 2013*. Aralık 20, 2011 tarihinde

Sloan Consortium: http://sloanconsortium.org/publications/survey/sizing_the_opportunity2003 adresinden alındı

Allen, E., Seaman, J., & Garret, R. (2007). *Blending In:The Extent and Promise of Blended Education in the United States.* Aralık 20, 2011 tarihinde The Sloan Consortium: http://sloanconsortium.org/sites/default/files/Blending_In.pdf adresinden alındı

Anderson, P. (2007). *What is Web 2.0? Ideas, technologies and implications for education.* JISC Technology & Standarts Watch.

Anderson, T. (2005). *Distance Learning: Social Software's Killer App?* May 2012 tarihinde AUSpace: http://auspace.athabascau.ca/bitstream/2149/2328/1 /distance_learning.pdf adresinden alındı

Anderson, T., & Garrison, R. (1998). Learning in a Networked World: New Roles and Responsibilities. C. C. Gibson içinde, *Distance Learners in Higher Education: Institutional Responses for Quality Outcomes* (s. 97-112). Wisconsin: Atwood Publishing.

Armstrong, J., & Franklin, T. (2008). *A Review of Current and Developing International Practice in the Use of Social Networking (Web 2.0) in Higher Education.* Franklin Consulting.

Barr, R. B., & Tagg, J. (2000). From Teaching to Learning: A New Paradigm for Undergraduate Education. D. DeZune içinde, *Learning From Change: Landmarks in Teaching and Learning in higher Education from Change Magazine 1969-1999* (s. 198-200). Sterling, Virginia: Stylus Publishing, LLC.

Beller, M., & Or, E. (2003). Learning Technologies at The Service of Higher Education: Global Trends and Local Israeli Opportunities. *Work, 20*(1), s. 23-33.

Bonk, C., & Reynolds, T. (1997). Learner-centred Web Instruction for Higher Order Thinking, Teamwork, Apprenticeship. B. Khan içinde, *Web-Based Instruction* (s. 167-178). Englewood Cliffs, NJ: Educational Tehcnology Publications.

Boyd, D. (2006). *The Significance of Social Software*. 12 10, 2011 tarihinde http://www.danah.org/papers/BlogTalkReloaded.html adresinden alındı

Brady, K. P., Holcomb, L. B., & Smith, B. V. (2010). The Use of Alternative Social Networking Sites in Higher Educational Setting: A Case Study of the E-Learning Benefits of Ning in Education. *Journal of Interactive Online Learning, 9*(2), s. 151-170.

Brown, M. (2009). *Learning and Technology — "In That Order".* April 2012 tarihinde EDUCAUSE Review: http://www.educause.edu/

EDUCAUSE+Review/EDUCAUSEReviewMagazineVolume44/LearningandTechnologyInThatOrd/174198 adresinden alındı

Chen, H., Cannon, D., Gabrio, J., Leifer, L. T., & Bailey, T. (2005). Using Wikis and Weblogs to Support Reflective Learning in an Introductory Engineering Design Course. *Proceeding of the 2005 American Society for Engineering Education Annual Conference & Exposition.* Portland, Oregon: American Society for Engineering Education.

Clark, I., & James, P. (2005). Blended Learning: An Approach to Delivering Science Courses Online. *Proceedings of the Blended Learning in Science Teaching and Learning Symposium* (s. 19-24). Sdney: UniServe Science.

Coates, H., James, R., & Baldwin, G. (2005). A Critical Examination of The Effects of Learning Management Systems on University Teaching and Learning. *Tertiary Education and Management, 11*(1), s. 19-36.

Coppola, N. W., Hiltz, S. R., & Rotter, N. G. (2004). Building Trust in Virtual Teams. *IEEE Transactions on Professional Communication, 47*(2), s. 95-104.

Felder, R. M., & Brent, R. (1996). Navigating the Bumpy Road to Student-Centered Instruction. *College Teaching, 44*(2), s. 43-47.

Ferdig, R. (2007). Examining Social Software in Teacher Education. *Journal of Technology and Teacher Education, 15*(1), s. 5-10.

Fishbein, M., & Ajzen, I. (1975). *Belief, Attitude, Intention, and Behavior.* New York: Wiley.

Garrett, N., Thoms, B., Soffer, M., & Ryan, T. (2007). *Extending the Elgg Social Networking System to Enhance the Campus Conversation.* April 2012 tarihinde http://map.ipgkti.edu.my/resource/ppismptesl/refer-internet_htm_files/Elgg-social%20network%20system%20to%20enhance%20campus%20conversation.pdf adresinden alındı

Garrison, D., & Shale, D. (1987). Mapping the Boundaries of Distance Education: Problems in Defining the Field. *American Journal of Distance Education, 1*(1), s. 4-13.

Gudmundsson, A., & Mathiasdottir, A. (2004). *Distributed learning in the Nordic Countries and Canada.* Ocak 10, 2012 tarihinde European Journal of Open, Distance and e-Learning: http://www.eurodl.org/index.php?tag=176&article=176&article=140 adresinden alındı

Harris, M., & Cullen, R. (2010). *Leading the Learner-Centered Campus: An Administrator's*

Framework for Improving Student Learning Outcomes. San Francisco, CA: Jossey-Bass.

Hartshorne, R., & Ajjan, H. (2009). Examining Student Decisions to Adopt Web 2.0 Technologies: Theory and Empirical Tests. *Journal of Computing in Higher Education, 21*(3), s. 183-198.

Heckman, R., & Annabi, H. (2005). A Content Analytic Comparison of Learning Processes in Online and Face-to-Face Case Study Discussions. *Journal of Computer-Mediated Communication, 10*(2).

Kamel Boulos, M., & Wheeler, S. (2007). The Emerging Web 2.0 Social Software: An Enabling Suite of Sociable Technologies in Health and Health Care Education. *Health Information and Libraries, 24*(1), s. 2-23.

Keegan, D. (1986). *Foundations of Distance Education* (2nd b.). London: Routledge.

Kozeracki, C. (1998). Institutional Entrepreneurship in Higher Education. *CELCEE Digest, 98*(5).

Lee, M. J., & McLoughlin, C. (2010). Beyond Distance and Time Constraints: Applying Social Networking Tools and Web 2.0 Approaches in Distance Education. G. Veletsianos içinde, *Emerging Technologies in Distance Education* (s. 61-87). Edmonton: AUPress.

Lefoe, G. (2003). *Characteristics of a Supportive Context for Distributed Learning: Case Study of the Implementation of a New Degree.* Ed.D. Thesis, University of Wollongong, Faculty of Education.

Legris, P., Ingham, J., & Collerette, P. (2003). Why Do People Use Information Technology? A Critical Review of the Technology Acceptance Model. *Information & Management, 40*, s. 191-204.

Lenhart, A. (2011, July). *Pew/Internet Research Center*. Nisan 20, 2012 tarihinde Pew/ Internet & American Life Project: http://pewinternet.org/Trend-Data-(Teens).aspx adresinden alındı

Maloney, E. (2007). What Web 2.0 Can Teach Us About Learning. *Chronicle of Higher Education, 25*(18), s. B26.

Mason, R., & Rennie, F. (2008). *E-Learning and social Networking Handbook: Resources for Higher Education* (1 b.). New York: Routledge.

Minocha, S. (2009). Role of Social Software Tools in Education: A Literature Review.

Education + Training, 51(5/6), 353-369.

Moore, M. G. (1989). Editorial: Three Types of Interaction. *American Journal of Distance Education, 3*(2), s. 1-7.

Motschnig-Pitrik, R., & Holzinger, A. (2002). Student-Centered Teaching Meets New Media: Concept and Case Study. *Educational Technology & Society, 5*(4), s. 160-172.

Poellhuber, B., & Anderson, T. (2011). Distance Students' Readiness for Social Media and Colloboration. *The International Review of Research in Open and Distance Learning, 12*(6), s. 101-125.

Saulnier, B. M., Landry, J. P., Longenecker, H. E., & Wagner, T. A. (2008). From Teaching to Learning: Learner-Centered Teaching and Assesment in Information Sytems Education. *Journal of Information Systems Education, 19*(2), s. 169-174.

Tagg, J. (2003). *The Learning Paradigm College.* San Francisco: Jossey-Bass/Anker.

UNESCO. (2002). *Open and Distance Learning.* Aralık 2011, 20 tarihinde UNESCO - Documents: http://unesdoc.unesco.org/images/0012/001284/128463e.pdf adresinden alındı

Urdan, T., & Weggen, C. (2000). *Corporate E-Learning: Exploring A New Frontier.* W.R. Hambrecht & Co.

Verduin, J., & Clark, T. (1991). *Distance Education: The Foundations of Effective Practice.* San Francisco: Jossey-Bass.

Vygotsky, L. (1978). *Mind in Society: The Development of Higher Pyschological Processes.* Cambridge, MA: Harvard University Press.

Williams, J. B., & Jacobs, J. (2004). Exploring the use of blogs as learning spaces in the higher education sector. *Australasian Journal of Educational Technology, 20*(2), 232-247.

Citation:
Akbiyik, A. (2019). Distance learners expactations and concerns about educational social software. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 254-270). ISRES Publishing, ISBN:978-605-698540-9.

Incorporating Assistive Technology for Students with Disabilities

Muhammad Zayyad

Al-Qasemi Academic College of Education, Israel

In the past three decades, there has been a growing exploration and recognition of the importance of assistive technology (AT) in the lives of students with disabilities in various forms of academic settings. The rapid expansion of the many uses of technology and computers in almost every aspect of our lives in general, and in most of our educational settings in particular, has drawn the attention of researchers regarding the impact of technology as a mediator in the learning achievement and performance of individuals with disabilities (Adebisi, Liman & Longpoe, 2015; Alper & Raharinirina, 2006; Atanga, Jones, Krueger & Lu, 2019; Blackhurst & Edyburn, 2000; Goor, Schwenn & Boyer, 1997, King-Sears, Swanson & Mainzer, 2011; Stearns, 2012). This awareness has pushed the agenda of policymakers worldwide to provide assistive devices needed to promote self-care, education, employment, leisure, and recreation for learners with disabilities (Ajuwon & Chitiyo, 2016). It has also brought to the forefront the need for effective legislation to train professionals in AT and to provide necessary supports for school principals, teachers, and educational providers to alleviate the learning and social inclusion gaps.

Background

As the vast majority of educators and policy makers strongly promote the philosophy of including individuals with disabilities to the maximum extent in the least restrictive environment (Howard, 2004; Rozalski, Stewart & Miller); the need to meet such an educational approach is critical and the challenges for adjustments and accommodations for all children and adults with disabilities are great as well (Marshak, Van Wieren, Ferrell, Swiss & Dugan, 2010; Owuor, Larkan, Kayabu, Fitzgerald, Sheaf, Dinsmore, ... & MacLachlan, 2018). According to the mandates in the Individuals with Disabilities Education act of 1997 (IDEA), all students must have the opportunity to access the core curriculum (Irish, 2003). Among those integrated individuals with disabilities are students with learning disabilities (LD) who are considered to be the largest student population with disabilities to be integrated within the general education system.

Since the reauthorization of the Individuals with Disabilities Education Act (IDEA) in the United States which was passed in 1997, the number of LD students who are included within the regular education system and taught in general education classrooms has increased consistently and substantially (Kim, Woodruff, Klein, & Vaughn, 2006; Perelmutter, McGregor & Gordon, 2017). According to the report of the US Department of Education in 1994, over 70% of LD students were integrated in the regular education classroom (Koury, 1996). Later the US Department of Education (2000) reported that over 80% of LD students spend more than half of their learning time in regular education classrooms. In a recent report, the National Center for Learning disabilities (2016), indicated that 70% of students with specific LD spend more than 80% of their academic day in the general education classrooms.

