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A Conversation with Dr. Donna Berlin about the History of ICRSME

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The International Consortium for Research in Science & Mathematics Education (ICRSME) held its first Consultation in 1986 in Port of Spain, Trinidad and Tobago. Since that first Consultation, 14 others have followed in 10 different cities across Central and South America and the Caribbean over a period of nearly 35 years. Many of these Consultations occurred before the time of the internet, email, cloud storage, social media, and video conferencing. Most of the rich history of ICRSME is in the minds, experiences, and stories of those who have attended the Consultations. We are, therefore, moving forward with an initiative to record and archive the unique history of ICRSME.

As part of this documentation process, we interviewed Dr. Donna Berlin, one of the founders and long-time organizers of ICRSME. Dr. Berlin is Professor Emeritus at The Ohio State University (OSU). Much of her work with respect to teaching, research, and service occurred at the intersection of mathematics and science education. She taught an integrated science and mathematics course at OSU and edited the *School Science and Mathematics Integrated Lessons* (SSMILes) feature in the *School Science and Mathematics* journal for several years (e.g., Berlin, 1989a, 1989b, 1990). Dr. Berlin, in collaboration with Dr. Art White also from OSU and founder and long-time organizer of ICRSME, developed two models: Berlin-White Integration of Technology Model (Berlin & White, 1987, 1995) and Berlin-White Integrated Science and Mathematics Model (Berlin & White, 1994). The models served as a foundation for their empirical research (e.g., Berlin & White, 2012). Dr. Berlin was honored with the School Science and Mathematics Association (SSMA) *Award for Excellence in Integrating Science and Mathematics* for her models and related research (OSU, n.d.) and with SSMA's *George G. Mallinson Distinguished Service Award* for her service to the organization (SSMA, 2006), including serving as President (2002-2004).

ICRSME and Collaboration

In our conversation with Dr. Berlin, collaboration was a persistent theme in the storied history of ICRSME. In fact, collaboration between science and mathematics educators served as the beginnings of ICRSME. Collaboration is also evident in the interaction and support between established and emerging science and mathematics educators. Further, the locations of the Consultations were a foundation for collaboration between science and mathematics educators across countries. Each of the following sections elaborates on these elements of collaboration through the voice of Dr. Berlin.

Science and Mathematics Education

STEM and STEAM have become a part of the lexicon in education. Before the advent of the acronyms, however, the work of Drs. Berlin and White already focused on the integration of mathematics and science. Dr. Berlin described the early days of this work:

> *I was a math educator, [Dr. White] was a science educator, and we saw the connections, and we were very amenable to them. But the mathematics education community was not at all. … The science educators were more comfortable with the notion of integration.*

Dr. Berlin further commented on how the international community perceived the integration of science and mathematics:

> *Because the international people were comfortable with [integration], more so than the people in the United States, it was a natural outgrowth to do [research] internationally.*

The initial international collaboration included individuals from countries including the United States, Costa Rica, Trinidad and Tobago, and Panamá. The need for face-to-face interaction initiated the organization of the first ICRSME Consultation:

> *We were all doing pieces of this research. … And communications were not what they are today. I mean, we were doing things over the telephone. And it really wasn't working really well. So, it was decided that we'd all get together and share what we were finding in our research.*

ICRSME and the initial Consultation were grounded in collaborative work centered in the integration of science and mathematics education.

> *[The initial Consultation] was set up as a meeting with sessions very similar to what we've been doing ever since … opportunities for us to get together and discuss our research. We built that into some of the other sessions as well. For some of the other Consultations, we would have some time set aside where people were doing similar kinds of research and they could just get together at a roundtable and just talk and share what they were doing.*

This work led to the development of further collaboration over subsequent Consultations.

Dr. Berlin discussed one of the latter outgrowths for ICRSME. Her interactions with teachers in La Manzanilla, Mexico led to work around the integration of science and mathematics via placed-based education.

> *[In Mexico], I started to connect … with the classroom teachers and they would tell us, for example, that they take the kids to the beach, because the beach was one block from their school. And then we were talking about all the different things that connect science and math that were right there at the beach, such as the tides, the erosion, the shells, the symmetry in the shells. … They were coming up with all the different ways they saw mathematics and science on the beach, in their own community. So, that's how we started to connect it to place-based education too; so, connecting science and math, literally in the community of the students.*

At this and subsequent ICRSME Consultations, Dr. Berlin presented and wrote chapters for the ICRSME books sharing place-based learning experiences for science and mathematics specific to the location of the Consultation (e.g., Berlin, 2011, 2014).

Collaboration Between Established and Emerging Science and Mathematics Educators

As previously shared, Dr. Berlin was awarded the 2006 *George G. Mallinson Distinguished Service Award* by SSMA for, among many reasons,

> Her display of excellence in the cultivation of new leaders, especially teachers and teacher educators, into leadership roles; and for her continual drive, passion, and integrity for excellence in science and mathematics teaching, learning, and leadership. (SSMA, 2006, p. 2)

In light of her longtime leadership role in ICRSME, these same qualities are ubiquitous throughout the Consultations and Virtual Conferences that the organization has held as well as the collaborative relationships it has generated between participants.

Such collegiality and supportive interactions between established and emerging science and mathematics educators exemplifies the *je ne sais quoi* of ICRSME and distinguishes it from other academic organizations. Dr. Berlin described how established faculty, new faculty, and graduate students were all treated as respected colleagues who supported each other in their academic pursuits:

> *There was nobody who was better than anyone else. The people who came were interested in collaboration, they were interested in sharing. They weren't interested in building themselves up, particularly at the expense of somebody else. I don't know how else to describe it.*

Most of us have witnessed, or experienced, harsh critical feedback given by audience members at an academic conference presentation. Many times, such criticism is weighed against graduate students or new faculty by senior colleagues who use such opportunities to show their expertise at the expense of the nascent researcher. Such interactions are not witnessed at ICRSME. Dr. Berlin described a situation that occurred in Chile:

> *[None] of the Chileans [wanted] to present. We sat down and talked with some of them, … they were afraid that their work wasn't good enough. … So, we finally said, "Try it." One [researcher] presented his work … we changed the program to make a spot for him. … He went back to his colleagues and said, "Oh, they're not going to eat us alive, don't worry about it." We then had to change the whole program a lot because they all wanted to present their work.*

ICRSME attendees quickly recognize the friendly and supportive nature of the organization and dispatch any fears of presenting.

Another way that collaboration between established and new faculty manifests is the attention given to ensuring all ICRSME presenters have an audience to provide them constructive feedback. Unlike large academic conferences with many concurrent sessions, ICRSME Consultations and Virtual Conferences keep the number of concurrent sessions low in order to prevent any presenter from facing an audience of few or none. Dr. Berlin described a particular event when the presentation by an established leader drew most of the ICRSME attendees, leaving a scant audience in another presentation session:

> *[An established ICRSME participant] went into the other room, and there were very few people there. And he was upset with it. And he took the people from the back of the room [with an audience], so it wouldn't be so obvious, and he suggested to them, probably strongly, to go into the other room because it just didn't look right.*

And the feedback provided by ICRSME participants is supportive and constructive. Dr. Berlin explained how participants focused on helping their colleagues achieve their academic goals:

> *The special part of it, to me and I and I think for many other people, was the collegial and supportive relationships. Everybody was there to help everybody else to get tenure, to get things published, to do better*

> *research, do better writing … that's the unique part of [ICRSME], everybody was really there to support one another.*

Such collaboration not only involves established and emerging science and mathematics educators but extends across a broad geographic region including Central and South America and the Caribbean, including scholars from an even greater range around the globe.

Collaboration Between Science and Mathematics Educators Across Countries

An important aspect of the collaboration that ICRSME fosters is its far-reaching geographic range. The map in Figure 1 shows the various locations of the Consultations. Further, the research shared at the Consultations comes from host country scholars and visiting academics from around the globe representing countries such as Amsterdam, Australia, Germany, Israel, Nigeria, Taiwan, Thailand, and United States.

Figure 1
Locations of ICRSME Consultations I through XV

Dr. Berlin described the benefit of the international participation in ICRSME Consultations:

> *We were collaborating on research, we wanted to share the research. With the Consultations, we were able to share it to a wider audience. We were able to get feedback from other people as well, and see what other people were doing related to what we were doing. Because it was research-based, it was all of benefit, really beneficial to all the people that were participating … college and university [faculty], … K-12 classroom teachers, … graduate students.*

When asked why the Consultations were always in Central and South American and Caribbean countries, Dr. Berlin explained that the locations were determined organically at the request of the international collaborators in the Consultations.

> *Because we started that way. We had people from the University of Costa Rica, the University of the West Indies, and the University of Panamá. … So, the people that were involved initially, and their contexts, kept it in Central America and South America. … And then it was their contacts; since we held the meetings in Central America, other people would come, and then they would want to hold it in their country. … Because of the ease of travel within the same region, that's why it stayed there.*

ICRSME collaboration does not end with sharing of research at biennial Consultations. Throughout the history of ICRSME, some exciting international collaborations have formed between visiting scholars and host country educators and schools. Some examples of such collaborative endeavors will be shared in a future editorial.

Conclusion

When asked about how she would articulate the mission of ICRSME, Dr. Berlin succinctly described her perspective:

> *If I had to pick two words, it would be collaboration and sharing. That's what was the initial mission and goals.*

Over the 35 years of Consultations, ICRSME has continued this culture of collaboration and sharing. We encourage ICRSME friends to contribute their experiences of collaboration and sharing via this survey for the documentation of ICRSME's history. We are also looking towards the future as the ICRSME community grows to include new host cities, to welcome new ICRSME friends, and to continue collaboration around science and mathematics education.

References

Berlin, D. F. (1989a). The integration of science and mathematics education: Exploring the literature [SMMILES Department]. *School Science and Mathematics, 89*(1), 73-76.

Berlin, D. F. (1989b). Introducing the SMMILES department. *School Science and Mathematics, 89*(2), 166.

Berlin, D. F. (1990). A graphing activity: Bottles, grades 8-11 [SMMILES Department]. *School Science and Mathematics, 90*(8), 732-736.

Berlin, D. F. (2011). Teaching science and mathematics through community and culture. In D. F. Berlin & A. L. White (Eds.), *Science and mathematics education: International innovations, research, and practices* (pp. 173-185). Columbus, OH: International Consortium for Research in Science and Mathematics Education.

Berlin, D. F. (2014). Place-based education: Connecting mathematics, science, community, and culture. In D. F. Berlin & A. L. White (Eds.), *Initiatives in mathematics and science education with global implications* (pp. 107-117). Columbus, OH: International Consortium for Research in Science and Mathematics Education.

Berlin, D. F., & White, A. L. (1987). An instructional model for integrating the calculator. *The Arithmetics Teacher, 34*(6), 52-54.

Berlin, D. F., & White, A. L. (1994). The Berlin-White integrated science and mathematics model. *School Science and Mathematics, 94*(1), 2-4.

Berlin, D. F., & White, A. L. (1995). Using technology in assessing integrated science and mathematics learning. *Journal of Science Education and Technology, 4*(1), 47-56.

Berlin, D. F., & White, A. L. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science and Mathematics, 112*(1), 20-30.

The Ohio State University (OSU). (n.d.). Donna Berlin: Biography. https://ehe.osu.edu/directory?id=berlin.1

School Science and Mathematics Association (SSMA). (2006, Fall). 2006 SSMA awards breakfast. *The Math-Science Connector*. https://www.ssma.org/assets/docs/Fall2006-R.pdf

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Effects of Language on Children's Understanding of Mathematics: Implications for Teacher Education

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ABSTRACT

Teacher educators have a moral and civic obligation to examine ways in which language and mathematics are connected and supported in teaching and learning mathematics. It is essential to examine the roles and influence of family, parents, community, teachers, administration, and teacher educators as they collaborate to support learners. Their role should be considered in preparing and supporting teachers to develop curriculum, plan instruction, and implement strategies that support students' development of language in the mathematics classroom. An examination of the literature regarding the effects of language on children's understanding of mathematics was conducted around six areas: 1) impact of language on understanding and meaning making; 2) symbols, expressions and language connections; 3) effects of teachers' listening orientation; 4) language development, play and family influences; 5) implications for multilingual learners; and 6) technology and digital media. Implications for teacher education and future research are presented. We offer readers a potential framework to consider for guiding teacher educators' practices and future research efforts. In so doing, we display various connections and interplays between language and children's mathematical meaning making and understanding.

Keywords: mathematics, language, teacher education, family, play

Introduction

As a profession, teacher educators have a moral and civic obligation to examine in a formal, directive manner ways in which language and mathematics are connected and how one supports the understanding of the other. It is essential that we examine the roles and influence of varying constituents such as family, parents, community, preservice teachers (PSTs) and inservice teachers (ISTs), school administration, teacher education and the public in general. We should commit to examining how to create opportunities for collaboration among and between these constituents in order to have a focused community of practice that supports learners' meaning making in mathematics. Further, teacher educators should consider their roles in preparing and supporting both

PSTs and ISTs to develop curriculum, plan instruction, and implement strategies that sustain the development of language competencies in the mathematics classroom.

The Association of Teachers Educators (ATE) developed standards for teacher educators (2018), "to help all teacher candidates and other school personnel impact student learning" (p. 1). These standards serve as a guide for teacher educators. *Standard 1* on teaching indicates that we, as teacher educators, should model research-based practices in teacher preparation and professional development. This entails having a strong knowledge of both content and pedagogical practices that include the appropriate use and application of language in mathematics. In *Standard 2,* cultural competence, ATE notes teacher educators have a role and responsibility to support PSTs and ISTs in connecting to communities, families, and cultures where both language and mathematics can be effective vehicles. Finally, ATE's *Standard 6* addresses collaboration, underscoring the need to engage all stakeholders in teacher education. These partnerships can facilitate teaching, learning, and research in the fields of mathematics and language education.

The Association of Mathematics Teacher Educators (AMTE) also ascribes to the important role of language in teaching and learning mathematics, as noted in the 2017 *Standards for Preparing Teachers of Mathematics*. AMTE advises teachers to "use mathematical language with care and precision" (p. 9), promote equitable practices by considering the "everyday, informal language of students that support or hinder the specialized use of language in mathematics" (p. 14), and attend to language and familiar contexts and experiences that include opportunities and support for multilingual students to use their own language (p. 22). AMTE further advocates that teacher educators should assist teachers in seeing "their role as helping children mathematize their world, nurturing understanding of mathematical concepts and relationships, and developing language to talk about those observations" (p. 59) while helping learners connect their informal language to formal mathematical language and notation, offering multiple opportunities for learners to communicate. In the context of both ATE and AMTE teaching standards, we approached the use of language and children's meaning making in mathematics from multiple dimensions.

Overview of Process

As teacher educators, many questions come to mind: What is language? What is mathematical language? Are there different contexts such as home, classroom, or playground to be examined? What is the role of language development--reading, writing, speaking and listening--and of academic language in the conceptual learning of mathematics? How do we consider the relational, computational, symbolic, and syntactical areas of language, including register, to foster meaning making and develop shared meaning? An eight-member Commission on the Effects of Language on Children's Conceptual Understanding of Mathematics appointed in 2015 by the Association of Teacher Educators considered these and other questions. The commission was tasked with examining the current theories, practices, and research on the effects of language on children's conceptual understanding of mathematics and determining implications for teacher education. To undertake this task, the following questions were identified:

1. What are the effects of language on children's meaning making and conceptual understanding of mathematics?
2. What implications do these effects have for mathematics teacher education?

The commission, made up of experienced mathematics teacher educators with PK-12 teaching experience, reviewed both the AMTE 2017 *Standards for Preparing Teachers of Mathematics* and the 2018 ATE Standards for Teacher Educators mentioned previously, along with mathematics curriculum standards noted in the National Council of Teachers of Mathematics' *Principles and Standards for School*

Mathematics (2000) and the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010). From this, six areas were identified to explore further (listed below). Then each committee member took an area and read and reviewed the literature, both theoretical and research studies, related to that area. These resources, along with the authors' individual areas of expertise and related research, helped frame the facets explored around mathematics and language. The commission met regularly to share summaries of findings, engage in further in-depth discussion to synthesize literature, as well as determine emerging patterns. This provided opportunities for verifying findings and coming to common agreements. Additionally, the group met with other teacher educators at the ATE annual conference for two years to gather feedback on the direction of the Commission's work and identify areas for further exploration regarding the effects of language on children's meaning making and conceptual understanding of mathematics. Through this process, the commission determined the following areas to discuss in this paper.

1. What mathematical language is and how it connects to meaning making and understanding
2. Symbols, expressions and language connections
3. Effects of teachers' listening orientation on students' mathematical learning
4. Mathematics language development: Play and family influences
5. Mathematics and multilingual learners
6. Technology and digital media

The Commission is not making the claim that these are the only areas of mathematics and language connections. For the purposes of this paper, however, it is critical to examine ways of forming and supporting a community of practice that aims to synthesize and summarize research on effective practices for developing students' conceptual mathematical understanding, meaning making, and effective communication of their understanding through language.

For many students, mathematics is experienced or seen as a foreign, unfamiliar language (Kenney et al., 2005). Mathematical language is used informally in some contexts, such as home, and more formally in school settings. In school contexts, some students struggle to make meaning of the formal mathematical language and the related mathematical ideas, especially those whose first language is not the spoken language of the classroom. Even further, when blending their formal and informal experiences, students encounter words and expressions having multiple meanings, such as *odd, mean,* and *fraction* (Wilkerson et al., 2015). It is important for teacher education programs to consider ways to prepare PSTs and support ISTs in identifying effective ways to encourage students in academic language development and applications. Additionally, it is important to examine the diverse environments where mathematical meaning making occurs, and their affordances, to identify effective ways of supporting students' language development and to further envision the roles of teacher education.

Hence, the commission examined this complex issue in the context of mathematical meaning making and understanding with the goals of (1) identifying current strategies used in practice that effectively support language and mathematical learning and (2) proposing further directions in terms of innovative approaches and research methods. This paper is a culmination of the Commission's explorations and syntheses, where ideas related to language and mathematics are examined through the lens of teacher education. We offer readers a literature review that showcases multiple facets of mathematics and language, illuminates the problems of practice, reports on related research, and points to areas for further research. Then, we offer a potential framework for consideration.

What is Mathematical Language and How Does it Connect to Understanding and Meaning Making?

We begin by offering our shared understanding of mathematical language. In the context of the mathematics education of young children, language is understood to be an evolving, developmental system. This system is comprised of spoken, written, visual, or bodily signs or actions and structures that are used in a cultural community for informal mathematical talk, exploration, or meaning making as well as formal mathematical communication and representation. For the purposes of this paper, the authors define mathematical language as the mathematics content, its literacy ramifications, and modes of discourse that occur within and among school, home, and community contexts. Specific facets include vocabulary, symbols, heuristics, questions, technology, critical literacies, and social interactions that influence children's reading, writing, listening, and speaking competencies and proficiencies with respect to communicating mathematical meaning making and understandings. Factors influencing mathematical language include linguistics and linguistic diversity, comprehension, and complexities in mathematics language acquisition (e.g., socioeconomic status (SES), students with differing abilities).

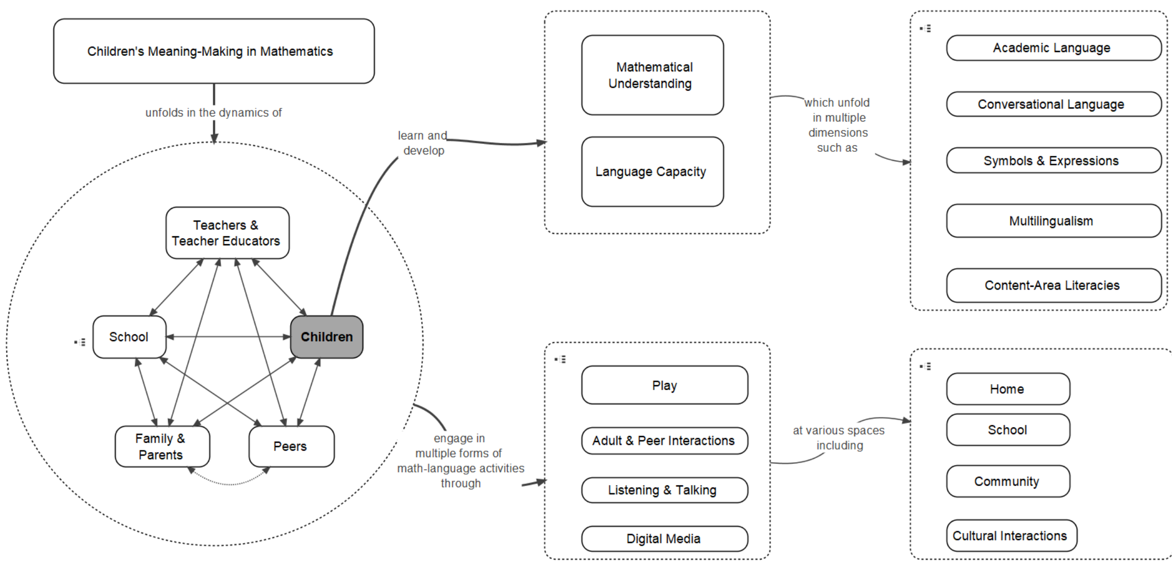
Additionally, we posit that understanding is a result of "learning as meaning making … a process by which people [actively] interpret situations, events, objects, [and/]or discourses, in light of their previous knowledge, experience, [and available cultural resources]" (Zittoun & Brinkmann, 2012, p. 106). Ivkovic (2019) further mentioned that as we engage in this process, we use multiple modalities to make meaning, interact, and communicate. Lee and Stephens (2020) summarized the key findings from a 2018 National Academies of Sciences, Engineering, and Medicine consensus report, entitled *English Learners in STEM subjects: Transforming classrooms, schools, and lives*. They noted that there have been parallel shifts in the fields of STEM subjects and second language acquisition away from a "focus of learners' mastery of discrete elements of content" towards an "emphasis on students' mak[ing] sense of phenomena and problems" (p. 429). A key construct from the consensus report that undergirds the crucial connections and interplays between language and children's mathematical understanding (see Figure 1) is that "[a]s English Learners engage in STEM disciplinary practices (e.g., developing models, arguing from evidence, constructing explanations), they use language for the purpose of making meaning of STEM subjects through social interactions with peers and the teacher in the classroom community" (p. 426).

In 2010, Moschkovich led an effort to consider various perspectives for research in mathematics education and language. She noted the complexity of mathematical language (Pimm, 1987), which includes specialized vocabulary and complex discourse (Crowhurst, 1994; Halliday, 1978; Moschkovich, 2007) associated with the mathematical language. She states, "I use the phrase 'the language of mathematics' not to mean a list of vocabulary words or grammar rules but the communicative competence necessary and sufficient for competent participation in mathematics discourse practices" (p. 3).

Since the 1980s, the National Council of Teachers of Mathematics (NCTM) has emphasized the critical role of communication with particular attention to the role of discourse and its contribution to the development of language by learners, and the connection to their ability and opportunity to express mathematical ideas (NCTM, 1989; 1991; 2000; 2014; 2018; 2020a, 2020b). NCTM (2014) identified eight effective mathematics teaching practices, one of which specifically targets discourse, stating, "Effective teaching of mathematics facilitates discourse among students to build shared understanding of mathematical ideas by analyzing and comparing student approaches and arguments" (p. 29). NCTM notes that discourse is "central to meaningful learning of mathematics" (p. 35). Further in the recent release of *Catalyzing Change* (NCTM 2018; 2020a; 2020b) one of the four recommendations made points specifically to broaden the purposes of learning mathematics so that each and every learner develops a deep understanding of mathematics, builds a positive mathematical identity, and is able to use mathematics to understand and critique their world. This focuses on meaning making in mathematics for which mathematical language is central. There is consequently a need for teachers to attend to the development of mathematical language to support students' meaning making and mathematical understanding.