This substantial increase in the percentage of integrated students with LD in the general educational system has drawn the attention of researchers and educators, who have tried to explore more educational methods and strategies that target their learning engagement to the maximum extent by examining the effect of AT on their learning performance (e. g., Anna Courtad & Bouck, 2013; Carver, Ganus, Ivey, Plummer & Eubank, 2016; Hall, Huges & Filbert, 2000; Hutinger, Johanson & Stoneburner, 1996; Raskind & Higgins, 1998; Watson, Ito, Smith & Andersen, 2010).

Students with LD experience significant difficulties with learning and grasping academic concepts in these settings, due to their processing deficiencies and social and behavioral adjustment problems. They are cognitively challenged in many areas, such as comprehension, organization, retaining information and linking it to prior knowledge, which affect their performance in reading, writing, math, reasoning, and grasping abstract concepts (Cheung & Slavin, 2013; Floyd & Judge, 2012; Hetzroni & Shreiber, 2004; Maccini, Gagnon & Hughes, 2002).

A major goal for educators working with LD students is to provide appropriate support and alternative teaching strategies to enhance their performance in academic and social skills to the maximum of their potential abilities (Hetzroni & Shreiber, 2004; McArthur, Ferretti, Okolo & Cavalier, 2001). One of the promising fields in education that is connected directly with the work of both teachers and students is the use of technology and computers in various ways to promote their learning (Maccini et al, 2002; McArthur et al., 2001). Recently, technology has been viewed as a promising instructional tool to mediate and accelerate the learning of all students, including those with various types of disabilities (Kim et al., 2006; Edyburn, 2004; Poonam & Nitika, 2017; Svensson, Nordström, Lindeblad, Gustafson, Björn, Sand,... & Nilsson, 2019; Stauter, Prehn, Peters, Jeffries, Sylvester, Wang & Dionne, 2019).

The importance of using technology in education has been widely discussed in the literature over the last three decades (e.g., Behrmann & Jerome, 2002; Bouck, 2010; Bouck, 2016; Bouck, Flanagan, Miller & Bassette, 2012; Hutinger, Johanson & Stoneburner, 1996; Kim et al., 2006; Poonam & Nitika, 2017; Raskind & Higgins, 1998). Just to give a brief glimpse of the growing interest of researchers regarding the integration of technology in the field of special education, a one year review of published articles in 31 international journals in the fields of early childhood, regular and special education, and technology in 2001 yielded 192 published articles related to assistive technology or and computer assisted instruction (Edyburn, 2002). In another review that was conducted by the Edyburn, two years later, a total number of 224 studies were located with a direct connection to special education and technology (Edyburn, 2004). In the recent years, the number of studies conducted on this topic has just increased.

Categories of Technology Integration

Recently the literature identified two main categories that include technology integration in the field of education for students with disabilities: a) tools that are used as a tutor and aim to enhance the learning skills, and b) tools that assist students in engaging in the learning activity (Sun Associates, 2010). Emerged from those two categories, four subcategories that have been identified as specific tool for the learning improvement. They include: a) technology used as stand-alone activity which provides instructions that are independent of the core school curriculum, b) technology that provides more independent learning chances and various practice drills, c) technology that is embedded into the teaching process, and d) technology for at risk students to accommodate for their skill deficits, especially for students with mild disabilities. When technology is being used as a stand-alone instruction, students would interact with the program and receive integrated practice as opposed to direct teaching where the teacher in the center. Such programs, are described as computer-based or web-based programs or interventions and they are designed specifically for struggling students.

The second major category in technology is to be used as an embedded instruction. The instructor uses graphic organizers, maps, or virtual manipulatives to illustrate concepts and to provide another method for those who have difficulties grasping concepts in a direct teacher-led fashion (Lacina, 2006). Those activities can be used with interactive tools to assist the learning, such as whiteboard, desktop computers, tablets, or other mobile devices. Interactive devices can help with the learning planning, analyzing, organizing, and summarizing of the materials.

Continuum of Assistive Technology

Assistive Technology (AT) has been regarded as a pivotal instrument in the educational system for all students in general and for those with disabilities in particular. AT defined as technology that increases, improves, or maintains the functional capabilities of students with disabilities (Mittler, 2007). It is designed to create more independence for individuals with disabilities to overcome environmental barriers that may hinder their learning in the various educational settings (Rose, Hasselbring, Stahl & Zabala, 2005).

AT devices are defined as “any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of a child with a disability” (IDEIA, 2004b).

Similarly, AT services can be defined as "any service that directly assists a child with a disability in the selection, acquisition, or use of an assistive technology device" (IDEIA, 2004c).

Blackhurst (2005) explores the various types and designs of assistive technology (AT) methods that have been developed and used in the educational arena to promote the learning and educational environment of students with learning disabilities. AT includes mechanical, electronic, and microprocessor-based equipment, non-mechanical and non-electronic aids, and specialized instructional materials, services, and strategies that people with disabilities can use to (a) assist them in learning, (b) make the environment more accessible, (c) enable them to compete in the workplace, (d) enhance their independence, or (e) otherwise improve their quality of life.

Among these AT services Blackhurst (2005) suggests productivity tools which include computer software, hardware, and related systems that enable people to work more effectively and efficiently. For example, computer software such as database programs can be used to store and rapidly retrieve information; word processing programs can be used to easily edit text material; expert system computer programs can aid in decision making, such as the educational placement of students with disabilities. The use of productivity tools with LD students can include specialized writing tools, such as writing organization tools, spelling checkers, speech synthesis and word prediction software, writing prompts, and multimedia composing tools (Blackhurst, 2005).

The Use and Importance of Assistive Technology

While it is important to understand the various uses of AT and computer based instruction, our primary concerns should relate to issues such as making decisions about the types of technology that are most appropriate for individual students with disabilities and ensuring that those technologies are obtained, implemented appropriately, and evaluated to determine their effectiveness (Alper & Raharinirina, 2006; Goegan, Le, Rioux & Daniels, 2019). Generally, AT implies different things to different people.

AT may refer to the use of different technological resources to support individuals with different types of disabilities to acquire social benefits and to reduce the negative influence of their disabilities on their well-being and community participation. For others, AT may relate to a wide spectrum of tools, technological aids, strategies, services and practices whose main objective is to improve the quality of life of persons with disabilities (Owuor et al., 2018).

The National Center on Educational Statistics, according to the U.S. Department of Education report, illustrated the degree to which the use of technology, particularly computers and the Internet, has become a pervasive part of the educational system

(Wehmeyer, Smith, Palmer & Davis, 2004). The various uses of electronic technology and computers among children and youth between the ages 5-17 in the US at the national level exceeds 90% of the students. Three out of four children at the age of 5 uses computers, and over 90% of the youth have access to a computer either at home or at school. (Wehmeyer et al., 2004).

Special education teachers in general promote the use of technology in teaching basic skills such as literacy and math. A recent study conducted with 1,000 special education teachers showed that 85% of the teachers use technology in teaching literacy. In addition, 97% of those teachers believe that technology can help students with disabilities acquire basic literacy skills (McArthur, et al., 2001). Further, the IDEA amendment of 1997 mandates that assistive technology (AT) needs of all students must be considered as part of the individualized educational program planning process (Alper & Raharinirina, 2006).

Raskind and Bryant (1996) emphasized the importance of selecting the most appropriate technology for individuals with learning disabilities, which requires a careful and systematic plan. Acknowledging the fact that individuals with learning disabilities have their own unique set of strengths, weaknesses, special abilities, interests, and experiences, they noted that not all assistive technologies are appropriate for all individuals in all situations. Therefore, a technology that may be appropriate for one person may be inappropriate for another. Similarly, a technology that is helpful for one purpose in one particular setting may be irrelevant in another situation or setting. Consequently, selecting the appropriate technology for an individual with a learning disability requires careful analysis of the interplay between the individual, the specific task/functions to be performed, the specific technology, and the specific contexts of interaction (Raskind, & Higgins, 1999).

Finally, without assistive technology and accessible environments, children with disabilities may NOT be able to:

- go from home to school,
- see what is written on the blackboard,
- hear and understand the teacher,
- read the textbooks,
- Use sanitation facilities,
- participate in sports and recreation,

- interact with classmates

Continuum of Assistive Technology

Students with disabilities are being treated and educated in settings that often can be without sufficient tools that meet their needs. They may receive educational assistance that does not necessarily requires technology, such as physio therapy or occupational therapy for their gross or fine motor skill. This would be considered as a no-tech assistive technology.

Others may need more specific help that demand the use of different degrees of technology in the like of low tech technology, mid-tech technology, and high-tech technology (Edyburn, Higgins & Boone, 2005; Zabala & Carl, 2005).

Low-tech Assistive Technology. Technology in general does not make the disability vanish, rather it lessen its impact on individuals with disability. There are, however, simple technologies that considered to be essential for individuals with disabilities. Such technologies are called Low-tech. Low tech AT are devices or equipment that do not require much training, may be less expensive and do not have complex or mechanical features. Such technologies include, ramps, switches, switch-operated toys, communication boards, car door openers, roll-in showers, handheld magnifiers, large print text, using paper and pen to communicate, canes and walkers, grabbers, specialized pen or pencil grips, post-it's, highlighter, squishy ball or sensory input, tactile ruler, page protector or colored transparency, manipulatives and much more.

Mid-tech Assistive Technology. AT devices or equipment that range in the middle of the continuum may have some complex features, may be electronic or battery operated, may require some training to learn how to use and are more expensive than the low-tech devices. Some examples include: manual wheelchairs, electronic organizers, Closed Caption Televisions (CCTV's), amplifiers, books on CD or E-Reader, environmental control units (ECU), alternate mouse or keyboard for the computer, braille translation software, switch adapted games or toys, adapted switches, adapted seating, adapted keyboard, calculator, electronic speller or dictionary, word prediction software etc.

High-tech Assistive Technology. High Tech AT refers to the most sophisticated devices or software, that have digital or electronic components, may be computerized, will likely require some training and effort prior to apply them to learn how to use. This is what we consider to the kind we "plug in." This is the most intense and expensive form of technology. Examples of High-tech AT may include: power wheelchairs and scooters, digital hearing aids, computers with specialized software such as voice recognition or magnification software, electronic aids to daily living, digital hands-free headsets, voice activated telephones, communication devices with voices, blue-tooth integration, digidrive technology, portable word processor, text to speech, speech to text, smart board, alerting device.

In our modern societies, one cannot avoid using different types of AT devices. However, due to its cost and complexity, some families of children with disabilities may not be able to afford high-tech AT devices. Therefore, solutions of low-tech AT should be offered to those children. Low-tech assistive technology might be a better option for many children because it involves incorporating furniture or toys that a family already owns and with which the child is already familiar. Low-tech assistive technology can be adapted quickly to meet the different needs of children as they grow and change. Family members can make these changes as they need to do so, without relying on a specialist. Low-tech is usually less expensive and requires fewer repairs. By trying out low-tech options first, families can help their children participate more naturally in family routines and activities.

Benefits of AT on Students with Disabilities

AT has the potential to increase developmental skills and provide solutions to challenges, such as behavior, attention, and communication, faced by students identified with disabilities (Parette & Stoner, 2008). Since the IDEA 2004 mandates for the provision of AT for all students with disabilities upon their educational or functional needs, researchers report on many benefits of using AT to support students with disabilities. While all learners are different, such benefits may include: a) provision of practical options for supporting students with disabilities in their least restrictive environment, may be used to enhance a student's communication skills, b) can support student's access to academic instruction, c) may be used to create visual supports and positive behavior support systems for students (Parish, 2017).