Figure 1

Design Framework for Exploring Language Effects on Children's Mathematical Understanding



In seeking mathematical understanding through discourse, student-teacher talks play a central role in the development of mathematical language. Khisty and Chval (2002) examined the role of pedagogic discourse related to teacher talk, in particular to second language learners. Interactions of two teachers with their students were analyzed. In the environment where the teacher used engaging mathematical talk, including rich mathematical words, students were able to demonstrate their understanding of the words and their meanings. The authors go on to offer the premise that the teacher plays a critical role in the communication process that forms the context for learning since the teacher is obviously present in the classroom, as the 'more capable other' (Vygotsky, 1978), and is the person who engineers the learning environment (p. 167). These authors contend that it is essential to better understand student and teacher interactions that occur in the classroom, that is, the influence of pedagogic discourse.

Research by Hebert and Powell (2016) found that fourth grade students had varied levels of success with the use of mathematical vocabulary. While mathematical vocabulary is only one aspect of mathematical language proficiency, it is important to examine how students acquire and use vocabulary in different contexts, as well as to analyze the implications for students' meaning making in mathematics. These authors found that many students' use of vocabulary was limited to procedural rather than conceptual aspects of the concept, although some students did include references to mathematical properties. Further, Lemke (2003) posits a semiotic relationship between mathematics, natural language and visual representations to support meaning making. He argues that "semiotics helps us understand how mathematics functions as a tool for problem-solving in the real world, and how this function may have played a key role in the historical evolution of mathematics" (p. 215), advocating for bridging verbal language, visual representations, symbolics of mathematics and the real world.

These studies and perspectives offer insights into the rich connections among language, meaning making, and mathematical understanding. As will be described in this paper, mathematics educators should attend to multiple aspects of teaching and learning mathematical language, including: mathematical understanding; vocabulary and classroom discourse; role of play and influence of families, language and culture; connections to reading and writing; effects of teachers' language and listening orientations on students' learning; second language learning; differing learning abilities; instructional practices; role of the teacher; role of technology and multimodal representation; structure and use of representations in mathematics; curriculum development; and equity. There is much to learn in terms of student support and engagement, considering the foundational nature of language in students' meaning making and conceptual understanding of mathematics.

Symbols, Expression, and Language Connections

Teachers use language, including both verbal and non-verbal expressions, to communicate mathematically with their students. Teachers focus on mathematical conceptualization, essential skills, and reasoning aimed at engaging students' developing mathematical understanding. Inside the classroom learning community, language conventions should be carefully chosen as an agreed-upon mutuality – where the teacher chooses words and phraseology; students simultaneously grapple with and then make sense of those concepts (Zhang et al., 2015). Teacher educators (mentors, supervising teachers, professors, teacher-leaders, evaluators, etc.) then provide a common ground of shared understanding in order to enter the dialogue. Thus, the language of symbolic expression factors into the teacher educator's practice. This ties directly to ATE *Standard 1* (ATE, 2018) that highlights the importance of modeling inside of instructional practice. Furthermore, all five content standards and corresponding process standards from NCTM (2000) link to the importance that symbolism, expression, representation, and notation play in mathematics instruction and the development of mathematical language.

The Importance of Symbols in Mathematics

Symbolic comprehension and symbolic number processing serve as critical corner stones of mathematics achievement (Sasanguie et al., 2013). When it comes to symbols in mathematics, students should be able to identify the meaning and the function of any given symbol. Teachers support by drawing connections to those meanings and functions in order that students can grasp the abstraction of those symbols (Zhang et al., 2015). Other studies show the predictive nature of symbolic processing on mathematical achievement, particularly relative symbolic number ability and later skill (Lyons et al., 2014).

The Influence of Language on Mathematical Comprehension of Symbols

Firmender et al. (2014) link the connection between student mathematical achievement and the instructional practice of using verbal communication alongside targeted mathematical language practice. This significant correlation reinforces the importance that language plays in mathematics aptitude. For teacher educators, this direct link should be understood and emphasized. Teacher educators can guide practice toward the effective use of academic vocabulary, mathematical meaning making, and discourse inside the classroom.

Teachers use language to communicate, and therefore teach, complex ideas which are often abstractly represented by symbols (Burns, 2006; Caglar, 2003). When introducing abstract concepts, teachers are able to support students in making meaning of key vocabulary, while also providing a visual example of how such words and symbols interact in the processing of the concept. Think about our commonly shared understanding of the equal symbol ("=") and the complexities of interpretation that arise around equivalence. Studies have shown that not only is symbolic representation a critical area, but when taught for meaning, support deeper understanding and provide opportunities for students to effectively communicate their understandings (Bishop et al., 2022; Stephens et al., 2021;). Teacher educators should discuss the need for instructional precision and appropriate use of mathematical symbols with connections with their students.

Implications for Teacher Education and Research

It is incumbent upon teacher educators to provide PSTs and ISTs with opportunities to develop the language skills needed in supporting students in making sense of symbols. This should exist in a robust learning environment in which practitioners have multiple and varied opportunities to practice the language of mathematics instruction (verbal, representational, assessment) through problem solving, resource utilization, and professional/pedagogical development (Socus & Hernandez, 2013). Thus, maintaining a classroom environment suitable for academic language where the discussion of and meaning making of symbolism can thrive.

Lim (2016) underscores the importance of transitioning mathematics students from working with numbers to working with symbols. In addition, emphasizing the relevance and meaning of working with symbols, especially in algebra is critical. This requires an emphasis in language, particularly in explicit instruction. Cain and Faulkner (2011) draw the conclusion that teaching symbols along with other mathematics concepts requires teachers to think in terms of building background knowledge and comprehension, not unlike the work that literacy teachers do in teaching reading. Teacher educators then execute the particulars of that methodology in order that the skill of symbolic language transfers.

Further research would look closely at the interplay between student achievement (both individual and collective data) and SES relative to student mastery of the language of symbols. Rutherford et al. (2010) suggest research that looks at both longitudinal collective data as well as individual student data in order to provide greater understanding of the instructional intervention that their software/pedagogically-driven view suggests. Furthermore, Lyons and colleagues (2014) echo the same desire in research for longitudinal studies on students' understanding of mathematics skills that are heavily reliant on adeptness with symbolism. This reinforces that a gap in research exists when studying symbolic system mastery and mathematics achievement (Sasanguie et al., 2013). Perhaps a deep look at the way in which those who are multilingual learners grapple with mathematical symbolic mastery would yield a greater understanding of language, symbols, and mathematical meaning making.

Classroom interchanges of talking and listening are mediated by sign systems, in general, and language, in particular. In considering the role of symbols, expressions, and language, it is important to examine the role of listening and its connection to students' mathematical learning. This is explored in the next section.

Effects of Teachers' Listening Orientation on Students' Mathematical Learning

Listening Orientations and Equity

Talking about one's mathematical ideas and listening to others' is an essential feature of interactions and communications that support meaning making. When communicating their mathematical thinking, the manner in which students feel listened to (or not) by their teacher and peers affects their academic and emotional engagement with the content. This has implications for equity pedagogy. Many researchers (Confrey, 1991; Davis, 1997; Steffe & D'Ambrosio, 1995) have described ways of listening to students as a vital part of a constructivist philosophy of teaching mathematics. Davis (1997) noted that many teachers engage in 'evaluative' listening, where they listen for an expected correct answer and respond with feedback aimed at fixing any ideas that stray from that expected, correct answer. Nathan and Petrosino (2003) called this an expert blind spot. With this manner of listening, students' thinking is often disregarded and the sources of their ideas are not often uncovered. Davis (1997) contrasts evaluative listening with hermeneutic listening, where he and others (Confrey, 1991; Steffe & D'Ambrosio, 1995) offer the concepts of de-centering, or the ability to take on another's perspective, and give reason to the child's thinking. Such listening involves immense intellectual effort and practice and serves to validate the student as a thinker and doer of mathematics. Franke and Kazemi (1991) found that listening to students in this manner was fundamental in advancing their mathematical thinking and understanding, an implication for equity pedagogy. Moschkovich (2004) offered the notion of 'appropriation', which is based on mutual teacher-student or student-student listening. "Appropriation involves joint productive activity, a shared focus of attention, and shared meanings…[as well as] taking what someone else produces during joint activity for one's own use subsequent productive activity" (p. 51). With regard to equity pedagogy, she also noted when working with multilingual learners the importance of listening with a mathematical reasoning focus rather than one of mathematical language correctness (Moschkovich, 2012). Davies and Walker (2007) studied "how four mathematics teachers listened to and made sense of students' ideas and the influence of content knowledge on their capacity to listen. [They found] that the depth of teachers' content knowledge—both subject matter knowledge and pedagogical content knowledge—mediated their enactment of effective listening practices" (p. 217).

Implications for Teacher Education and Research

Looking into the future, it would be beneficial for a study of teachers' listening orientations to focus on mathematics teacher preparation programs, as well as ISTs' continuing professional development. AMTE *Standards P3*, *P4* and *C2* focus on providing beginning teachers with opportunities to hone their knowledge, skills and dispositions toward teaching mathematics to support students' sense-making, understanding and reasoning. ATE *Standard 4* encourages teachers to engage in career-long professional development where they systematically reflect on their own teaching practices with the goal of improving. To achieve these ends, in addition to engaging PSTs and ISTs in experiences to deepen their mathematics content and pedagogical content knowledge, Arcavi and Isoda (2007) point teacher educators and professional development specialists to *the importance of an explicit focus on listening*. These authors define listening to students as "giving careful attention to hearing what students say (and to see what they do) and trying to understand it and its possible sources and entailments" (p. 112). This orientation toward listening "is not a passive undertaking." Instead, these authors offer the following components to mathematics teaching that is supportive of such listening:

1. Detecting, taking up and creating opportunities in which students are likely to engage in freely expressing their mathematical ideas;
2. Questioning students in order to uncover the essence and sources of their ideas;
3. Analyzing what one hears (sometimes in consultation with peers) and making the enormous intellectual effort to take the 'other's perspective' in order to understand it on its own merits; and
4. Deciding in which ways the teaching can productively integrate the students' ideas. (p. 112).

We urge mathematics teacher educators and professional development specialists to integrate the above components offered by Arcavi and Isoda (2007) so that listening becomes an important foci of effective mathematics teaching and learning. This is further underscored in research about teacher noticing, as teachers actively listening to students is one key component. It connects to making instructional decisions, understanding student thinking and lesson planning among other areas (Jacobs et al., 2011; Munson, 2020). We also recognize that for young mathematicians, play is a natural medium through which mathematical ideas are nurtured and communicated. In the next section, we discuss the importance of play as a conduit for Funds of Knowledge (Gonzalez et al., 2005) to facilitate mathematical language development.

Mathematics Language Development: Play and Family Influences

Importance of Play for Language Development

The NCTM Communication Process Standard states that a learner should be given the opportunity to grasp mathematical concepts before being forced to use formal mathematical terms. It is through exploring the ideas and working through their informal meanings that a learner becomes engaged and takes ownership of the ideas (NCTM, 2000). Play, the most natural way of learning for young children, is the means through which this process is conducted (National Association for the Education of Young Children [NAEYC], 2009).

As mentioned in the introduction, ATE *Standard 1* guides teacher educators to inform, or remind teachers that there are best ways to facilitate student development. AMTE *Standard EC.8* calls for "Well-prepared beginning teachers of mathematics at the early childhood level create mathematical learning environments characterized by exploration…[and] draw upon children's mathematical, cultural, and linguistic strengths thereby developing conceptual …." Thus, the importance of learning about and providing mathematical learning environments where math-talk is encouraged and used is supported by national standards for teacher educators. In addition, Gonzalez et al.'s (2005) work with Funds of Knowledge support the importance of play and knowledge of family interactions to help develop children's mathematical language.

Types of Play

Play is often described as either free-play, or guided-play where an adult helps, supports, guides and tutors to scaffold the child's play. Johnson et al. (1987) discuss the characteristics of free-play where internal reality takes over external reality (termed nonliterality). Play is freely chosen and produces pleasure and enjoyment, and in free-play the process is experienced as more important than the product. Saracho (2012) reports that children who engage in symbolic play, such as pretending a pot is a hat, are beginning to use symbolic representation to communicate their thought process. When children engage in this symbolic thinking, they are better able to engage in abstract thinking, which contributes to mathematical understanding.

Fisher and colleagues (2013) found that guided-play helped scaffold students' understanding. Additionally, students engaged in curriculum involving and revolving around play activities linked to learning outcomes obtained higher scores than those who were not (Holmes et al., 2015). Likewise, some research supports that free-play alone is not as efficient as guided-play in promoting mathematical understanding (Ginsberg et al., 2008). It is important that students have ample amounts of time for play and exploration to connect their play to mathematical concepts (Beaver et al., 2017).