Chiang and Liu (2011) in their research on the benefits of assistive reading software noted that children with reading impairment could benefit from assistive technology in regards of their reading development process and increase their chances of not falling behind peers. Further, AT as in the form of smartphones and tablets may assist children with reading impairment to have an equal chances for learning in school as their peers without reading difficulties. Furthermore, AT could facilitates information gaining process, and subsequently increases motivation and interest to learn in reading activities. Finally, the authors noted that AT had wider effects on its users due to reducing stigmatizing situations when learners with learning disorders leave the classroom for special education were avoided and positive effects on family life were noted.

In their review of the literature on the benefits of AT Copley and Ziviani (2004) noted that one of the chief benefits of AT use that is highly relevant for children with multiple disabilities is as a means of enabling mastery or control over their environment, including enhanced exploratory play and independence in activities of daily living. The authors indicated that facilitation of independence was among the most frequently cited benefit by parents and teachers. Further, they added, among the benefits enhance social interactions among peers, increased motivation, and reported self-esteem. Another area that AT beneficial for children with disabilities as noted by Copley and Ziviani (2004) is the improvement of academic skills, such as hand writing, motor skills, reading acquisition and comprehension, visual attention and perception, and mathematic skills. Finally, AT has improved the overall working habits and productivity of children with disabilities.

Challenges and Barriers to AT

Although AT considered as an essential component in the education of students with disabilities, it is however, a challenge for many parents, students and educators. AT intended to facilitate psychosocial functioning, lack of resources to purchase AT equipment constitutes an environmental barrier. Scarcity of trained teachers to assist in choosing and obtaining AT devices also represents a barrier within the social environment and educational setting (Scherer & Glueckauf, 2005). Scherer and Glueckauf (2005) in their review to the provision of AT noted that despite the increased availability of AT, approximately 30% of ATs are discarded within 1 year. They referred this to several reasons, including the product not meeting user expectations or needs, setting the user apart from others, and failing to save time or energy. Further, it is the understanding that AT features designed to address one need may negatively affect other needs. One example Scherer and Glueckauf (2005) provided: a device that is highly customizable may have many features and optional controls that makes it too complex for someone with a cognitive disability to handle it alone.

Copley and Ziviani (2004) conducted an intensive literature review on the application of AT for children and youth with multiple disabilities and noted that the barriers were found include: a) lack of appropriate staff training and support, b) negative staff attitudes, c) inadequate assessment and planning processes, d) insufficient funding, e) difficulties procuring and managing equipment, and f) time constraints. Much of the literature emphasize the role of the teacher in the day to day implementation of technology. Lack of appropriate preparation for those teachers resulted in lack of applications of the AT, lack of familiarity with the equipment, incomplete awareness of the application, and negative attitudes towards the implementation of such devices and programs with the children.

Assistive Technology Frameworks and Aplications for Students with Disabilities

With the digitized revolutionary era, one cannot ignore the rapid change in the modern life in terms of the various available choices of AT devices and programs. To name just few of them, recently we have witness high-tech AT apps of touch phones and smart devices, in the form of memory applications, emotional, social, and directive and so on. The following are just few examples that are mostly available for free of charge:

1. **Be my eyes app**. for the blind, is a free app that connects blind and low-vision people with sighted volunteers and company representatives for visual assistance through a live video call. It has been translated into more than 80 languages around the world.

2. **Autism Xpress.** A simple app designed to help young people with autism express their emotions. Autism Xpress uses a feeling finder and games in a fun and easy-to-use package.

3. **Voice Dream Reader.** For children and adults with reading disabilities and ADD/ ADHD, Voice Dream Reader allows a student to highlight text which will then be read to them. For a learner who comprehends things better aurally.

4. **Stop, Breathe & Think.** Fantastic for students with anxiety and stress disorders, this is a meditation app which encourages users to think about how they're feeling, while also providing short mindfulness and meditation exercises tailored to their mood.

5. If… The Emotional IQ Game. Fantasy game promotes real-life social and emotional skills. If… helps children aged between 6-12 years develop the skills that lead to emotional intelligence. Parents and teachers can view reports on a student's progress, potentially opening further productive conversations and opportunities.

6. **Dyslexia Toolbox. A** free app on Apple iTunes and a recent addition to the Apple app store Marketed as being "by dyslexic people, for dyslexic people", this toolbox features a whole host of assistive technology features for K-12 students with dyslexia. Type pads, word prediction, digital overlays and text readers are all included.

7. **My Talk Tools Mobile.** This is an innovative app which enables students with communication difficulties to say what they want, using a sequence of words, sounds and images. A good solution for people with down-syndrome, cerebral palsy, hearing or visual impairments, and autism. It can be configured to feature certain images and play certain sounds, so it can be set up for a particular student to best aid them.

8. **ModMath.** ModMath is a free app for the iPad, targeted at helping students with dyslexia and dysgraphia do math. It was created by parents of a child

with dysgraphia, and remains focused on providing a clear tool to solve math problems without ever picking up a pencil.

The SETT Framework

In an educational framework developed by Zibala (2005), the researcher suggested that for students with disabilities to progress in learning there should be four components interact with each other: a) student, b) environment, c) tools, and d) task. At least one key question should be asked by the educational team for each of the four components for the purpose of considering the appropriate assistive technology for students with disabilities. As for the student, a teacher should ask: what is the area of instructional concern and what are the student's current abilities? For the environment, the questions that should be posed are: what are the main characteristics and physical arrangement of the learning environment of the students? This may relate to the learning setting, such as learning in small group, a whole class, or pre designed learning stations. As for the task, the teacher should ask: what are the task expectations and specific learning tasks required to enhance student's achievement and performance? Finally, for the framework to be more effective the teacher should be concerned of the AT that is suitable for each of the students. The question to be asked here is: what tools or devices (low or high tech) should be used to support the student's learning?

According to Zibala (2005) the SETT framework is built on the premise that AT teams must first gather information about the student, the customary environments in which the students spend their time, and the tasks that are required for the students to be active participants in the teaching/learning processes that lead to educational success.

To conclude, AT is a powerful tool that teachers, parents and children with different types of disabilities can rely on and benefit from. The benefits of applying AT in educational settings and day-to-day conditions for students with disabilities in general and for those students with LD who are fully included in mainstream classroom obviously overcome its shortages. What is needed to succeed in applying such technology, is to continuously train teachers and parents on the use of such devices and programs, to make sure they are aware of its importance to the learning and development of children with disabilities, and to make sure that the school setting is equipped with the necessary structure and technology devices.

References

Adebisi, R. O., Liman, N. A., & Longpoe, P. K. (2015). Using Assistive Technology in Teaching Children with Learning Disabilities in the 21st Century. *Journal of Education and Practice*, *6*(24), 14-20.

Ajuwon, P. M., & Chitiyo, G. (2016). Survey of the use of assistive technology in schools in Nigeria. *The Journal of the International Association of Special Education*, *16*(1), 4-13.

Alper, S., & Raharinirina, S. (2006). Assistive technology for individuals with disabilities: A review and synthesis of the literature. *Journal of Special Education Technology*, *21*(2), 47-64.

Anna Courtad, C., & Bouck, E. C. (2013). Assistive technology for students with learning disabilities. In *Learning disabilities: Practice concerns and students with LD* (pp. 153-173). Emerald Group Publishing Limited.

Atanga, C., Jones, B. A., Krueger, L. E., & Lu, S. (2019). Teachers of Students with Learning Disabilities: Assistive Technology Knowledge, Perceptions, Interests, and Barriers. *Journal of Special Education Technology*, 0162643419864858.

Behrmann, M., & Jerome, M. K. (2002). *Assistive technology for students with mild disabilities: Update 2002. ERIC Digest*. Retrieved May 12, 2005, from http://www.ericdigests.org/2003-1/assistive.htm.

Blackhurst, A. E. (2005). Perspectives on applications of technology in the field of learning disabilities. *Learning Disability Quarterly*, *28*(2), 175-178.

Blackhurst, A.E., & Edyburn, D.L. (2000). A brief history of special education technology. Special Education Technology Practice, 2(1), 21-35.

Bouck, E. C. (2016). A national snapshot of assistive technology for students with disabilities. *Journal of Special Education Technology*, *31*(1), 4-13.

Bouck, E. C. (2010). Chapter 6 Technology and students with disabilities: Does it solve all the problems. In *Current issues and trends in special education: Research, technology, and teacher preparation* (pp. 91-104). Emerald Group Publishing Limited.

Bouck, E. C., Flanagan, S., Miller, B., & Bassette, L. (2012). Technology in action. *Journal of Special Education Technology*, *27*(4), 47-57.

Carver, J., Ganus, A., Ivey, J. M., Plummer, T., & Eubank, A. (2016). The impact of mobility assistive technology devices on participation for individuals with disabilities. *Disability and Rehabilitation: Assistive Technology*, *11*(6), 468-477.

Cheung, A. C., & Slavin, R. E. (2013). Effects of educational technology applications on reading outcomes for struggling readers: A best-evidence synthesis. *Reading Research Quarterly*, *48*(3), 277-299.

Chiang, H. Y., & Liu, C. H. (2011). Evaluation of the benefits of assistive reading software: Perceptions of high school students with learning disabilities. *Assistive Technology*, *23*(4), 199-204.

Copley, J., & Ziviani, J. (2004). Barriers to the use of assistive technology for children with multiple disabilities. *Occupational Therapy International*, *11*(4), 229-243.

Edyburn, D. L., Higgins, K., & Boone, R. (2005). Handbook of special education technology research and practice (pp. 239-270). Whitefish Bay, WI: Knowledge by Design.

Floyd, K. K., & Judge, S. L. (2012). The Efficacy of Assistive Technology on Reading Comprehension for Postsecondary Students with Learning Disabilities. *Assistive Technology Outcomes and Benefits*, *8*(1), 48-64.

Goegan, L. D., Le, L., Rioux, B. P., & Daniels, L. M. (2019). Examining Factors that Support Continued Use of Assistive Technology by Postsecondary Students with Disabilities. *Canadian Journal for New Scholars in Education/Revue canadienne des jeunes chercheures et chercheurs en éducation*, *10*(1).

Goor, M. B., Schwenn, J. O., & Boyer, L. (1997). Preparing principals for leadership in special education. *Intervention in school and clinic*, *32*(3), 133-141.

Hall, T. E., Hughes, C. A., & Filbert, M. (2000). Computer assisted instruction in reading for students with learning disabilities: A research synthesis**.** *Education & Treatment of Children, 23*(2), 173-193.

Hetzroni, O., E., & Shrieber, S., E. (2004). Word processing as an assistive technology tool for enhancing academic outcomes of students with writing disabilities in general classroom. *Journal of Learning disabilities. 37*(2), 143-155.

Higher Education Opportunity Act, 20 U.S.C. § 1001 et seq. (2008). Retrieved from http://www.nacua.org/documents/heoa.pdf

Howard, P. (2004). The least restrictive environment: How to tell. *JL & Educ.*, *33*, 167.

Hutinger, P., Johanson, J., & Stoneburner, R. (1996). Assistive technology applications in educational programs of children with multiple disabilities: A case study report on the state of the practice. *Journal of Special Education Technology*, *13*(1), 16-35.

Individuals with Disabilities Education Improvement Act of 2004b, I A U.S.C. (§ 602 (1) (A)). Retrieved from: https://sites.ed.gov/idea/regs/b/b/300.105

Individuals with Disabilities Education Improvement Act of 2004c, I A U.S.C. (§ 602 (2)). Retrieved from: https://sites.ed.gov/idea/regs/b/b/300.105

Irish, C. (2003). Using peg and keyword mnemonics and computer-assisted instruction to enhance basic multiplication performance in elementary students with learning and cognitive disabilities. *Teaching Exceptional Children. 17*(4), 14-25.