Importance of Play in Child Development

Ramani and Eason (2015) found that by engaging in play, children may enhance their counting skills, spatial skills, and geometry understanding. These authors recommend teachers seek out curricula that encourages free-play in centers, encourages math-talk amongst students, and includes parents in mathematical play opportunities. Clements and Sarama (2005) claim, "High quality math learning emerges from children's play, their curiosity, and their natural ability to think" (p. 25), while Emfinger (2009) reinforces the value of "pretend play as a curricular tool to facilitate the development and consolidation of numerical skills" (p. 333). Others, such as Bulotsky-Shearer et al. (2014), report that through cooperative play (symbolic or constructive play activities) early skills in expressive and receptive language, problem solving, creativity, mathematics and spatial skills, are practiced, modeled, reinforced and extended by peers.

Implications for Teacher Education and Research

Purpura and Logan's (2015) study found a child's mathematical language was a predictor of mathematics performance. Linking this with the findings from Duncan et al. (2007) show a preschool child's mathematical abilities, not literacy skills, are a better predictor of success later in school, with critical implications for teacher education. These studies provide the impetus to continue research in early childhood mathematics play and how to prepare teachers and parents to provide these learning experiences. Parks and Blom (2014; 2015) call for teachers to become more familiar with children's development of important concepts by engaging in math-talk during guided- or free-play. Future research should address the connection between mathematics-specific literacy and play. There are natural opportunities for different types of challenging talk and these could be investigated in relation to Funds of Knowledge (Gonzalez et al., 2005) to see how they may facilitate or constrain child-directed talk (Gest et al., 2006). Additionally, Razfar (2012) calls for research on the use of play and games to facilitate mathematical learning for multilingual learners.

Influence of Family and Home Regarding Mathematics and Language

Young children's experiences with mathematics at home vary. Understanding these differences aligns with two aspects of the ATE Standards (2018). Knowing practices based on research and how families support children's mathematical engagement is aligned to *Standard 2*, cultural competence and *Standard 6*, collaboration. These two elements are critical for teacher educators to consider when working with future early childhood teachers. As identified below, the family's role is complex and early childhood teachers need to collaborate with families, while being culturally responsive.

Common mathematical activities families support include counting objects, oral counting, printing numbers, and activities involving shape (Missall et al., 2015). Families engage children in different ways depending on the activity. Vandermaas-Peeler et al. (2009) indicate more numeracy exchanges during children's play than when reading books. Siblings also can influence young children's mathematical development by how they interact during play. Howe et al. (2016) reviewed play interactions of sibling dyads and reported that siblings, depending on age, taught concepts such as number, measurement, and geometry.

Some research focused on ways to support families' mathematical conversations. Fenton et al. (2016) explored how to engage preschoolers in mathematical thinking at home. Using a Strengths Approach, the teacher and families co-constructed possible activities that related to the child's interest. For instance, one child's interest in dinosaurs, engaged the child in sorting them by size. Vandermass-Peeler et al. (2016) studied conversations of preschool children and their parents at a science museum. The families, provided with guidance in supporting children's reasoning, used more specific terms related to the mathematics presented in the exhibit. Eason and Ramani (2020) investigated how preschoolers and parents used mathematical language depending on the amount of support provided when using the same materials. These authors write, "formal learning yielded the greatest amount of math talk, guided play still showed an advantage over unguided play in eliciting parent and child math talk" (p. 559). These findings highlight the importance of helping families to support children's emerging mathematical knowledge and language development. Early childhood teachers' role is a critical element outlined in the AMTE standards. *Standard EC.6* describes the importance of early childhood teachers collaborating "with families in a mutually respectful, reciprocal manner to enhance and connect children's in-school and out-of-school mathematical development." Knowing different ways to support families in this process is important to support children's mathematical meaning making.

Saracho (2012) adds that before children enter formal schooling, they have acquired large amounts of mathematical knowledge. This knowledge is based on their interaction with others and their environment. These experiences may support children's mathematical development in varying ways. Pupura and Reid (2016) showed a child's mathematical language is a significant predictor of numeracy skills for preschoolers and kindergarteners. Anderson and Gold (2006) indicate that home practices influence how children approach mathematical tasks at school, such as strategies for playing board games or completing puzzles. While Segers and colleagues (2015) found that the home literacy environment did not affect numeracy skills; but instead, parent's numeracy expectations and activities did. Factors such as parental education seem to influence the development of this knowledge (Pupura & Reid, 2016). Conflicting evidence related to families' SES influence emerged from a review of the literature. Vandermaas-Peeler et al. (2009) indicated more numeracy exchanges between parents and children in higher SES groups, while Missall et al. (2015) found no significant difference in such exchanges among families from different SES groups.

Implications for Teacher Education and Research

As children transition into elementary school, it is important to consider the possible influences that might support children's mathematical meaning making. Early childhood teachers should understand the role of the family in order to create high quality learning environments as outlined in the AMTE (2017) standards. Teacher education programs need to consider how to support preservice early childhood educators. Programs should provide opportunities for candidates to interact with families and children. These interactions can lay the foundation for understanding how to support families in developing mathematical understanding and language. Having experiences in a supportive environment about how to prepare family friendly materials are critical.

Future research in this area could focus on understanding more about how families support young children's mathematical development. The studies reviewed included small sample sizes, so replication or expansion would provide more evidence of factors that might influence children's mathematical meaning making prior to elementary school. Observational data of family interactions during play and other everyday experiences could help to understand the many layers of these ideas. Furthermore, family questionnaires about the type of support that would be helpful could guide early childhood professionals in building supportive and culturally responsive ways to facilitate families' approaches to engaging children in mathematical conversations.

In the next section, we explore how families interact with children as they progress through elementary and secondary school in supporting ways to communicate mathematically.

Older Children, Family, and Play

As previously emphasized, family members are those social factors that can positively influence mathematical language. Hence, it is important that the home interactions described above continue into the middle and secondary grade levels. Equally essential is awareness of and responsiveness to challenges family members may face when trying to support children with mathematics. For example, when family members come from different learning environments, unfamiliarity with current practices can cause anxiety and frustration (Vukovic et al., 2013). In response, researchers recommend providing exploratory support for families with the use of open-ended tasks that are free from clear, predetermined procedures.

Mangram and Metz (2018) specifically promote playful mathematics experiences as vehicles for engaging families in mathematical problem solving, regardless of parents' mathematics proficiency and comfort level. Mistretta (2013) reports on such an experience entitled Which One Doesn't Belong? (Fuys & Welchman-Tischler, 1979). She found this task to help reduce family members' stress, and develop confidence in their ability to communicate about mathematical ideas in ways that can transfer well into the middle and secondary grade levels.

The following example is not a unique classroom idea; however, it is one suggested for teacher educators to consider using or adapting when preparing teachers with resources for engaging older families in mathematics meaning making and related language use. The task involves comparing and contrasting four examples to determine one that is different from the others. Specifically, when shown four computation examples such as -5 + -2, 8 x -2, -5 + (-7), and -9 ÷ 3, responses may include a) -5 + -2 because it is the only example that has both an even and an odd integer b) 8 x -2 because it is the only example that begins with a positive integer, d) -5 + (-7) because it is the only example that has parentheses, or d) -9 ÷ -3 because it is the only example with a positive solution.

The existence of different correct solutions affords families multiple entry points into the conversation that do not necessarily hinge on parents' level of mathematics proficiency. Such verbal discourse provides family members opportunities to individually make their thinking audible as well as recognize, and celebrate, the reasoning of others. In turn, a strength-based stance on family engagement can emerge that acknowledges family members as partners in mathematics meaning making.

Implications for Teacher Education and Research

Edwards et al. (2019) report new teachers' unfortunate lack of experience working with families. Given such a circumstance, along with the vast amount of playful tasks that exist for supporting mathematical language, teacher educators' use of and inquiry around how such tasks can help shape PST learning experiences with respect to working with families warrants attention. In addition, Froiland and Davison (2016) report family member expectations and intrinsic motivation as contributing significantly to the development of mathematics achievement in 9th through 11th grades. In turn, these researchers suggest studying interventions designed to enhance family member expectations and motivation. Playful tasks may serve as such an intervention to study.

Another research venue stems from O'Sullivan et al. (2014) who report family members' self-efficacy as associated with family engagement among low-income urban junior high school families. The authors suggest lack of confidence as possibly contributing to these families not providing direct assistance with mathematics. Hence, inquiry around how playful tasks can influence self-efficacy among middle and secondary grade level families has potential for contributing to the knowledge base.

It will be important to also consider how students are engaged in mathematical language in their home language and/or in their new language. The following section provides insight into English language learning populations and related opportunities for cultivating mathematical language.

Mathematics and Multilingual Learners

Many researchers have studied the effects of language learning on mathematical learning. Although language learners can refer to a variety of students, this section specifically considers students who are learning English in addition to their primary language and attending schools taught in English. Throughout the paper we use the term multilingual learner (ML) to reflect students who have a primary language, perhaps learned at home, but are learning new languages and in particular being taught in a language that is not their primary language. Many people may think that MLs do not face additional struggles in mathematics classes since mathematics uses symbols, which are understood across many languages. However, this is a myth (Janzen, 2008). Many face substantial barriers in mathematics when it is not taught in their primary language.

Mathematics Assessment of MLs

Multilingual learners often score significantly lower on mathematics assessments. However, do lower test scores mean less mathematical understanding or are we assessing the students' language understanding? MLs usually score lower than their native English-speaking peers on large-scale assessments, and the achievement gap is larger on language-heavy questions. Studies by Martiniello (2008) and Wolf and Leon (2009) further support that MLs struggle more on linguistically complex test items. However, when language accommodations are made, such as presenting simplified language, ML students' performance improves (Abedi & Lord, 2001; Alt et al., 2014; Martiniello, 2008; Newkirk-Turner & Johnson, 2018; Wolf & Leon, 2009). Kurz et al. (2017) claim that elementary PSTs need experience working with MLs to better understand the complexities of teaching these students. The authors provide a framework to assist teachers in making accommodations to mathematics word problems. This framework describes language adaptations, mathematical adaptations, tool/visual adaptations, and structural adaptations. With modifications to mathematics assessments, mathematics material is more accessible to MLs and they can be more accurately assessed on their mathematical understanding.

MLs in the Classroom

A student's performance on an exam is far more complex than their language competency. Ercikan et al. (2015) explain that many factors of language, culture, and context can affect student performance even when the questions are linguistically simple. The comma and decimal point are used differently for place value. Ordinal numbers are notated differently in different languages. Some languages, such as Japanese, use numerical classifiers, which have no literal translation to a language that does not use numerical classifiers such as English. There are many additional challenges for MLs (Miura & Okamoto, 2003). Driver and Powell (2017) encourage the combined use of culturally and linguistically responsive instruction where teachers "consider the unique learning characteristics of their students including native language, English language proficiency, race and ethnicity, home and community culture, and past educational experiences" (p. 43). Chval and colleagues (2021) stress the importance of academic language for MLs and their need to develop specialized mathematical language and the need to engage them in experiences where they can distinguish between multiple meanings of words (e.g., mean or change). These authors advocate for implementing instructional strategies that help students distinguish between everyday language that may be used at home or in their community and specialized mathematical language, and help them to connect or transition their use of everyday language to specialized mathematical language.

Implications for Teacher Education and Research

Teacher educators should strive to develop culturally efficacious mathematics instructors. This can be done by encouraging teachers to better know themselves, as well as to know their students and their communities (Flores et al., 2015). Teachers can support MLs by encouraging student discussion and small group communication. Group work will allow students to hear and speak the language of mathematics in English, which will increase their mathematical understanding as well as develop their

English proficiency. Teachers should not discourage students from speaking in their native language when working in small groups (Gann et al., 2016; Janzen, 2008; Murrey, 2008; Zahner, 2012). Murrey (2008) recommends that teachers explain the mathematics conceptually in an appropriate context before introducing the academic vocabulary. The use of manipulatives may be helpful; however, it is important for teachers to know their students' English language proficiency level. Using manipulatives does not help develop a contextual mathematics understanding if the language barrier is quite large (Janzen, 2008). Similarly, technology can be a great tool in the classroom, but language ability is a critical factor in student understanding with its use (Ganesh & Middleton, 2006). All students, especially MLs, will benefit when teachers get to know the students and their cultures (Janzen, 2008). Multiple instruments are available to educational leaders and teachers to assess teacher beliefs, attitudes and knowledge about MLs (Fernandez & McLeman, 2012; Flores et al., 2015; Gann et al., 2016; Reeves, 2006). Survey results can inform district leaders in planning effective professional development on cultural and linguistic issues.