Kim, A. H., Woodruff, A. L., Klein, C., & Vaughn, S. (2006). Facilitating co-teaching for literacy in general education classroom through technology: focus on students with learning disabilities. *Reading & Writing Quarterly. 22,* 269-291

King-Sears, M. E., Swanson, C., & Mainzer, L. (2011). TECHnology and literacy for adolescents with disabilities. *Journal of Adolescent & Adult Literacy*, *54*(8), 569-578.

Lacina, J. (2006). Learning to read and write using the internet: Sites you don't want to miss! *Childhood Education*, *83*(2), 117.

McArthur, C. A., Ferretti, R. P., Okalo, C. M., & Cavalier, A. R. (2001). Technology applications for students with literacy problems: A critical review. *Elementary School Journal. 101*(3), 273-301. Retrieved November 20, 2006, from ERIC database.

Maccini, P., Gagnon, J.C., & Hughes, C. A. (2002). Technology-based interventions for secondary students with learning disabilities. *Learning Disability Quarterly*. 25, 247-262.

Marshak, L., Van Wieren, T., Ferrell, D. R., Swiss, L., & Dugan, C. (2010). Exploring barriers to college student use of disability services and accommodations. *Journal of Postsecondary Education and Disability*, *22*(3), 151-165.

Mittler, J. (2007). Assistive technology and IDEA. In C. Warger (Ed.), Technology integration: Providing access to the curriculum for students with disabilities. Arlington, VA: Technology and Media Division (TAM). Retrieved Nov.15, 2019 from: http://www.tamcec.org/wp-content/uploads/2016/08/AssistiveTech-and-IDEA-Regs.pdf

National Center for Learning disabilities (2016). The state of LD: supporting academic success. Available on line at: https://www.ncld.org/supporting-academic-success

Parette, H. P., & Stoner, J. B. (2008). Benefits of assistive technology user groups for early childhood education professionals. *Early Childhood Education Journal*, *35*(4), 313-319.

Parish, A. (2017). Assistive Technology to support students with special needs. Center for Innovation and Leadership in Special Education. Available online at: https://www.kennedykrieger.org/stories/linking-research-classrooms-blog/assistive-technology-support-students-special-needs

Perelmutter, B., McGregor, K. K., & Gordon, K. R. (2017). Assistive technology interventions for adolescents and adults with learning disabilities: An evidence-based systematic review and meta-analysis. *Computers & education*, *114*, 139-163.

Poonam, P., & Nitika, N. (2017). Use of Computer Technology to Help Children with Special Needs. *International Journal of Advanced Research in Computer Science*, *8*(4).

Raskind, M. H., & Higgins, E. L. (1998). Assistive technology for postsecondary students with learning disabilities: An overview. *Journal of Learning Disabilities*, *31*(1), 27-40.

Rozalski, M., Stewart, A., & Miller, J. (2010). How to determine the least restrictive environment for students with disabilities. *Exceptionality*, *18*(3), 151-163.

Rose, D. H., Hasselbring, T. S., Stahl, S., & Zabala, J. (2005). Assistive technology and universal design for learning: Two sides of the same coin. Handbook of special education technology research and practice, 507-518.

Scherer, M. J., & Glueckauf, R. (2005). Assessing the benefits of assistive technologies for activities and participation. *Rehabilitation Psychology*, *50*(2), 132.

Stauter, D. W., Prehn, J., Peters, M., Jeffries, L. M., Sylvester, L., Wang, H., & Dionne, C. (2019). Assistive Technology for Literacy in Students with Physical Disabilities: A Systematic Review. *Journal of Special Education Technology*, *34*(4), 284-292.

Stearns, S. C. (2012). Integration of technology into the classroom: Effects on reading comprehension. *Research Papers*.

Svensson, I., Nordström, T., Lindeblad, E., Gustafson, S., Björn, M., Sand, C., ... & Nilsson, S. (2019). Effects of assistive technology for students with reading and writing disabilities. *Disability and Rehabilitation: Assistive Technology*, 1-13.

Owuor, J., Larkan, F., Kayabu, B., Fitzgerald, G., Sheaf, G., Dinsmore, J., ... & MacLachlan, M. (2018). Does assistive technology contribute to social inclusion for people with intellectual disability? A systematic review protocol. *BMJ open*, *8*(2), e017533.

Sun Associates. (2010). *What the research says - Best practices in technology integration.* Retrieved from http://www.sun-associates.com/tlresources.html

Watson, A. H., Ito, M., Smith, R. O., & Andersen, L. T. (2010). Effect of assistive technology in a public school setting. *American Journal of Occupational Therapy*, *64*(1), 18-29.

Wehmeyer, M. L., Smith, S. J., Palmer, S. B., & Davies, D. K. (2004). Technology use by students with intellectual disabilities: An overview. *Journal of Special Education Technology*, *19*(4), 7-21.

Zabala, J. S., & Carl, D. F. (2005). Quality indicators for assistive technology services in schools. Handbook of special education technology research and practice, 179-207.

Citation:
Zayyad, M. (2019). Incorporating assistive technology for students with disabilities. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 271-285). ISRES Publishing, ISBN:978-605-698540-9.

Augmented Reality and Education

Fatih Serdar Yildirim
Akdeniz University, Turkey

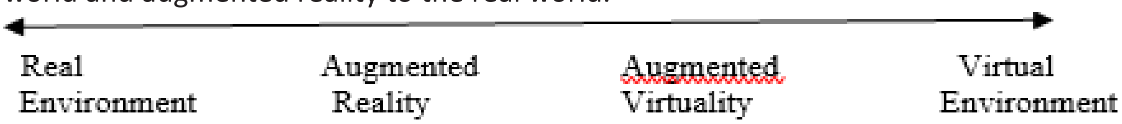
Introduction

Augmented Reality, or AR in short, is a real-time and interactive experience created by enriching real-world environmental elements using data from computer-based graphics, video, and GPS. Virtually generated images and graphics are added to real world images with the help of various software and hardware used, and a new type of experience is created by enriching the existing reality without leaving the reality.

Augmented reality involves strengthening and supporting reality by providing information that is not detectable by people's senses and cognitive processes under normal conditions (Azuma, 1999). Augmented reality basically gives the individual a virtual experience as if it were real in the physical environment and in real time. A new environment is created by placing various virtual objects on the snapshot of the individual's environment. The real environment is supported by digitally generated images, sound, graphics and GPS data. In this way, people in the given environment can even talk with objects (Aslan, 2017).

The image created with augmented reality has basically 3 features. These features; combination of the real world and the virtual image, the real-time interaction of virtual objects and the resulting image being located in three-dimensional environment (Azuma, 1997; Wu, Lee, Chang, & Liang, 2013). Augmented reality is not environments where reality is created from the beginning, but where existing reality is supported (Erbaş & Demirer, 2015).

Milgram and Kishino showed the concept of augmented reality on the diagram of real-virtual continuity (As cited in: Özarslan, 2011). This continuity is moving from the real environment to the virtual environment (Kesim and Ozarslan, 2012). When real-virtual continuity is examined, augmented reality and augmented virtuality are positioned in the middle of the generated diagram; augmented virtuality being closer to the virtual world and augmented reality to the real world.



Real-Virtual Continuity

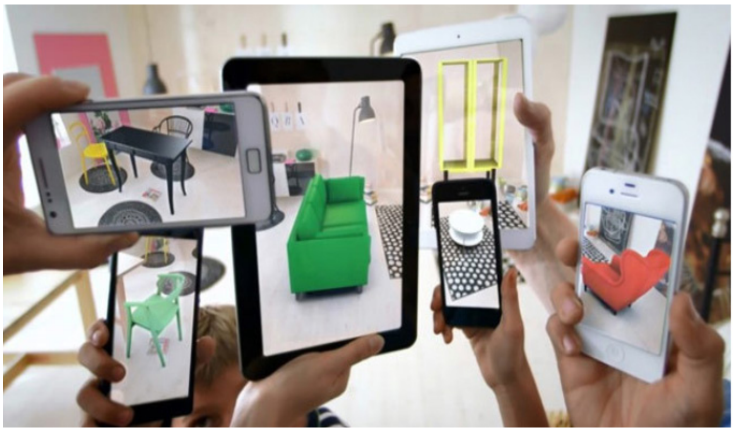
Azuma (1997) described augmented reality as a type of virtual reality in his study. Although virtual reality and Augmented reality applications have similar basic elements such as virtual objects, real-time response and having visual equipment, there have some differences, too (Sin and Zaman, 2010).

While the user is in an artificial environment created in virtual reality technologies (Sin and Zaman, 2010), he cannot see the real world around him, but AR applications allow the user to see the real world placed on virtual objects (Azuma, 1997). Unlike virtual reality, AR creates real-world perception by enabling users to see a real-world environment enriched with 3D images produced, and also realizes user interaction with virtual objects (Devkan, Demircioğlu and Akkuş 2016).

Historical Process of Augmented Reality

The concept of Augmented Reality was first introduced in the early 1990s, but on the other hand, various studies have been carried out on the first wearable device with AR features since the late 1960s. Even though completely mechanical, the first product to create a feeling of augmented reality is Sensorama, developed by Morton Heilig in 1962. Sensorama is built on a system that emits smells in accordance with the images and sounds seen in a film and transmits vibrations to the user. However, the concept of AR was first introduced into the literature through the study of Caudell and Mizell (1992), which indicated that it was more appropriate to virtualize and process the required amount of images in their research (As cited in: Bozyer, 2015).

In particular, improvements in processor (GPU and CPU) capacities and the development of camera lenses of mobile devices, have enabled the rapid deployment of applications with AR technologies.



Today, Augmented Reality (AR) application range extends to dozens of different fields from real-time camera filters used for entertainment purposes, to new generation educational applications, from furniture shopping applications that enable products to be displayed in real environments before purchase, to tourism, military, health, museum, advertising and Industry 4.0 solutions.

In particular, the widespread use of mobile devices (desktop and laptop computers, tablets, smartphones, etc.) has increased the use of AR in educational settings (Wu, Lee, Chang and Liang, 2013, Uluyol and Eryılmaz, 2014).

Today, as a result of many researches on the applications of educational technologies, there is an increasing interest in emerging technologies. The content of these studies is generally related to the development of student-centered learning and adaptive learning environments (Bacca, Baldiris, Fabregat and Graf, 2014).

Use of Augmented Reality in Education

The new generation, which is called the digital generation or generation Z, is predicted to be different from the previous generations due to the fact that they were born and raised in a digital age (Oblinger & Oblinger, 2005). This new generation is intertwined with internet technologies and digital equipment in their daily lives. For this reason, it can be said that the traditional learning methods and environments used in the upbringing of previous generations cannot be sufficient to attract the Z generation.

A true learning experience is always necessary for individuals, and the involvement of more senses in the learning process makes learning more efficient. This is why augmented reality applications can be described as a new and developing technology in education (Lai & Hsu, 2011; Luckin & Fraser, 2011).

According to Özarslan (2013), effective learning takes place as long as the learner has fun in the learning process and actively participates in the learning process. On the other hand, it is said that integration of augmented reality applications into the education process allows experiences with real or near-realistic interactions between the learner, teacher, environment and content to be lived and learners to freely discover, design their own learning experiences and learn real life elements by doing or living. In addition, it is possible to embody abstract concepts with augmented reality technology, to enable different learning styles, and to develop support materials that provide a learner-centered approach in the flexible learning process with virtual elements to be placed in the real world.

Augmented reality allows students to apply knowledge and skills that are seamlessly learned by combination of real-world and learning environments. Since learning students can share their knowledge and experiences among themselves, the augmented reality environments created allows face-to-face interaction with the aim of transfer of information (Lave & Wenger, 1991).

Augmented reality is used not only in interactive applications, but also in books, as in the case of the Magic Books. In addition to being able to be read as regular books, when the images and objects in the book are observed, a three dimensional image is obtained through the necessary enrichment made by mobile devices in advance (Lee, 2012).

The rapid change and development in technology has transformed AR not only to be a technology that requires special hardware, but also as a technology that can be easily used on computers, tablets or mobile devices.

Especially the increase in the use of mobile devices has increased the use of AR in educational environments (Wu, Lee, Chang and Liang, 2013). Thus, the use of AR in education has become an important research topic in recent years and some of these studies are shown in Table 1.

Table 1. Some Studies on the Use of Augmented Reality in Education

Author	**Date**	**Field**
Freitas, Campos	2008	Comparison of augmented reality and traditional classroom applications.
Abdüsselam, Karal	2012	The effect of the use of augmented reality in the learning of physics on academic achievement.
Cuendet, Bonnard, Do-Lenh, Dillenbourg	2013	A study showing that augmented reality studies can be carried out in the classroom
Çetinkaya, Akçay	2013	Use of augmented reality in education environment
Tülü, Yılmaz	2013	Using augmented reality in education with an iPhone
Erbaş, Demirer	2014	Augmented reality applications in education: Google Glass, Example 1
Yılmaz, Batdı	2016	Meta-Analytical and Thematic Comparative Analysis of Integration of Augmented Reality Applications into Education
Atasoy,Tosik-Gün, Kocaman-Karoğlu	2017	Determination of Primary School Students' Attitudes and Motivation Situations Against Augmented Reality Applications
Buluş Kırıkkaya, Şentürk	2018	The Effect of Using Augmented Reality Technology in the Unit of "Solar System and Beyond" on Academic Achievement of Students
Yalçın Çelik	2019	Experience of Augmented Reality Materials of Prospective Biology and Chemistry Teacher Candidates

Researchers' studies show that augmented reality (AR) applications contribute positively to educational environments. It can be said that the use of AR applications increases students' academic achievement (Buluş Kırıkkaya and Şentürk, 2018; Chen and Wang, 2015; Hwang, Wu, Chen and Tu, 2016; Sırakaya, 2015). Research also shows that AR supports learning by doing (Singhal, Bagga, Goyal and Saxena, 2012).

Augmented Reality in Science Education

Even though the content of science courses is very much in the daily life of students, it is among the most difficult courses for students. The reasons for this undesirable situation are the lack of lecture hours, excessiveness of the concepts they need to learn, the abstractness of the concepts to be taught, mathematical expressions and calculations, and the inadequate graphic and table interpretation skills of the students. In order to improve this situation, some solution suggestions such as using laboratory applications and increasing the science class hours have been presented. (Timur, Timur, Özdemir ve Şen, 2016). There may also be teacher-related reasons for students' difficulties in science classes. Reasons such as teachers mostly using traditional methods, their lack of assessment techniques cause students to experience misconceptions.

Looking at the recent studies in the literature, we can say that augmented reality applications are a tool preferred by researchers in science education (Table 2). According to the results of these studies, it can be said that augmented reality applications make a significant contribution to science education. Some of these studies are presented in Table 2.

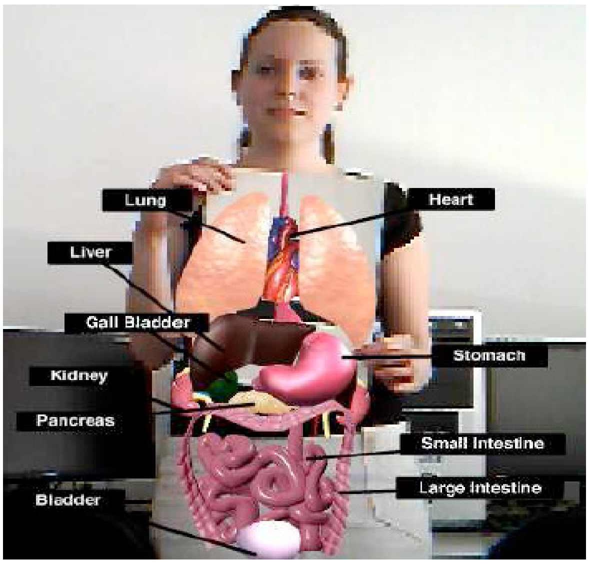
Table 2. Augmented Reality Studies in Science Education

Researcher(s)	Subject of Study	Study Results
Abdüsselam (2014)	Magnetism	Provided a better understanding of the subjects.
Akçayır, Akçayır, Pektaş and Ocak (2016)	Laboratory training	Helped improve students' laboratory skills and attitudes.
Avcı and Taşdemir (2019)	Periodic Table	More effective understanding processes for the subjects.
Buluş Kırıkkaya and Şentürk	Astronomy	An positive effect on academic achievement is observed.
Chen and Wang (2015)	Astronomy	Increased students' success
Yalçın Çelik (2019)	Biology and Chemistry course materials	Students found augmented reality materials more impressive and remarkable than other course materials.
Delello (2014)	Astronomy	Increased student participation and motivation
Furio et al. (2015)	Water cycle	Increased students' motivation
Hwang, Chen and Chou (2016)	Ecology	Class participation has increased and positive learning outcomes achieved.
Lin, Duh, Li, Wang and Tsai (2013)	Momentum	Learning level has improved.
Matcha and Rambli (2013)	Electric	Contributed to cooperative learning
Vilkoniene (2009)	Digestive system	Increased students' success
Zhang et al, (2014)	Astronomy	Increased the permanence of learning.

Augmented reality applications make teaching of the subjects possible by combining real and virtual and enabling the observation of situations that cannot be observed in the classroom environment (Kerawalla et al., 2006).

When Table 2 is examined, it is seen that applications prepared with augmented reality technology are used in teaching many different science education subjects and effective results are obtained as a result of these applications.

In particular, science subjects such as astronomical events that cannot be observed in a classroom environment, or chemical experiments that cannot be conducted in classroom environments where the learning is happenings, can be taught to the learners by doing and living thanks to augmented reality.



On the other hand, many research results show that augmented reality (AR) technology makes learners learn abstract concepts that are difficult to learn easier (Abdülsselam, 2014; Kamarainen et al., 2013; Wu et al., 2013) by objectifying them (Shelton and Stevens, 2004). When augmented reality is evaluated in this respect, it provides an opportunity to teach abstract subjects such as magnetism and electricity by objectification.

Attitude causes the individual to behave biased in the decision-making process and directs the individual's behavior (Nuhoğlu, 2008). Accordingly, students' positive attitude towards learning science will determine their level in learning science subjects. In this context, it can be said that augmented reality technology applications will contribute to students' positive attitudes and motivation towards learning science. Also in this context, it is possible to come across many studies examining the effect of augmented reality (AR) technology on students' attitudes and motivation in the literature (Delello, 2014; Furió et al., 2015; Perez-Lopez and Contero, 2013).

Conclusion and Discussion

Nowadays, augmented reality (AR) applications can be standardized in the coming period, and with the increase of use of smartphones and tablet computers, it will be widely used in all areas of our lives. It is very difficult to limit the uses of augmented reality in our daily lives. This situation attracts the attention of developers, because AR is a new technology. As a result of this interest, augmented reality technology is emerging in different fields with each passing day. AR's fields of application are a very wide area such as advertising, design, health, military, and education, and a new field joins the range of AR every day.

Augmented reality technology has attracted attention in the field of education with its ability to interact with virtual and real objects, increase learners' attention and motivation, and enable them to learn by living (Singhal, Bagga, Goyal and Saxena, 2012). The applications of this technology are observed in many disciplines and different levels of education and it can be said that it is effective in teaching the events that cannot be followed with the naked eye, showing the situations that may be dangerous and concretizing abstract concepts (Walczak, Wojciechowski and Cellary, 2006).

Constructivist approach of augmented reality and it allowing learning by doing - living experiences and new generations, called generation Z, that are intertwined with new technologies using digital technologies effectively have helped it become more and more common everyday in the field of education. Today, it is seen that various studies have been carried out in many different fields, especially in the fields of health education, science education, mathematics education, foreign language education and teacher education with augmented reality technology.

As a result of the studies, it has been concluded that augmented reality technology has many benefits such as providing contextual support to learners, providing spatial skills, creating a more attractive learning environment, and visualizing and concretizing concepts (Majoros & Neumann, 2001; Kaufmann & Schmalstieg, 2003; Shelton, & Hedley, 2002; Dori & Belcher, 2005; Klopfer & Squire, 2008; Sumadio & Rambli, 2010).

In the light of these studies, as a result of AR's contribution to students' attitudes and motivation towards science learning, more comprehensive studies can be conducted for the creation of AR-based learning materials and the development of existing ones for use in science education. Efforts can be made to successfully integrate AR technology into the education process. Considering the reflections of technology on our daily lives, the applications of augmented reality technology will continue to appear in every aspect of our lives in the coming years.

References

Abdüsselam, M. S. (2014). Fizik öğretiminde artırılmış gerçeklik ortamlarının kullanımlarına ilişkin öğretmen ve öğrenci görüşleri: 11.sınıf manyetizma konusu örneği. *Pegem Eğitim ve Öğretim Dergisi*, *4*(1), 59–74

Akçayır, M., Akçayır, G., Pektaş, H. M. ve Ocak, M. A. (2016). Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Computers in Human Behavior*, *57*, 334–342.

Aslan, R. (2017). Uluslararası rekabette yeni imkânlar: Sanal gerçeklik, artırılmış gerçeklik ve hologram. *Ayrıntı Dergisi*, 5(49), 21-26.

Atasoy, B., ,Tosik-Gün, E., Kocaman-Karoğlu, A. (2017). İlköğretim Öğrencilerinin Artırılmış Gerçeklik Uygulamalarına Karşı Tutumlarının ve Güdülenme Durumlarının Belirlenmesi. *Ahi Evran Üniversitesi Kırşehir Eğitim Fakültesi Dergisi (KEFAD) Cilt 18, Sayı 2, Ağustos 2017, Sayfa 435-448*

Avcı, A.F., Taşdemir. Ş.(2019). Artırılmış ve sanal gerçeklik ile periyodik cetvel öğretimi. *Selçuk-Teknik Dergisi. Cilt 18, Sayı:2-2019*

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, 6(4), 355-385.

Azuma, R. T. (1999). The challenge of making augmented reality work outdoors. *Mixed* *reality: Merging real and virtual worlds*, *1*, 379-390.

Bacca, J., Baldiris, S., Fabregat, R., & Graf, S. (2014). Augmented reality trends in education: a systematic review of research and applications. *Journal of Educational Technology & Society, 17*(4), 133.

Bozyer, Z. (2015). Augmented reality in sports: Today and tomorrow. *International Journal of Science Culture and Sport (IntJSCS)*, 3(4), 314-325.

Buluş Kırıkkaya, E., ve Şentürk, M. (2018). Güneş sistemi ve ötesi ünitesinde artırılmış gerçeklik teknolojisi kullanılmasının öğrenci akademik başarısına etkisi. *Kastamonu Eğitim Dergisi, 26*(1), 181-189. doi:10.24106/kefdergi.375861

Chen, C. ve Wang, C.-H. (2015). Employing augmented-reality-embedded instruction to disperse the imparities of individual differences in earth science learning. *Journal of Science Education and Technology*, *24*(6), 835–847.

Cuendet, S., Bonnard, Q., Do-Lenh, S., & Dillenbourg, P. (2013). Designing augmented reality for the classroom. *Computers & Education, 68*, 557-569.

Delello, J. A. (2014). Insights from pre-service teachers using science-based augmented reality. *Journal of Computers in Education*, *1*(4), 295–311.