This section has examined mathematical teaching and learning of students who are learning the English language. Although MLs tend to score lower on assessments, much of the achievement gap is due to language deficiencies. In the classroom, there are several techniques that teachers can implement to better support MLs. In the next section, we discuss a language that many young students are fluent in before kindergarten--technology.

Technology and Digital Media

Digital technologies and interactive media have transformed almost all aspects of our social and cultural practices, including children's meaning making with both language and mathematics. Blending visual, auditory, and haptic representations in a multimodal and interactive environment, digital technologies are particularly appealing to young children. When used strategically, digital technologies can change the nature of children's linguistic and mathematical experiences, promoting their competencies in meaning making using language and mathematical resources (Beschorner & Hutchison 2013; Chmiliar, 2017; Clements et al., 2008; Couse & Chen 2010; Falloon 2013; Falloon & Khoo 2014; Kucirkova et al., 2014; NAEYC, 2012; NCTM, 2015; Patchan & Puranik, 2016). In teacher education, both the ATE and the AMTE recognize the essential roles of digital technologies in instruction and assessment. ATE (2018) characterizes technology use from a social and cultural perspective, encouraging teacher educators to model best practices and technology integration in the global context of teaching, learning, and assessment. AMTE (2017) emphasizes technology as a type of instructional tool that should be strategically used by educators to promote students' sense-making and understanding of mathematics. On the other hand, inappropriate technology use or abuse may cause harm to children's cognitive development and social emotional well-being (Twenge et al., 2018). In fact, children today are spending an alarming amount of time on digital media, raising serious concerns among caregivers, educators, and policy-makers (Vulchanova et al., 2017).

The Emergence of Digital Literacy

Mathematics is a kind of academic language, calling for reading, writing, and sense-making strategies in quantitative reasoning and inquiry. A lack of literacy competence in mathematics can seriously hinder the academic and social performance of school children as well as citizens at all levels (Madison & Steen, 2003; Steen, 2001). Accordingly, there have been persistent efforts to re-conceptualize and re-design literacy instruction in content areas, including school mathematics (Draper & Siebert, 2010; Manzo et al., 2009; Siebert & Hendrickson, 2010). This shift toward a focus on literacy and language in mathematics education highlights, on the one hand, the mediating role of language in all aspects of mathematical cognition and, on the other hand, the foundational role of quantitative reasoning in daily language use and other social and cultural settings. Indeed, mathematics has become inseparable from the evolving scope of literacies in what is often called digital literacy, a synergistic integration of traditional literacy, media literacy, quantitative literacy (de Lange, 2003), and interactive technologies. The emergence of digital literacies has not only broadened conventional literacy education and research but also opened new frontiers for educational development in assessment, instruction, and interventions (Goodman et al., 2010).

Digital technologies, versatile by design, support a wide spectrum of traditional and contemporary media and pedagogical paradigms, including the integration of audio, visual, and other multimodal representations. Both the design and the content of digital media such as mobile apps are significant factors in determining an app's educational value and the quality of children's experience (Couse & Chen, 2010; Falloon, 2013; Falloon & Khoo, 2014; Kucirkova et al., 2014). More importantly, a teacher's pedagogical choices and guidance play critical roles in ensuring the effective use of technology and digital media in enhancing children's learning and development, including meaning making in mathematics (Clements et al., 2008; Couse & Chen, 2010; Falloon & Khoo, 2014).

Implications for Teacher Education and Research

The evolving nature of digital literacy may lead to practical and theoretical disruptions in the educational enterprise, including the language and mathematical development of young children, as these digital tools find their way naturally and informally into homes, classrooms, communities, and workplaces. Because of the lack of research on the long-term impact of digital media on children, it seems imperative that educators follow the NAEYC (2012) recommendations for developmentally appropriate practices (DAP). This is in light of children's vulnerability and sensitivity to the novelty and multimodal stimuli of digital tools and researchers should continue to study this impact in partnership with practitioners.

Traditionally, human communication is accomplished through face-to-face interactions, supplemented by printed or recorded materials. Today, the prevalence of digital media has provided new possibilities and theoretical perspectives for human communication, blending hearing, vision, touch, and other sensory modalities (Vulchanova et al., 2017). Existing research points to the powerful affordances of digital media in transforming children's educational experiences, which, however, is subject to appropriate design, content, and teacher guidance. Therefore, in teacher education programs, both PSTs and ISTs should be mindful of DAP and the social and emotional ramifications of digital media use while striving to use new tools for linguistic and mathematical understanding and equity (AMTE, 2017; ATE, 2018; NAEYC, 2012).

Summary of Findings

Table 1, while not an exhaustive list, identifies several implications for teacher educators and offers ideas for further research to consider based on this synthesis. The implications and ideas for further research are delineated by the six areas addressed in this paper examining the effects of language on children's understanding of mathematics, particularly related to meaning making of mathematics.

Discussion and Conclusion

The teaching of mathematics and utilization of mathematical language are both very complex phenomena. Many researchers, such as Pengelly (1990), have recognized linkages between mathematics and language with multiple approaches that include nuances such as mathematics as a language, mathematical language, and language and learning mathematics, to name a few. As teachers and teacher educators, we should be aware of all the varying aspects of mathematical language. How best can teachers—both PSTs and ISTs--be prepared for this critical work? The synthesis of research in the area of mathematics and language provided in this paper underscores the importance of the continued study of students' mathematical language, both inside and outside classroom walls, as means for supporting students' mathematics meaning making.

Table 1

Implications for Teacher Educators and Ideas for Further Research Based on the Literature

Areas addressed	Implications for teacher educators	Ideas for further research
1. What mathematical language is and how it connects to meaning making and understanding	• Engage teachers in experiences to broaden their understanding of what mathematical language is and its role in mathematical meaning making.	• Examine types of supports and engagement that are beneficial in supporting language development for students to deepen conceptual understanding and making meaning of mathematics.
2. Symbols, expressions and language connections	• Provide multiple and varied opportunities to support making sense of symbols. • Create a robust learning environment that supports academic language and allows meaning making of symbolism to thrive.	• Consider ways that multilingual leaners grapple with mathematical symbols to yield greater understanding and make significant connections between language, symbols, and mathematical meaning.
3. Effects of teachers' listening orientation on students' mathematical learning	• Provide explicit focus on listening and its connection to teacher noticing to facilitate meaning making of mathematics.	• Examine teachers' listening orientations and how they do or do not focus on mathematical meaning making. • Analyze instructional decision making related to listening orientations.
4. Mathematics language development: Play and family influences	• Ensure that teachers have a deep understanding of their role in play to support student learning. • Provide opportunities for teachers to strategically observe play, engage in play, and have experiences teaching from a play perspective to build mathematical meaning. • Provide opportunities for teachers to interact with families and children to understand how to better support families in developing mathematical understanding and meaning making.	• Examine the connection between mathematics-specific literacy and play. • Study the impact of various math instructional materials and interventions that engage families with their children and can help shape mathematical understanding and collaboration. • Examine how families support young student's mathematical development and how to support positive self-efficacy of families in supporting their children in mathematics.
5. Mathematics and multilingual learners	• Develop teachers understanding of culture and its impact on mathematical instruction and meaning making. • Provide opportunities for teachers to experience the impact of discussions, use of manipulatives, and technology and the role of academic language and discourse in teaching and learning mathematics.	• Study the impact of varied manipulatives and technology as used with multilingual learners. • Examine types of professional development that could impact teachers' beliefs, efficacy, attitudes, and understanding of multilingual learners and how to use this data to develop professional development specifically to target mathematical meaning making.
6. Technology and digital media	• Include a wide variety of technologies in teacher's experiences while attending to the developmentally appropriate use of that technology.	• Design studies to examine the long-term impact of digital media on children's understanding of mathematics and the social and emotional ramifications with a particular focus on current technologies. • Examine how technology tools support or hinder linguistic and mathematical understanding.

We offer readers Figure 1 as a potential framework to consider for guiding teacher educators' practices and future research efforts. In so doing, we display various connections and interplays between language and children's mathematical meaning making and understanding. The framework begins with an overarching theme of children's meaning-making in mathematics and unfolds with the dynamic interplay of teachers and teacher educators, schools, families and parents, and children and their peers. These dynamic connections impact the development of mathematical understanding and help build language capacity through engaging in a myriad of mathematics and language activities such as play, listening, interactions, talking and use of technology. These occur in varied spaces both formal and informal (home, school, community and cultural interactions) and manifest in development of academic language, conversational language, use of symbols, consideration of multilingualism, and mathematical content literacies.

Our synthesis and related representation illuminate symbols as processes; a lens less utilized in some classrooms. We highlight the importance of responding to mathematical language needs during instructional planning, instructional delivery, assessment, and evaluation as language is an important facet in all of these areas as students strive to make sense of mathematics. Finally, we underscore the goal of reaching each and every student, that is, students struggling to understand, gifted students, and those learning English as a new language so all are successful in mathematics learning and develop a positive mathematical identity. Our Commission team urges all stakeholders including mathematics teacher educators, researchers, community/family partners, and professional development specialists to promote and provide support and appropriate training for practitioner inquiry that further develops students' mathematical language in schools and at home.

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References

Abedi, J., & Lord, C. (2001). The language factor in mathematics tests. *Applied Measurement in Education*, *14*(3), 219–234. https://doi.org/10.1207/S15324818AME1403_2

Alt, M., Arizmendi, G. D., & Beal, C. R. (2014). The relationship between mathematics and language: Academic implications for children with specific language impairment and English language learners. *Language, Speech & Hearing Services in Schools*, *45*(3), 220-233. https://doi.org/10.1044/2014_LSHSS-13-0003

Anderson, D. D., & Gold, E. (2006). Home to school: Numeracy practices and mathematical identities. *Mathematical Thinking & Learning*, *8*(3), 261-286.

Arcavi, A., & Isoda, M. (2007). Learning to listen: From historical sources to classroom practice. *Educational Studies in Mathematics*, *66*(2), 111-129. https://doi.org/10.1007/s10649-006-9075-8

Association of Mathematics Teacher Educators. (2017). *Standards for preparing teachers of mathematics.* https://amte.net/standards

Association of Teacher Educators. (2018). *Standards for teacher educators.* https://ate1.org/standards-for-teacher-educators

Beaver, N. H., Wyatt, S.S., & Jackman, H. L. (2016). *Early childhood curriculum: A child's connection to the world.* Cengage Learning.

Beschorner, B., & Hutchison, A. (2013). iPads as a literacy teaching tool in early childhood. *International Journal of Education in Mathematics, Science and Technology. 1*(1), 16-24.

Bishop, J. P., Hardison, H. L., & Przybyla-Kuchek, J. (2022). Responsiveness to students' mathematical thinking in middle-grades classrooms. *Journal for Research in Mathematics Education. 53*(1). 10-40

Bulotsky-Shearer, R. J., Bell, E. R., Carter, T. M., & Dietrich, S. L. R. (2014). Peer play interactions and learning for low-income preschool children: The moderating role of classroom quality.

Early Education and Development. 25, 815-840. https://www.doi.org/10.1080/10409289.2014.864214
Burns, M. (2006). Marilyn Burns on the language of math. *Instructor, 115*(7), 41-43.
Cain, C., & Faulkner, V. (2011). Teaching number in the early elementary years. *Teaching Children Mathematics, 18*(5), 288-295.
Chmiliar, L. (2017). Improving learning outcomes: The iPad and preschool children with disabilities. *Frontiers in Psychology, 8*, 660. https://www.doi.org/10.3389/fpsyg.2017.00660
Chval, K., Smith, E., Trigos-Carrillo, L., & Pinnow, R. J. (2021). *Teaching math to multilingual students grades K-8: Positioning English learners for success.* Corwin, A Sage Company.
Clements, D.H., & Sarama, J. (2005). Think math! How to support and encourage your child's natural interest in math concepts. *Scholastic Parent & Child*, *13*(2), 25.
Clements, D. H., Sarama, J., Yelland, N. J., & Glass, B. (2008). Learning and teaching geometry with computers in the elementary and middle school. In G. W. Blume & M. K. Heid (Eds.), *Research on technology and the teaching and learning of mathematics: Research syntheses* (Vol. 1, pp. 109-154). Information Age Publishing.
Confrey, K. (1991). Learning to listen: A students understanding of powers of ten. In E. von Glasserfeld (Ed.), *Radical constructivism in mathematics education* (p. 111-138). Kluwer.
Couse, L. J., & Chen, D. W. (2010). A tablet computer for young children? Exploring its viability for early childhood education. *Journal of Research on Technology in Education, 43*(1), 75-96. https://doi.org/10.1080/15391523.2010.10782562
Crowhurst, M. (1994). *Language and learning across the curriculum*. Allyn and Bacon.
Davies, N. & Walker, K. (2007). Teaching as listening: Another aspect of teachers' content knowledge in the numeracy classroom. (pp. 217-225). *Proceedings of the 30th annual conference of the mathematics education research group of Australia.*
Davis, B. (1997). Listening for differences: An evolving conception of mathematics teaching. *Journal for Research in Mathematics Education 28*(3), 355-376. https://www.doi.org/10.2307/749785
de Lange, J. (2003). Mathematics for literacy. In B. L. Madison & L. A. Steen (Eds.), *Quantitative literacy: Why numeracy matters for schools and colleges* (pp. 76-89). National Council on Education and the Disciplines.
Draper, R. J., & Siebert, D. (2010). Rethinking texts, literacies, and literacy across the curriculum. In R. J. Draper, P. Broomhead, A. P. Jensen, J. D. Nokes & D. Siebert (Eds.), *(Re)Imagining content-area literacy instruction* (pp. 20-39). Teachers College Press.
Driver, M. K., & Powell, S. R. (2017). Culturally and linguistically responsive schema intervention: Improving word problem solving for English language learners with mathematics difficulty. *Learning Disability Quarterly*, *40*(1), 41–53. https://doi.org/10.1177/0731948716646730
Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428-1446. https://www.doi.org/10.1037/0012-1649.43.6.1428
Eason, S. H. & Ramani, G. B. (2020). Parent–Child math talk about fractions during formal learning and guided play activities. *Child Development*, 91(2), 546–562. https://www.doi.org/10.1111/cdev.13199
Emfinger, K. (2009). Numerical conceptions reflected during multiage child-initiated pretend play. *Journal of Instructional Psychology*, *36*(4). 326 –334.
Ercikan, K., Chen, M. Y., Lyons-Thomas, J., Goodrich, S., Sandilands, D., Roth, W. M., & Simon, M. (2015). Reading proficiency and comparability of mathematics and science scores for students from English and non-English backgrounds: An international perspective. *International Journal of Testing*, *15*(2), 153–175. https://doi.org/10.1080/15305058.2014.957382

Edwards, P.A., Spiro, R.J., Domke, L.M., Castle, A.M., White, K.L., Peltier, M.R., & Donohue, T.H. (2019). *Partnering with families for student success.* Teachers College Press.

Falloon, G. (2013). Young students using iPads: App design and content influences on their learning pathways. *Computers & Education, 68*, 505-521. https://doi.org/10.1016/j.compedu.2013.06.006

Falloon, G., & Khoo, E. (2014). Exploring young students' talk in iPad-supported collaborative learning environments. *Computers & Education, 77*, 13-28. https://www.doi.org/10.1016/j.compedu.2014.04.008

Fenton, A., MacDonald, A., & McFarland, L. (2016). A strengths approach to supporting early mathematics learning in family contexts. *Australasian Journal of Early Childhood*, *41*(1), 45-53. https://doi.org/10.1177/183693911604100107

Fernandez, A., & McLeman, L. (2012). *Developing the mathematics education of English learners scale (MEELS).* In Van Zoest, L. R., Lo, J.-J., & Kratky, J. L. (Eds). *Proceedings of the 34th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education.* Kalamazoo, MI: Western Michigan University. 591-597.

Firmender, J., Gavin, M., & McCoach, D. (2014). Examining the relationship between teachers' instructional practices and students' mathematics achievement. *Journal of Advanced Academics, 25*(3), 214-236. https://doi.org/10.1177/1932202X14538032

Fisher, K. R., Hirsh-Pasek, K., Newcombe, N., & Golinkoff, R. M. (2013). Taking shape: Supporting preschoolers' acquisition of geometric knowledge through guided play. *Child Development*, *84*(6), 1872 –1878. https://doi.org/10.1111/cdev.12091

Flores, B. B., Claeys, L., Gist, C. D., Riojas Clark, E., & Villarreal, A. (2015). Culturally efficacious mathematics and science teacher preparation for working with English learners. *Teacher Education Quarterly*, *42*(4), 3–31.

Franke, M. L., & Kazemi, E. (1991). Teaching as learning within a community of practice: Characterising generative growth. In T. Wood, B.S. Nelson, & J. Warfield (Eds.), *Beyond classical pedagogy: Teaching elementary school mathematics* (pp. 47-74). Lawrence Earlbaum.

Froiland, J. M., & Davison, M. L. (2016). The longitudinal influences of peers, parents, motivation, and mathematics course-taking on high school math achievement. *Learning and Individual Differences*, *50*, 252-259. https://doi.org/10.1016/j.lindif.2016.07.012

Fuys, D., & Welchman-Tishler, R. (1979). *Teaching mathematics in the elementary school.* HarperCollins.

Ganesh, T. G., & Middleton, J. A. (2006). Challenges in linguistically and culturally diverse elementary settings with math instruction using learning technologies. *Urban Review*, *38*(2), 101–143. https://doi.org/10.1007/s11256-006-0025-7

Gann, L., Bonner, E. P., & Moseley, C. (2016). Development and validation of the mathematics teachers' beliefs about English language learners survey (MTBELL). *School Science & Mathematics*, *116*(2), 83-94. https://doi.org/10.1111/ssm.12157

Gest, S. D., Holland-Coviello R., Welsh, J. A., Eicher-Catt, D. L., & Gill, S. (2006). Language development subcontexts in head start classrooms: Distinctive patterns of teacher talking during free play, mealtime, and book reading. *Early Education and Development, 17*(2), 293-315. https://doi.org/10.1207/s15566935eed1702_5

Ginsberg, H. P., Lee, J. S., Boyd, J. S., (2008). Mathematics education for young children: What it is and how to promote it. *Social Policy Report*, 22(1). In Sherrod, L. & Brooks-Gunn, J. Eds. pp. 3-22. Society for Research in Child Development.

Gonzalez, N., Moll, L., & Amanti, C. (Eds.) (2005). *Funds of knowledge: Theorizing practices in households, communities, and classrooms.* Routledge.

Goodman, K., Fries, P. H., & Strauss, S. L., (2016). *Reading—the grand illusion: How and why people make sense of print.* Routledge.

Halliday, M. A. K. (1978). Sociolinguistics aspects of mathematical education. In M. Halliday (Ed.), *The social interpretation of language and meaning* (pp. 194-207). University Park Press.

Hebert, M. A., & Powell, S. R. (2016). Examining fourth-grade mathematics writing: Features of organization mathematics vocabulary, and mathematical representations. *Reading and Writing, (29)*7, 1511-1537. https://doi.org/10.1007/s11145-016-9649-5

Holmes, R. M., Romeo, L., Ciralo, S. & Grushko, M. (2015). The relationship between creativity, social play and children's language abilities. *Early Child Development and Care, 185*(7), 1180-1197. https://doi.org/10.1080/03004430.2014.983916

Howe, N., Adrien, E., Della Porta, S., Peccia, S., Recchia, H., Osana, H. P., & Ross, H. (2016). 'Infinity means it goes on forever': Siblings' informal teaching of mathematics. *Infant and Child Development, 25,* 137-157. https://www.doi.org/10.1002/icd.1928

Ivkovic, D. (2019). Multilingualism, collaboration, and experiential learning with multiple modalities: The case of Mondovision. *Innovation in Language Learning and Teaching.* https://www.doi.org/10.1080/17501229.2019.1599002

Jacob, V. R., Lamb, L. L. C., Philipp, R., A. & Schappelle, B. P. (2011). Deciding how to respond on the basis of children's understanding. In M. G. Sherin, V. R. Jacobs & R. A. Phillip (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 97-116). Routledge.

Janzen, J. (2008). Teaching English language learners in the content areas. *Review of Educational Research*, *78*(4), 1010-1038.

Johnson, J. E., Christie, J. F. & Yakey, T. D., (1987). *Play and early childhood development.* Harper Collins.

Kenney, J. M., Hancewicz E., Heuer, L., Metsisto, D., & Tuttle, C. L. (2005). *Literacy strategies for improving mathematics instruction.* Association for Supervision and Curriculum Development.

Khisty, L. L., & Chval, K. B. (2002). Pedagogic discourse and equity in mathematics: When teachers' talk matter. *Mathematics Education Research Journal. 14*(3), 154-168. https://doi.org/10.1007/BF03217360

Kucirkova, N., Messer, D., Sheehy, K., & Fernández Panadero, C. (2014). Children's engagement with educational iPad apps: Insights from a Spanish classroom. *Computers & Education, 71*, 175-184. https://doi.org/10.1016/j.compedu.2013.10.003

Kurz, T. L., Gómez, C., & Jimenez-Silva, M. (2017). Guiding preservice teachers to adapt mathematics word problems through interactions with ELLs. *Journal of Urban Mathematics Education*, *10*(1), 32–51.

Lee, O. & Stephens, A. (2020). English learners in STEM subjects: Contemporary views on STEM subjects and language with English learners. *Educational Researcher*, 49, 6, 426–432 https://www.doi.org/10.3102/0013189X20923708

Lemke, J. L. (2003). Mathematics in the middle: Measure, picture, gesture, sign, and word In M. Anderson, A. Saenz-Ludlow, S. Zellweger, & V. Cifarelli (Eds), *Educational perspectives on mathematics as semiosis: From thinking to interpreting to knowing (pp. 215-234*). Legas Publishing.

Lim, K. (2016). Fostering algebraic understanding through math magic. *Mathematics Teacher, 110*(2), 110-118. https://www.doi.org/10.5951/mathteacher.110.2.0110

Lyons, I., Price, G., Vaessen, A., Blomert, L., & Ansari, D. (2014). Numerical predictors of arithmetic success in grades 1-6. *Developmental Science 17*(5). https://doi.org/10.1111/desc.12152

Madison, B. L., & Steen, L. A. (Eds.). (2003). *Quantitative literacy: Why numeracy matters for schools and colleges.* National Council on Education and the Disciplines.