Dori,Y., & Belcher, J. (2005). Learning electromagnetism with visualization and active learning. Editör J. Gilbert, *Models and modeling in science education* (pp. 187---216). New York, NY: Springer.

Erbaş,Ç. & Demirer, V. (2014). Eğitimde Artırılmış Gerçeklik Uygulamaları: Google Glass Örneği. ournal of Instructional Technologies & Teacher Education Vol. 3 No 2 (2014), 8-16

Erbaş,Ç. & Demirer, V. (2015). Eğitim Teknolojileri Okumaları, "Eğitimde sanal ve artırılmış gerçeklik uygulamaları" 2015, ISBN: 978- 605- 318- 126- 2, 131 – 148.

Freitas, R., & Campos, P. (2008, September). SMART: a System of Augmented Reality for Teaching 2 nd grade students. In Proceedings of the *22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction-*Volume 2 (pp. 27-30). British Computer Society

Furió, D., Juan, M.-C., Segui, I. ve Vivó, R. (2015). Mobile learning vs. traditional classroom lessons: a comparative study. *Journal of Computer Assisted Learning*, *31*(3), 189–201.

Hwang, G.-J., Wu, P.-H., Chen, C.-C. ve Tu, N.-T. (2016). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interactive Learning Environments*, *24*(8), 1895–1906.

Kaleci, Devkan & Demircioglu, Tuba & Akkus, Ilyas. (2016). Örnek Bir Artırılmış Gerçeklik Uygulaması Tasarımı. 10.13140/RG.2.1.2627.8165.

Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S. ve Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers ve Education*, *68*, 545–556.

Kaufmann, H., Schmalstieg, D. (2003). Mathematics and geometry education with collaborative augmented reality, Computers & Graphics, 27(3), 339-345.

Kerawalla, L., Luckin, R., Seljeflot, S. ve Woolard, A. (2006). Making it real: exploring the potential of augmented reality for teaching primary school science. *Virtual Reality*, *10*(3–4), 163–174.

Kesim, M., & Ozarslan, Y. (2012). Augmented reality in education: current technologies and the potential for education. Procedia-Social and Behavioral Sciences, 47, 297-302

Klopfer, E., Squire, K. (2008). Environmental detectives: The development of an augmented reality platform for environmental simulations. *Education Technology Research and Development*, 56(2), 203-228.

Lai, Y.-S. & Hsu, J.-M. (2011). Development trend analysis of augmented reality system in educational applications. *2011 International Conference on Electrical and Control Engineering*, 6527-6531.

Lave, J. & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. NY: Cambridge University Press

Lee, K. (2012). Augmented reality in educationand training. *Springer Science & Business Media B.V.*,56(2) 13–21.

Lin, T.-J., Duh, H. B.-L., Li, N., Wang, H.-Y. ve Tsai, C.-C. (2013). An investigation of learners' collaborative knowledge construction performances and behavior patterns in an augmented reality simulation system. *Computers ve Education*, *68*, 314–321.

Luckin, R., & Fraser, D. S. (2011). Limitless or pointless? An evaluation of augmented reality technology in the school and home. *International Journal of Technology Enhanced Learning, 3*(5), 510-524.

Majoros, A., Neumann, U. (2001). Support of Crew Problem---Solving and Performance with Augmented Reality. In *Bioastronautics Investigators' Workshop, Galveston, TX January* (pp. 17---19).

Matcha, W. ve Rambli, D. R. A. (2013). Exploratory study on collaborative interaction through the use of Aagmented reality in science learning. *Procedia Computer Science*, *25*, 144–153.

Perez-Lopez, D. ve Contero, M. (2013). Delivering educational multimedia contents through an augmented reality application: A case study on its impact on knowledge acquisition and retention. *Turkish Online Journal of Educational Technology - TOJET*, *12*(4), 19–28.

Shelton, B. E. ve Stevens, R. (2004). Using coordination classes to interpret conceptual change in astronomical thinking. *Proceedings of the 6th international conference for the learning sciences. Lawrence Erlbaum ve Associates,* Mahweh, NJ.

Shelton, B. E., Hedley, N. R. (2002). Using augmented reality for teaching earth---sun relationships to undergraduate geography students. *Augmented Reality Toolkit, The First IEEE International Workshop* (pp. 8---pp). IEEE.

Sırakaya, M. (2015). *Artırılmış gerçeklik uygulamalarının öğrencilerin akademik başarıları, kavram yanılgıları ve derse katılımlarına etkisi*. Yayımlanmamış doktora tezi. Gazi Üniversitesi, Eğitim Bilimleri Enstitüsü, Ankara.

Singhal, S., Bagga, S., Goyal, P. ve Saxena, V. (2012). Augmented chemistry: Interactive education system. *International Journal of Computer Applications, 49*(15), 1-5.

Sin, A. K., & Zaman, H. B. (2010). Live Solar System (LSS): Evaluation of an Augmented Reality book-based educational tool. In Information Technology (ITSim), 2010 International Symposium in (Vol. 1, pp. 1-6). IEEE.

Sumadio, D.D., Rambli, D.R.A. (2010). Preliminary evaluation on user acceptance of the augmented reality use for education *Second international conference on computer engineering and applications*, Vol. 2 (pp. 461–465). IEEE.

Oblinger, D. G., & Hagner, P. (2005). Seminar on Educating the Net Generation. EDUCAUSE, Tempe, AZ.

Özarslan, Y. (2011). Öğrenen İçerik Etkileşiminin Genişletilmiş Gerçeklik ile Zenginleştirilmesi. 5th International Computer & Instructional Technologies Symposium Proceedings Book. Elazığ: ICITS, ss. 726-729

Özarslan, Y. (2013). Genişletilmiş Gerçeklik İle Zenginleştirilmiş Öğrenme Materyallerinin Öğrenen Başarisi Ve Memnuniyeti Üzerindeki Etkisi. Anadolu Üniversitesi, Sosyal

Bilimler Enstitüsü, Uzaktan Eğitim Anabilim Dalı. Eskişehir.

Timur B., Timur S., Özdemir M., & Şen C. (2016). İlköğretim Fen Bilimleri Dersi Öğretim Programındaki Ünitelerin Öğretiminde Karşılaşılan Güçlükler ve Çözüm Önerileri, *Eğitimde Kuram ve Uygulama, 12* (2), 389-402.

Tülü, M. & Yılmaz, M. (2013). Iphone ile artırılmış gerçeklik uygulamalarının eğitim alanında kullanılması. *Akademik Bilişim Kongresi*, Akdeniz Üniversitesi, Antalya. Ocak, 23-25, 2013.

Vilkoniene, M. (2009). Influence of augmented reality technology upon pupils' knowledge about human digestive system: The results of the experiment. *Online Submission*, *6*(1), 36–43.

Uluyol, Ç. ve Eryılmaz, S. (2014). Examining pre-service teachers' opinions regarding to augmented reality learning. *Gazi University Journal of Gazi Educational Faculty, 34*(3), 403-413.

Yalçın Çelik, A. (2019). Biyoloji ve Kimya Öğretmen Adaylarının Artırılmış Gerçeklik Materyalleri Deneyimi. Karaelmas Journal of Educational Sciences 7 (2019) 123-132

Yılmaz, Z.A., Batdı, V. (2016). Artırılmış Gerçeklik Uygulamalarının Eğitimle Bütünleştirilmesinin Meta-Analitik ve Tematik Karşılaştırmalı Analizi. Eğitim ve Bilim Cilt 41 (2016) Sayı 188 s.273-289

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y. ve Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education.*Computers ve Education*, *62*, 41–49.

Zhang, J., Sung, Y.-T., Hou, H.-T. ve Chang, K.-E. (2014). The development and evaluation of an augmented reality-based armillary sphere for astronomical observation instruction. *Computers ve Education*, *73*, 178–188

Citation:
Yildirim, F.S. (2019). Augmented reality and education. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 286-297). ISRES Publishing, ISBN:978-605-698540-9.

From TPaCK to DPaCK – Digitalization in Education Requires more than Technical Knowledge

Johannes Huwer
University of Education Weingarten, Germany

Thomas Irion
University of Education Schwäbisch Gmünd, Germany

Sebastian Kuntze
University of Education Ludwigsburg, Germany

Steffen Schaal
University of Education Ludwigsburg, Germany

Christoph Thyssen
University of Technics Kaiserslautern, Germany

Introduction

The Challenges of digital transformation in STEM education are discussed on many levels of the educational system. Up to now, political initiatives (DigitalPakt Schule, 2019) and guidelines of the German Standing Conference of the Ministers of Education and Cultural Affairs on education in the digital world (KMK, 2017) have set a financial and generalized framework from a predominantly media education perspective. In contrast, there are still few concepts considering the specific subject-related and content-driven potentials and challenges of technology-enhanced learning in teacher training programs. For coordinated pre- and in-service teacher education and training, however, these models are crucial to provide a professional and evidence-based framework to decide for relevant knowledge and competences that are particularly important for STEM teachers. According to the KMK the competences in the digital world (KMK, 2017) include the transfer of knowledge beyond the subjects: on the one hand every teacher is expected to possess basic knowledge in the field of digitalization and the related technology. This, as provided also in the DigiCompEdu-model (https://ec.europa.eu/jrc/en/digcompedu), includes the ability to select digital education and training material based on deeper educational reflection, to design and to distribute it. Knowledge and skills should be applied reflexively,to create and to assess learning processes in an adequate way considering contemporary (digital) technology. On the other hand teachers should be used to apply transfer strategies facilitating students competence development competence development for students possible. Thus the expected profile of future teachers consists of general pedagogical content knowledge (Shulman, 1987) and its technological enrichment or - according to the SAMR-model (Puentedura, 2006) - technology-based transformation of teaching and learning.

A well-known model to describe this specific and essential teachers' professional knowledge is the TPaCK-model (Technological, Pedagogical and Content Knowledge, Koehler, Mishra & Cain, 2013). It illustrates and relates the *Technological Knowledge*

*(*Technologisches Wissen, TK) to the PCK areas mentioned by Shulman (1986) as an intersectional model (Fig. 1, detailed description of this model is provided as online supplement to this article). One intersection, the *Technological Pedagogical Content Knowledge (TPaCK)* (Koehler, Mishra & Cain, 2013), seems to be particularly crucial. The *Technological Pedagogical Content Knowledge* is understood as educational knowledge integrating technological tools in subject and content teaching.