Mangram, C., & Metz, M. T. S. (2018). Partnering for improved parent mathematics engagement. *School Community Journal*, *28*(1), 273-294. http://www.schoolcommunitynetwork.org/SCJ.aspx

Manzo, U. C., Manzo, A. V., & Thomas, M. M. (2009). *Content area literacy: A framework for reading-based instruction* (5th ed.). John Wiley & Sons.
Martiniello, M. (2008). Language and the performance of English-language learners in math word problems. *Harvard Educational Review*, *78*(2), 333-368,429. https://doi.org/10.17763/haer.78.2.70783570r1111t32
Mills, K. A. (2010). A review of the "digital turn" in the new literacy studies. *Review of Educational Research*, *80*(2), 246-271. https://doi.org/10.3102/0034654310364401
Missall, K., Hojnoski, R. L., Caskie, G. I. L., & Repasky, P. (2015). Home numeracy environments of preschoolers: Examining relations among mathematical activities, parent mathematical beliefs, and early mathematical skills. *Early Education and Development*, *26(*3), 356-376. https://doi.org/10.1080/10409289.2015.968243
Mistretta, R.M. (2013). "We do care," Say parents. *Teaching Children Mathematics, 19*(9), 572-580.
Miura, I. T., & Okamoto, Y. (2003). Language supports for mathematics understanding and performance. In A. J. Baroody & A. Dowker (Eds.), *The development of arithmetic concepts and skills: Constructing adaptive expertise* (pp. 229–242). Lawrence Erlbaum Associates, Publishers.
Moschkovich, J. N. (2004). Appropriating mathematical practice: A case study of learning to use and explore functions through interaction with a tutor. *Educational Studies in Mathematics*, *55*(1-3), 49-80. https://doi.org/10.1023/B:EDUC.0000017691.13428.b9
Moschkovich, J. N. (2007). Examining mathematical discourse practices. *For the Learning of Mathematics, 27*(1), 24-30.
Moschkovich, J. N. (Ed.). (2010). *Language and Mathematics Education: Multiple Perspectives and Directions for Research*. Information Age Publishing.
Moschkovich, J. N. (2010). Language(s) and learning mathematics: resources, challenges, and issues for research, In Moschkovich (Ed) *Language and mathematics education: Multiple perspectives and directions for research*, (pp. 1-28). Information Age Publishing, Inc.
Moschkovich, J. (2012). *Mathematics, the Common Core and Language*: *Recommendations for Mathematics Instruction for ELs Aligned with the Common Core.* http://ell.stanford.edu/sites/default/files/pdf/academic-papers/02-JMoschkovich%20Math%20FINAL_bound%20with%20appendix.pdf
Munson, J. (2020). Noticing aloud: Uncovering mathematics teacher noticing in the moment. *Mathematics Teacher Educator. 8*(2), 25-36.
Murrey, D. L. (2008). Differentiating instruction in mathematics for the English language learner. *Mathematics Teaching in the Middle School*, *14*(3), 146–153.
Nathan M. J. & Petrosino, A.J. (2003). Expert blind spot among preservice teachers. *American Educational Research Journal, 40*(4), 905-928. https://doi.org/10.3102/00028312040004905
National Academies of Sciences, Engineering, and Medicine. (2018). *English learners in STEM subjects: Transforming classrooms, schools, and lives*. The National Academies Press.
National Association for the Education of Young Children. (2009). Developmentally appropriate practice in early childhood programs serving children from birth through age 8. https://www.naeyc.org/sites/default/files/globally-shared/downloads/PDFs/resources/position-statements/PSDAP.pdf
National Association for the Education of Young Children. (2012). *Technology and interactive media as tools in early childhood programs serving children from birth through age 8*. https://www.naeyc.org/sites/default/files/globally-shared/downloads/PDFs/resources/topics/PS_technology_WEB.pdf
National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* NCTM.
National Council of Teachers of Mathematics. (1991). *Professional standards of teaching mathematics.* NCTM.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. NCTM.

National Council of Teachers of Mathematics. (2014). *Principles to action: Ensuring mathematical success for all*. NCTM.

National Council of Teachers of Mathematics. (2015). *Strategic use of technology in teaching and learning mathematics.* https://www.nctm.org/uploadedFiles/Standards_and_Positions/Position_Statements/Strategic%20Use%20of%20Technology%20July%202015.pdf

National Council of Teachers of Mathematics (NCTM). 2018. *Catalyzing Change in High School Mathematics: Initiating Critical Conversations*. NCTM.

National Council of Teachers of Mathematics (NCTM). 2020. *Catalyzing Change in Middle School Mathematics: Initiating Critical Conversations*. NCTM.

National Council of Teachers of Mathematics (NCTM). 2020. *Catalyzing Change in Early Childhood and Elementary Mathematics: Initiating Critical Conversations*. NCTM.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGA Center and CCSSO) 2010. *Common Core State Standards for Mathematics. Common Core State Standards (College-and Career Readiness Standards and K-12 Standards in English Language Arts and Math*. NGA Center and CSSO. http://www.corestandards.org/

Newkirk-Turner, B. L., & Johnson, V. E. (2018). Curriculum-based language assessment with culturally and linguistically diverse students in the context of mathematics. *Language, Speech & Hearing Services in Schools*, *49*(2), 189–196. https://doi.org/10.1044/2017_LSHSS-17-0050

O'Sullivan, R. O., Chen, Y., & Fish, M. (2014). Parental mathematics homework involvement of low-income families with middle school students. *School Community Journal*. *24*(2), 165-187.

Parks, A. N., & Blom, D. C. (2014/2015). Helping young children see math in play. *Teaching Children Mathematics*, *20*(5), pp. 310-317.

Patchan, M. M., & Puranik, C. S. (2016). Using tablet computers to teach preschool children to write letters: Exploring the impact of extrinsic and intrinsic feedback. *Computers & Education, 102*, 128-137. https://doi.org/10.1016/j.compedu.2016.07.007

Pengelly, H. (1990). Acquiring the language of mathematics. In J. Bickmore-Brand *(Ed), Language in mathematics* (pp. 10-26). Heinemann.

Pimm, D. (1987). *Speaking mathematically: Communication in mathematics classrooms*. Routledge.

Purpura, D. J., & Logan, J. A. R. (2015). Brief report: The nonlinear relations of the approximate number system and mathematical language to early mathematics development. *Developmental Psychology, 51*(12), 1717-1724. https://www.doi.org/10.1037/dev0000055

Purpura, D. J., & Reid, E. E. (2016). Mathematics and language: Individual and group differences in mathematical language skills in young children. *Early Childhood Research Quarterly*, *36*, 259-268. https://www.doi.org/10.1016/j.ecresq.2015.12.020

Ramani, G. B., & Eason, S. H. (2015). 1 2 3 it all adds up: Learning early math through play and games. *Kappan*, *96*(8), 27-32.

Razfar, A. (2012). ¡Vamos a jugar counters! Learning mathematics through funds of knowledge, play, and the third space. *Bilingual Research Journal*, *35*(1), 53-75. https://doi.org/10.1080/15235882.2012.668868

Reeves, J. R. (2006). Secondary teacher attitudes toward including English-language learners in mainstream classrooms. *The Journal of Educational Research*, *99*(3), 131-143. https://www.doi.org/10.3200/JOER.99.3

Rutherford, T., Kibrick, M., Burchinal, M., Richland, L., Conley, A., Osborne, K., Schneider, S., Duran, L., Coulson, A., Antenore, F., Daniels, A., & Martinez, M. (2010, May). Spatial temporal mathematics at scale: An innovative and fully developed paradigm to boost math achievement among all learners. *Paper presented at the annual convention of the American Educational Research Association Denver CO.*

Saracho, O. N. (2012). *An integrated play-based curriculum for young children*: *Symbolic play*. Taylor & Francis.

Sasanguie, D., Gobel, S., Moll, K., Smets, K., & Reynvoet, B. (2013). Approximate number sense, symbolic number processing, or number-space mappings: What underlies mathematics achievement? *Journal of Experimental Child Psychology 114* (3), 418-43. https://doi.org/10.1016/j.jecp.2012.10.012

Segers, E., Kleemans, T., & Verhoeven, L. (2015). Role of parent literacy and numeracy expectations and activities in predicting early numeracy skills. *Mathematical Thinking and Learning: An International Journal*, *17*(2-3), 219-236. https://doi.org/10.1080/10986065.2015.1016819

Siebert, D., & Hendrickson, S. (2010). (Re)Imagining literacies for mathematics classrooms. In R. J. Draper, P. Broomhead, A. P. Jensen, J. D. Nokes & D. Siebert (Eds.), *(Re)Imagining content-area literacy instruction* (pp. 40-53). Teachers College Press.

Socus, M. & Hernandez, J. (2013). Mathematical problem solving in training elementary teachers from a semiotic logical approach. *The Mathematics Enthusiast, 10* (1-2).

Steen, L. A. (Ed.). (2001). *Mathematics and democracy: the case for quantitative literacy*. Woodrow Wilson National Fellowship Foundation.

Steffe, L. P., & D'Ambrosio, B. S. (1995). Towards a working model of constructivist teaching: A reaction to Simon. *Journal for Research in Mathematics Education, 26*(2), 146-159.

Stephens, A, Stroud, R., Strachota, S., Stylianou, D., Blanton, M., Knuth, E., & Gardiner, A. (2021). What early algebra knowledge persists 1 year after an elementary grades intervention? *Journal for Research in Mathematics Education. 52*(3), 332-348.

Twenge, J. M., Joiner, T. E., Rogers, M. L., & Martin, G. N. (2018). Increases in depressive symptoms, suicide-related outcomes, and suicide rates among U.S. adolescents after 2010 and links to increased new media screen time. *Clinical Psychological Science, 6*(1), 3-17. https://doi.org/10.1177/2167702617723376

Vandermaas-Peeler, M., Massey, K., & Kendall, A. (2016). Parent guidance of young children's scientific and mathematical reasoning in a science museum. *Early Childhood Education Journal*, *44*, 217–224. https://doi.org/10.1007/s10643-015-0714-5

Vandermaas-Peeler, M., Nelson, J., Bumpass, C., & Sassine, B. (2009). Numeracy-related exchanges in joint storybook reading and play. *International Journal of Early Years Education, 17*(1), 67–84. https://www.doi.org/10.1080/09669760802699910.

Vukovic, R.K., Roberts, S.O., & Wright, L.G. (2013). From parental involvement to children's mathematics performance: The role of mathematics anxiety. *Early Education and Development. 24*(4), 446-467. https://doi.org/10.1080/10409289.2012.693430

Vulchanova, M., Baggio, G., Cangelosi, A., & Smith, L. (2017). Editorial: Language development in the digital age. *Frontiers in Human Neuroscience, 1*(447), 1-7. https://doi.org/10.3389/fnhum.2017.00447

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Wilkerson, T. L., Fetterly, J. & Wood, B. (November 2015). Problem posing and problem solving: Using young adult literature to develop mathematical understandings. In J. A. Hayn, J. S. Kaplan, A. Nolan, and Olvey, A. A (Eds.) *Young Adult Nonfiction: Gateway to the Common Core.* Rowman & Littlefield Publishers.

Wolf, M. K., & Leon, S. (2009). An investigation of the language demand in content assessments for English language learners. *Part of a Special Issue on English Language Learners*, *14*(3/4), 139–159. https://doi.org/10.1080/10627190903425883

Zahner, W. C. (2012). ELLs and group work: It can be done well. *Mathematics Teaching in the Middle School*, *18*(3), 156–162.

Zhang, X., Clements, M., & Ellerton, N. (2015). Engaging students with multiple models of fractions. *Teaching Children Mathematics (22)*3, 138-147.

Zittoun T., Brinkmann S. (2012) Learning as Meaning Making. In: Seel N.M. (eds) *Encyclopedia of the Sciences of Learning*. Springer. https://doi.org/10.1007/978-1-4419-1428-6_1851

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STEM Touchstones for Teacher Professional Learning: An Analysis of Teacher Content and Pedagogical Content Knowledge in a Place-based Professional Development Program

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ABSTRACT

The Vermont STEM Leadership Institute (VSTEM) was designed to provide professional learning and leadership opportunities for K-12 educators teaching primarily in high-need schools. The fundamental premise of the program was to actively engage teachers in constructivist curriculum and pedagogy coupled with authentic scientific research experiences within the context of local environments or "places." This study investigated changes in content and pedagogical content knowledge that teachers exhibited in their science teaching practice over the course of their program participation. Data analysis revealed that teachers' science content knowledge and pedagogical content knowledge were enhanced by VSTEM program participation with moderate to strong indications about place-based education, project-based learning, and the importance of engaging students in authentic scientific research. The study found that participants learned new content-specific teaching strategies and implemented standards-based units and lessons that aligned with constructivist theories of teaching and learning.

Keywords: in-service teacher professional learning, pedagogical content knowledge, science content knowledge, pedagogical knowledge, project-based learning, place-based education

Introduction

Despite national efforts to highlight science, technology, engineering, and mathematics (STEM) education and careers in the U.S. over the last 60 years, U.S. students still perform marginally on National Assessment of Educational Progress (NAEP) evaluations of mathematics and science knowledge, and a comparatively small percentage of U.S. students pursue STEM postsecondary degrees and careers (Atkinson & Mayo, 2010). Nationally, 41% of fourth graders and 34% of eighth graders are proficient in mathematics compared to 29% of fourth graders and 29% of eighth graders demonstrating proficiency in science (National Center for Education Statistics, 2019). In Vermont, mathematics achievement is comparable to the national average with 39% of fourth graders and 38% of eighth graders achieving proficiency in mathematics. Comparatively, the results are significantly better in science with 48% of fourth graders and 44% of eighth graders demonstrating proficiency in science in Vermont (National Center for Education Statistics, 2019).