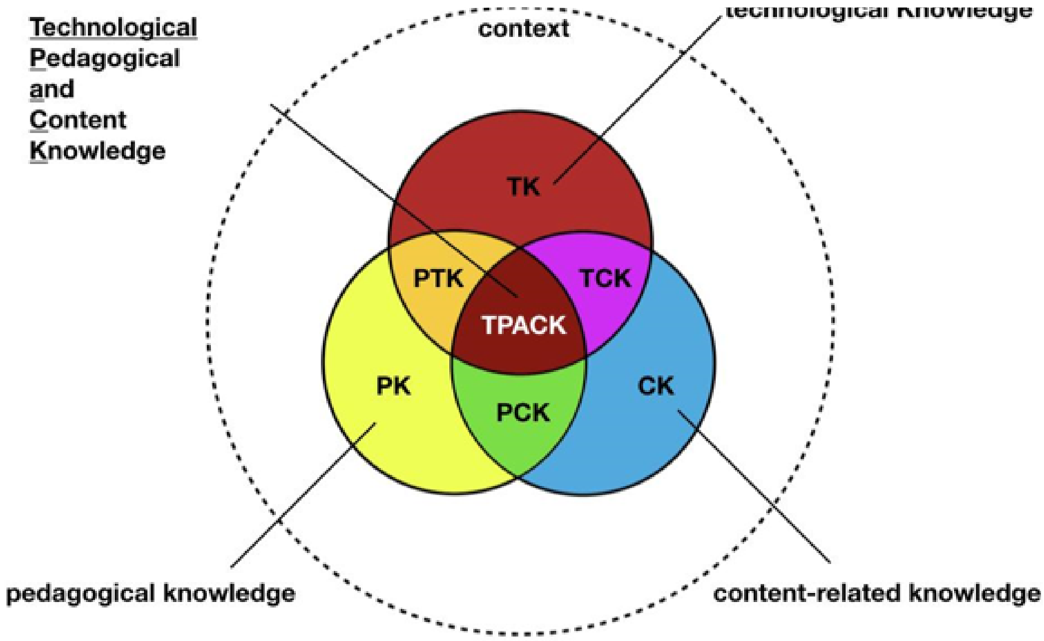


Figure 1. TPaCK-Model (Koehler, Mishra & Cain, 2013)

Content knowledge itself is an important foundation for teachers to act professionally – but it is not enough. The concept of competence (e.g. Weinert, 2001) includes not only mere knowledge and skills but also the willingness and motivational readiness to actually use them in various situations. One of the variable situations In the field of digitalization is the inclusion of techniological progress requiring the constant and ongoing professional development. This, for example, can be anticipated by the following question: "Does it make sense to have students write blogs in STEM class?" To answer this question it is obvious that TPaCK is necessary. Relating the question to an actual teaching topic, it is primarily inevitable to analyze learning potentials in the context of literacy, of the writing or designing a webblog against the background of a certain topic area. One must be willing - first mentally - to engage in such a teaching scenario, to confront critical considerations to added value for the subject learning of the pupils, to analyze specific tasks and aids. 21st century teaching and learning (EC, 20017) considers the challenges and potentials of a digital transformation highlighting the need of an adequate training to increase specific facets of teachers' professional knowledge include technology in STEM teaching.

Challenges of Digitalization – Professional Knowledge in Reply to Digitality

Technological knowledge on its own does not meet the needs of digital transformation processes of the recent past and near future. Problem solving and responsible decision-making in everyday life intertwined with digital components goes beyond pure technical knowledge and must take into account problems and risks of technical solutions as well as developments triggered by the use and usability of communication systems in social and cultural areas. Those developments equally influence the individual thinking and acting: Stalder (2018) argues that digital technology reorganizes how people thing and act: For instance, information is no longer institutionally filtered (e.g. by newspaper editors), it is available to everybody without social or cultural filters and each individual conected to the internet becomes a publisher.The linking of information and its unmanageable quantity lead to “changed practices of filtering and thus orientation” in a “chaotic sphere of information” (ibid., p. 10), so Stalder.

Since this kind of structure and handling of information also influences the perception of reality and learning, four terms are essential to define the requirements for teachers’ professional knowledge:

1. digitality,
2. referentiality,
3. community and
4. algorithmicity

and their features, which are explained in detail below.

The term digitality is a neologism of the words digital and materiality/reality (cf. Stalder, 2016).The area of action and perception in people is therefore extended by digitally transmitted spaces. Stalder (2016) differentiates referentiality, community and algorithmicity as basic features of digitality: referentiality encompasses the creation of a separate reference system, according to which an individual organizes the encountered information and experiences. It starts with drawing attention to particular information. But every post in social media (e.g. posts in facebook, pictures on instagram and the associated reactions), for example, creates an image reflecting the common interests of a social group sharing it. This commonly sustained frame of reference stabilizes meaning, generates options for action and and allows purposeful access to resources. The world of food and fitness youtubers and influencers might be a good example: Here, sensory connections are generated which indeed seem conclusive for the audience and followers (in some cases up to 5 million followers!), but usually lack a foundation when inspected from a scientific perspective. Many myths are currently emerging about scientific phenomena, in which social media activity about chemtrials for instance, are only the top of the iceberg. To bring back order to the unmanageable flood of information, filters are necessary which are provided by algorithms: analysing individual search and surfing behavior on the internet, preferences and interest of a single person is detected easily and precisely this information is offered with preference. The knowledge about this algorithmicity on the other hand is crucial for individuals to asses the information provided by a social group and to categorize it in sense of referentiality.

Those processes of change must be acknowledged within STEM teaching, because both the social discourses as well as the planning and design of educational processes will be significantly shaped by the, multi-perspective reflection of digital transformation and the processes of cultural change linked to it. From an educational perspective, many learners are not only to be adapted to the societal changes, but must also be put into position to design those processes (Kammerl 2015, Kerres 2018).

In addition there is another aspect: even STEM research creates and is visibly making use of a methodological spectrum (e.g. data mining in large databases) affected by digitality which also challenges teachers' professional knowledge. Another example is "in silicio research", in which entire living systems are digitally modeled and used to gain knowledge, such as the simulation of dendritic networks, population dynamics or biochemical simulations.

Pivotal companions of learning processes in the sight of a digital transformation are well educated teachers, who should be able to establish a digital-analoguous balance within educational contexts. Considering the process of cultural change outlined above the already mentioned TPaCK- model (Koehler, Mishra & Cain, 2013) falls short and should be expanded by the perspective of digitality enabling to look at pedagogical and scientific problems densely interrelated with referentiality, community and algorithmicity. A description of the TPaCK-model and its components is provided in the online supplement of this article. Below, a model will be developed according to the goals set by the KMK standards, after which digitally literate and responsible acting students shall be educated. Digital literacy is understood as a diversity of partial abilities and skills to use and design digital spheres including all technical, social and political components (Beck et al., 2018). The learners should thus be capable to use digital platforms appropriately and self-determined, to detect and avoid the concomitant risks, to maintain appropriate contact and to pursue their interests constructively (CMGT, 2019). At the same time educational systems and teachers should take on the potentials of the digitality's communicative practice for learning processes and make use of it. For this, teachers must have corresponding professional knowledge to take on digitality's communicative potentials and, consequently, topromote digitality-related competences in students (cf. competences in the digital world). For this reason the existing TPaCK- model should be extended by the aspect of digitality.

The "*Digitality-Related Pedagogical and Content Knowledge*"- Model (DPaCK): The Extension of Technical Knowledge Through Digitality

The perspective of digitality reveals that the technical change, which could be easily experienced by everyone on a daily basis by the means of, for example, the handling of certain devices and systems, shows less observable alterations on a societal, communication-theoretical or social level. The fact that online shopping is now technically possible anytime and anywhere has resulted in side effects that go beyond logistic and changed purchase behavior and must be critically evaluated by ecological (movement of goods, demolition of returns) as well as societal (the emergence of a problematic low-wage sector for logistics companies) aspects. Furthermore, through rating systems in online shops and video portals new forms of exchange emerge, which are often more relevant for the selling of products than traditional marketing measures or test reports in professional magazines. Not only delimited or virtual worlds are created like, for example, game worlds or simulations. Digital systems and realities (e.g. assistant systems with huge data pools, so-called “Big Data”, digital images of persons for the determination of credit ratings) are rather interacting and interfering to such an extent that “the digital” and “the analog” connect (Baecker 2017, Kerres 2018). This connection of digital and analoguous reality and the resulting facets, goes beyond a pure technical digitalization. The extended understanding of digitality and digitalization needs appropriate skills like social, systemic, semiotic knowledge in the matching scientific context to be able to assess options in decision-making situations, to appraise after-effects and to act competently and deliberately. In this way, for example, the self-concept of adolescents is also constituted mirroring the body images and life concepts shared in the social media (cf. Klapp & Klötter, 2019) Therefore an increased prevalence of developing psychological disorders increases throughout permanent social comparison (e.g. Lup, Trup & Rosenthal, 2015). But also the public perception of challenges of the 21st century like, for example, climate change depends to a large degree on visual communication in social media (Wang et al., 2018).

Hence, the task is not only to provide scientifically proper arguments, but to reflect the target groups’ collective reference frame – in this case pupils – for educational communication processes.

Based on an incomplete, pure technical perspective of the TPaCK-model, the first extension necessary seems to be the reflection of the socio-social, cultural and communication-related challenges of the digitality concept (Fig. 2). Since digitality transmitted through the algorithmicity contains all aspects of the technical knowledge as a foundation for further deliberations, it is useful to replace the technical knowledge with digitality knowledge. This way the listed challenges for this area of expertise can be portrayed without loosing the "TK" aspects of the TPaCK-model of to Mishra et. al (2013).

As a result, facets of digitality are taken into account, for example social, societal or ethical aspects, which are then linked to the respective intersections of CK and PK.

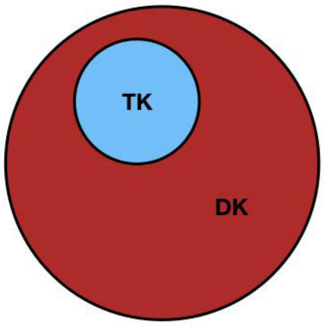


Figure 2. Relation of Technological Knowledge (TK) and Digitality-related Knowledge (DK)

The substitution of the technological knowledge with digitality-related knowledge also results in new intersections with the areas of Shulman (1986), analogous to the TPaCK-model (Fig. 3).

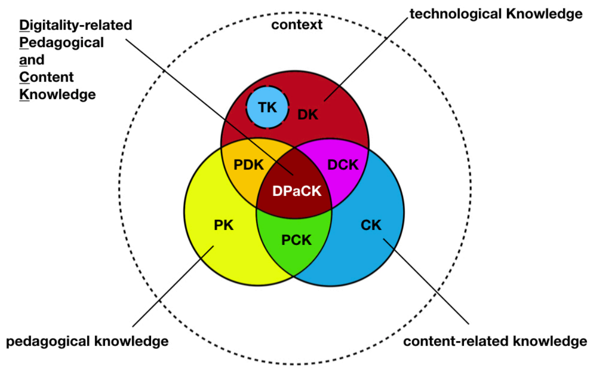


Figure 3. The DPaCK-Model: Extension of the TPaCK- Model of Koehler et al. (2013) with Aspects of Digitality

In addition, however, there is digitality-related analytical competence based on these areas of knowledge (Fig. 4, see also section 5 below). Not least, this competence helps at a meta-level to keep professional knowledge stocks up to date in the sight of advancing developments through corresponding review and evaluation. In the following, the areas of digitality-related professional knowledge, which is a central prerequisite for digitality-related analytical competence, are described in more detail:

- Digitality-related knowledge (DK) encompasses the digitality knowledge about the handling of technologies. This includes all aspects of the original technological knowledge (Koehler, Mishra & Cain, 2013) extended by the aspects of digitality that go beyond technical knowledge.

Examples: In a culture of digitality people need not only an understanding of mechanical procedures and algorithmic processes, but also competences of interaction in altered cultural spheres. The usage of digital technologies for thinking, working and handling processes equally demands competences to the utilization and selection of new forms of digitality. For example, learning with explanatory videos in science lessons (beyond educational or pedagogical knowledge, see below for more information) requires not only technical mastery of the camera, but also skills in the cinematic design of information units and in the opportunities of communication in the discourse systems linked to the publication (forum discussion, referencing, remix).

- Digitality-related and pedagogical knowledge (DPK) encompasses the intersection of digitality-related knowledge and the understanding of recent concepts to design approaches for training and learning processes.

  Examples: Like this, teachers have to reflect and consider in what way, for example, income-dependent effects can occur in the classroom when choosing digital-technical educational resources. This results, for example, into a BYOD concept (bring your own device) problem, if it comes to new forms of bullying ("You don't have an iPhone!"). In fact, this form of bullying exists already for some time, but it obtains a greater relevance given the fact that the student is forced to reveal that he/she does not have the latest smartphone due to the application planned by the teacher. Another example to be mentioned are the changes of symbolic systems and technologies in learning contexts as well as the concomitant altered communication forms in educational processes. Explanatory videos, for instance, facilitate not only the individual perception (e.g. individualizing of learning pace and sequence) but also flipped classroom scenarios (Seibert, Kay & Huwer, 2019). In addition, the use of animation software, innovative visualization formats and machine learning or learning analytics allows the design of adaptive, multimodal and multicodal learning environments. Designing customized and tailored learning environments necessitates teachers' knowledge of digitality that goes beyond DK and TPK.

- Digitality-related and content-related knowledge (DCK) includes the intersection of digitality-related knowledge and scientific knowledge or scientific methods of the subject with regard to the handling of technologies.

  Examples: The trisomy 21 blood test, which would not be possible without digital devices allowing quantitative PCR (polymerase chain reaction), has triggered a discussion, by changing abortion decisions, about terms such as "selection", "discrimination against the disabled" and the right to live with a disability. Individual medicine orrisk rates in health insurances would not be possible without digitalization in research and diagnosis and would lead to the question which consequences digital techniques entail. Public scientific databases e.g in genomics or climate research are essential resources for researchers all over the world, but they are also considered as pandora's box related to data storage and analysis issues in the public perception. Techniques like CRISPR/Cas as key for designer babies, selective medicine, special insurance plans based on genetic testing and data mining, data recording of the driving style in automobiles with integration of big data algorithms imply how intensively resulting societal questions related to the economic exploitation within the digital transformation processes should be debated with an informed and scientific background. Those examples show that in this area the professional element joins the digitality-related knowledge.

Digitality-related pedagogical and content-related knowledge (DPaCK) encompasses die intersection of digitality-related knowledge, pedagogical knowledge and content knowledge. It therefore creates the foundation for the design of subject-specific teaching and learning processes with technologies. Examples: For instance, the answer to the question, if it is useful within a specific educational content to make students write blogs needs DPaCK, because not only the digitally supported scientific method of a subject needs to be reflected, but also its combination with the content structure of the subject topic. The know-how, when and with which methodological setting it is useful to motivate students using a digital tool to solve a mathematical problem (e.g. the phase of exploring the properties of a geometric figure around a dynamic geometry system or phase of outsourcing a complex transformation to a computer algebra tool) would be another example.

Suggestions for Teacher Education and Training

STEM teachers are challenged on the one hand to keep up with the subject-specific and content-related dimensions of digital transformation in their educational disciplines, on the other hand they must reflect rapidly changing individual and societal media practices in the lives of adolescents when they are planning educational processes and learning opportunities (Allert & Richter, 2017). Considering the different scientific subjects' competence fields formulated by the KMK (2004) it is useful to offer commensurate occasions of reflection from the perspective of digitality within teacher education and training. The model provided in figure 3 gives an orientation to organize these occasions and to derive distinct goals for pre- and in-service teachers' professionalisation .

In addition, the model provides a foundation for the interdisciplinary exchange and collaboration within STEM education, media education and educational sciences. Not least of all, an orientation potential emerges for practice-oriented research of STEM teachers' professional knowledge. In return, the results can help to develop the digitality-related education and teacher training.

For example, in the competence area "knowledge acquisition", the methods of digital research (e.g. molecular modelling in the subject chemistry) are to be taught as well as the associated effects for each scientist and the epistemological consequences: Scientific theory occupies itself with what "science is and could be" (Frank 2003, 289) and therefore with knowledge principles, methods, goals and results of scientific research (Kornmeier, 2007). New methods, enabled by digitalization, are shifting the goals and intended results of science and in that way require a new ethical consent of scientists for which limits. So it becomes necessary, especially in the competence field "assessment" to orientate on professional content-related and ethical arguments, as well as to reflect on the effects of individual and social media practices.

In response to the question what precise consequences for the design of (STEM) class looks like, a critic reader will determine at this point at the latest that those challenges are difficult to be mastered; for sure, the interactive whiteboards installed in schools all over Germany can only be a desperate attempt to keep up with the speed of digital transformation. But how can the university teaching in science education assume responsibility and consider the concept of digitality, as well as the integration of rapid technological developments in the different disciplines? It remains to be answered here as well, how a inter- and trans-disciplinary collaboration between media education and educational sciences can be realised in order to meet this challenge in a coordinated and interconnected manner. Several development and research projects have currently been initiated at national and international level to address these challenges and they will deliver insights for educational design and teacher education in the next few years (e.g. the "TPACK 4.0" project as part of the state initiative digital@bw).

The DPaCK model offers an approach for discussion to STEM teachers to conceptualize a framework for educational design in the context of digitality. Building on this, the model offers a systematic-conceptual foundation for Educational-Design-Research (McKenney & Reeves, 2018) in the field of diagnosis (e.g. acquisition of individual competency profiles), as well as for the development of harmonized curricula (e.g. obligatory mediation of DPaCK in teacher training studies).

Consequences for Scientific Discussion

The DPaCK-model encounters ambiguous challenges: On the one hand it considers the concept of digitality which reflects highly dynamic changes in society and culture. This is an evolution of its ancestorical TPaCK model widening the perspective of digitally enhanced STEM-teaching. On the other hand a fixed model is counteractin exactly the dynamical nature of the digitality concept. Against this background, the present model can only be used as baseline and it serves as starting point for discussion in the community of STEM educators. Finding a balance between structure and openness, a constant exchange between teaching practitioners and STEM education research is needed to succeed in the change process. We would also like to discuss whether socio scientific issue could be another dimension of knowledge.

Acknowledgements

We thank the Joachim Herz Foundation for their support within the "Kolleg Didaktik:digital".

References

Allert, H. & Richter, C. (2017). Culture of digitality instead of digital education revolution (Kultur der Digitalität statt digitaler Bildungsrevolution). *Paedagogische Rundschau*, *71*(1), 19-32.

Ball, D., Thames, M.H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special?. *Journal of Teacher Education, 59*(5), 389–407.

Baecker, D. (2017). How is digitization changing our thinking and our way of dealing with the world? (*Wie verändert die Digitalisierung unser Denken und unseren Umgang mit der Welt?)* In R. GLÄß & B. LEUKERT (Eds.), *Handel 4.0: Die Digitalisierung des Handels – Strategien, Technologien, Transformation*, 3-24. Berlin, Heidelberg: Springer.

Beck, R., Greger, V., Hoffmann, C. et al. (2018). Digital maturity. An analysis of the ability of citizens in Germany to constructively and confidently deal with digital spaces. Final Report of the National (Digitale Mündigkeit. Eine Analyse der Fähigkeiten der Bürger in Deutschland zum konstruktiven und souveränen Umgang mit digitalen Räumen. Abschlussbericht des Nationalen) E-Governement Kompetenzzentrum. https://negz.org/wp-content/uploads/2018/06/NEGZ-ISPRAT-Studie-Dig-M%C3%BCnd-Abschlussbericht.pdf (13.09.2019)

BMBF (2019). Administrative Agreement DigitalPakt School 2019 to 2024 (Verwaltungsvereinbarung DigitalPakt Schule 2019 bis 2024), https://www.bmbf.de/files/19-03-15_VV_DigitalPaktSchule_Wasserzeichen.pdf (15.09.2019)

CMGT (2019) http://www.cmgt.uni-leipzig.de/projekte/digitale_muendigkeit.html (23.09.2019)

European Commission. High Level Group on Science Education, European Commission. Science, & Economy. (2007). Science education now: A renewed pedagogy for the future of Europe (Vol. 22845). Office for Official Publications of the European Communities.

Frank, U. (2003): Some reasons for the revival of scientific theory (Einige Gründe für die Wiederbelebung der Wissenschaftstheorie). in: Die Betriebswirtschaft, *63*(3), 278-292.

Kammerl, R. (2015). Media education - an educational offer in which media literacy comes out the back? (Medienbildung - ein Bildungsangebot, bei dem Medienkompetenz hinten rauskommt?) *Kinder- und Jugendschutz in Wissenschaft und Praxis*, *60*(1), 3-7.

Kerres, M. (2018). Education in the Digital World: We have the choice. (Bildung in der digitalen Welt: Wir haben die Wahl.) *denk-doch-mal.de, Online-Magazin für Arbeit-Bildung-Gesellschaft*, *02*(18). http://denk-doch-mal.de/wp/michael-kerres-bildung-in-der-digitalen-welt-wir-haben-die-wahl/ (31.09.2019).

Klapp, A. & Klotter, J. (2019). # Fitness vs. # BodyPositive - the different social construction of health on Instagram. Prevention and health promotion. (# Fitness vs. # BodyPositive – die unterschiedliche soziale Konstruktion von Gesundheit auf Instagram. Prävention und Gesundheitsförderung.) [online first, https://doi.org/10.1007/s11553-019-00708-5].

KMK (2017). Education in the digital world (*Bildung in der digitalen Welt*) https://www.kmk.org/fileadmin/Dateien/veroeffentlichungen_beschluesse/2018/Strategie_Bildung_in_der_digitalen_Welt_idF._vom_07.12.2017.pdf (15.09.2019)

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education*, *193*(3), 13-19.

Kornmeier, M. (2007). Science theory and scientific work. (Wissenschaftstheorie und wissenschaftliches Arbeiten.) Heidelberg: Physica-Verlag. DOI 10.1007/978-3-7908-1919-9.

Lup K., Trub, L., & Rosenthal, L. (2015). Instagram# instasad?: exploring associations among instagram use, depressive symptoms, negative social comparison, and strangers followed. *Cyberpsychology, Behavior, and Social Networking*, *18*(5), 247-252.

McKenney, S., & Reeves, T. C. (2018). *Conducting educational design research*. London: Routledge.

National Research Council Committee on Information Technology Literacy. (1999). *Being fluent with information technology literacy*. Washington, DC: National Academy Press.

Schier, A. (2018). Identities in digitality from "digial lifestyle" to "design your life". Generation and political culture in the sign of changed living environments in Germany in the digital discourse in advertising. (*Identitäten in Digitalität vom „digial lifestyle" zu „design your life". Generation und politische Kultur im Zeichen gewandelter Lebenswelten in Deutschland im Digitalitäts-Diskurs in Werbung.)* Hamburg: Kovacs.

Seibert, J., Kay, C., & Huwer, J. (2019). EXPlainistry - Documentation, explanation and visualization of chemical experiments supported by ICT in schools. *Journal of Chemical Education, 96*(6), 2503–2509. doi:10.1021/acs.jchemed.8b00819

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Stalder, F. (2016). Culture of digitality. (*Kultur der Digitalität)*. Berlin: Suhrkamp.

Stalder, F. (2018). Challenges of digitality beyond technology. (Herausforderungen der Digitalität jenseits der Technologie. *Synergie. Fachmagazin für Digitalisierung in der Lehre*, *5*, 8-15.

Wang, S., Corner, A., Chapman, D. & Markowitz, E. (2018). Public engagement with climate imagery in a changing digital landscape. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(2), 509.

Weinert, F.E. (2001). Concept of competence: a conceptual clarification. In D. Rychen & L. Salganik (Eds.), *Defining and selecting key competencies* (S. 45-65). Seattle: Hogrefe and Huber.

Citation:
Huwer, J., Irion, T., Kuntze, S., Schaal, S. & Thyssen, C. (2019). From TPaCK to DPaCK – Digitalization in education requires more than technical knowledge. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 298-309). ISRES Publishing, ISBN:978-605-698540-9.

Education Research Highlights in Mathematics, Science and Technology is published annually from the selected papers invited by the editors.

This edition includes 3 sections and 18 papers from the field of Science Education, Mathematics Education and Educational Technology.

All submissions are reviewed by at least two international reviewers.

The purpose of the book is to provide the readers with the opportunity of a scholarly refereed publication in the field of education in mathematics, science and technology.

Education Research Highlights in Mathematics, Science and Technology is published by ISRES Publishing.