Over the past nine years, as a response to the continued need for ongoing improvement and support of STEM teaching and learning in the U.S., national learning standards have been updated to promote STEM curriculum, teaching, and achievement goals more broadly. The Common Core State Standards for Mathematics (National Governors Association Center for Best Practices, 2010) and Next Generation Science Standards (NGSS Lead States, 2013) call for STEM teaching and learning that advance scientific and computational thinking practices, evidence-based and inquiry-based teaching and learning, and critical and creative problem solving across the K-12 spectrum, particularly for underrepresented and underserved students in high-need schools. Federally funded programs such as the Mathematics and Science Partnerships (MSP) program (Merrill & Daugherty, 2010) have responded to this call for improved STEM instruction and student achievement by supporting educational partnerships between state education agencies, higher education institutions, and high-need school districts with the long-term goal of improving teacher quality and academic achievement and learning in mathematics and science for all students.

The quality and success of inquiry and project-based teacher professional learning programs is dependent on evidence-based best practices that focus on a number of essential factors that improve classroom teaching and student learning (Banilower et al., 2007; Loucks-Horsley et al., 2003; Meiers & Ingvarson, 2003). Ingvarson (2005) identified five key characteristics that suggest that effective STEM professional development should be content focused, involve active learning, provide feedback, involve collaborative examination of student work, and have long-term follow-up. Researchers also recommend extensive support and mentoring in methods of implementing inquiry-based approaches as well as models and actual experience in implementing these approaches before teachers attempt to do so within their own STEM classrooms (Fitzgerald et al., 2019).

The Vermont STEM Leadership Institute (VSTEM), an MSP-funded professional learning program, was designed to provide professional learning and leadership opportunities for K-12 educators teaching primarily in high-need schools in Vermont. VSTEM functioned to model content knowledge and pedagogical content knowledge (Park & Oliver, 2008; Shulman, 1986; Van Driel et al., 2002) aligned to the Next Generation Science Standards (NGSS) disciplinary core knowledge and scientific practices for teaching and learning. The fundamental premise of VSTEM was to actively engage teachers in authentic inquiry and research practices aligned with constructivist curriculum and teaching methods within the context of local environments or "places". The long-term goal was for teachers to develop deeper knowledge of scientific principles and concepts supported by student-centered pedagogies in order to transform their own classrooms into dynamic and stimulating places of interdisciplinary STEM inquiry for students. See Appendix A for a summary of VSTEM goals, objectives, and outcomes.

This mixed methods study examines changes in K-12 teacher content knowledge and pedagogical content knowledge resulting from participation in the VSTEM program. Using a convergent parallel mixed methods design (Creswell & Plano Clark, 2011), qualitative and quantitative data were collected and analyzed separately over the two-year project (2015-2017), and then combined to answer the two interrelated research questions:

(1) What pre-post differences in teachers' science content knowledge were evident over the course of participation in VSTEM?

(2) What evidence of pedagogical content knowledge (PCK) did teachers demonstrate as an outcome of their participation in VSTEM?

Literature Review

Social Constructivist Theories of Teaching

Social constructivist theories of teaching and learning (Julyan & Duckworth, 2005; O'loughlin, 1992; Palinscar, 1998; Solomon, 1987) inform the theoretical and conceptual framework of VSTEM. Program tenets and practices are grounded in the notion that knowledge is socially constructed from prior knowledge and experiences and that students and teachers learn best when learning experiences are contextualized, reflective, research-based, inquiry-based, and relevant to everyday experiences (Prawat & Floden, 1994). VSTEM pedagogy exemplifies best practices of reflective teaching and assessment by eliciting the prior knowledge and conceptions (Duckworth, 2006; Graves, 1999; Wandersee et al., 1994) that teachers have about science content and pedagogy and engaging them in authentic local scientific research that embodies many of the NGSS disciplinary core ideas, practices, and cross-cutting concepts.

Research on Teacher Knowledge

As an MSP-funded project with a focus on improving teacher quality, we were interested in examining the impact of VSTEM activities on teacher content knowledge and pedagogical content knowledge. Content knowledge or subject matter knowledge pertains to the depth and breadth of teachers' understanding of the concepts, principles, and theories that constitute the disciplines that they teach (Magnusson et al., 1999). Pedagogical knowledge pertains to general knowledge of the practices, strategies, and methods that teachers employ in their curriculum, instruction, and assessment. Pedagogical content knowledge (PCK) is the critical junction where content knowledge and pedagogical knowledge intersect, and where teachers organize, represent, and formulate their subject matter for student understanding and learning (Shulman, 1986). PCK refers to the connections that teachers make between what they know about "how" to teach the content with "what" they teach (Cochran, 1997). According to Shulman (1986), PCK includes:

> the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. Pedagogical content knowledge also includes an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning. (p. 9)

Cochran et al. (1993) extended Shulman's theory of pedagogical content knowledge to include two additional components: (1) teachers' knowledge of students' abilities and learning strategies and (2) teachers' understanding of the social, political, cultural, and physical environments. According to Cochran (1997), PCK is highly specific to the concepts being taught. In the following excerpt, Cochran (1997) describes how a teacher integrates the different components of PCK through their planning and instruction.

> The teacher critically reflects on and interprets the subject matter; finds multiple ways to represent the information as analogies, metaphors, examples, problems, demonstrations, and/or classroom activities; adapts the material to students' developmental levels and abilities, gender, prior knowledge, and misconceptions; and finally tailors the material to those specific individual or groups of students to whom the information will be taught. (p. 1)

Although the construct of PCK has had a profound influence on science education (Berry et al., 2015) the current consensus among education researchers—including Shulman himself (Shulman, 2015)—is that PCK is more complex than first imagined. Numerous models for PCK have been developed to account for this complexity (Kind, 2009). In this study we draw on the model proposed by Magnusson et al. (1999), which is the most widely adapted/adopted PCK model in the field (Kind, 2015; Park & Oliver, 2008). Building on Grossman (1990) and Tamir (1988), Magnusson et al. (1999) conceptualized pedagogical content knowledge for science teaching as having five components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding about specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science (pp. 96-97).

Of the five PCK components identified by Magnusson et al. (1999), two are particularly germane to this study: (a) orientations toward science teaching and (b) knowledge and beliefs about instructional strategies for teaching science. Orientations toward science teaching refers to the goals of teaching science that a particular teacher would have and the typical characteristics of instruction for a teacher having that orientation. This particular study focuses on a project-based orientation to teaching science (Krajcik et al., 2007; Tal et al., 2006), the goal of which is to involve students in "investigating solutions to authentic problems" (Magnusson et al., 1999, p. 100). Knowledge and beliefs about instructional strategies includes both subject-specific strategies and topic-specific strategies. Subject-specific strategies are "general approaches to or overall schemes for enacting science instruction" while topic-specific strategies refers to "strategies that are useful to helping students comprehend specific science concepts" (Magnusson et al., 1999, pp. 110-111). Magnusson et al. (1999) suggest two categories of topic-specific strategies: *representations* (e.g., illustrations, examples, models, analogies) and *activities* (e.g., problems, demonstrations, simulations, investigations, experiments) (pp. 111, 113).

Research on PCK typically focuses on teacher knowledge of a specific science content area (Bayram-Jacobs et al., 2019; McNeill & Knight, 2013; Beyer & Davis, 2012; Falk, 2012; Van Driel et al., 2002). To make PCK visible, researchers combine observations of content-specific instructional practice—PCK in-action (Bayram-Jacobs et al., 2019)—with opportunities for teachers to discuss, analyze, and reflect on their content-specific teaching. For example, McNeill and Knight (2013) examined the impact of professional development on teachers' PCK of scientific argumentation by asking teachers to design a lesson to introduce argumentation to students and reflect on their experience teaching that lesson. Similarly, Bayram-Jacobs et al. (2019) examined PCK development regarding teaching socio-scientific issues (SSI) by having teachers prepare, teach, and reflect on a specially designed SSI lesson. Over time, science education researchers have adopted a more dynamic conception of PCK that emphasizes how teachers use PCK in practice (Bayram-Jacobs et al., 2019; Beyer & Davis, 2012; Falk, 2012; McNeill & Knight, 2013; Van Driel et al., 2002).

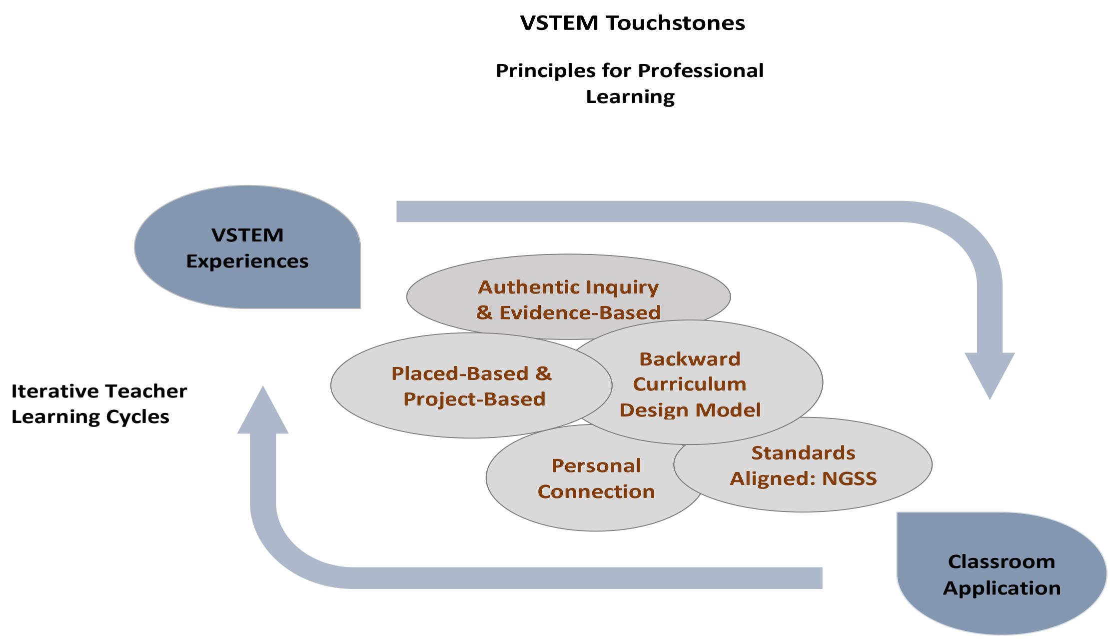
VSTEM Touchstones

The VSTEM touchstones are fundamental standards or criteria aligned with constructivist theories of teaching and learning (Julyan & Duckworth, 2005; O'loughlin, 1992; Palinscar, 1998; Solomon, 1987) that serve as foundational principles for teacher professional learning in the program (See Figure 1). The touchstones support a shared understanding of best curriculum and teaching practices that increases the likelihood that the curriculum work teachers are engaged in will have purpose, meaning, and persistence over time (Rice, 2012).

Key touchstones such as project-based learning (Krajcik et al., 1994; Tal et al., 2006) and place-based education (Demarest, 2015) promote problem-solving and authentic inquiry (Blumenfeld et al., 1991; Cuevas et al., 2005; Geier et al., 2008; Kahle et al., 2000; Krajcik et al., 2008) within the context of "local places" resulting in a project, product, or artifact that is interdisciplinary in nature and has personal connection and meaning to both students and teachers. In order for teachers to understand how to design place-based projects outside the boundaries of the classroom, many of the VSTEM activities take place in and around local lakes, quarries, and streams as well as in science and engineering laboratories at the university. Principles of backward design (Wiggins & McTighe, 2005) are central to the VSTEM curriculum framework and serve as the foundation for the project planner that teachers utilize in the development of a place-based project required for program participation.

Figure 1

VSTEM Touchstones



Research Methods

Research Context

The VSTEM program was designed to engage teachers in authentic research alongside scientists, graduate students, and teacher educators during a week-long summer institute followed by monthly workshops and school-based lesson studies during the academic year. The summer institutes consisted of field trips to local quarries or aboard the University of Vermont (UVM)'s *Melosira Research Vessel* and workshops conducted at UVM's Ecosystem Science Labs. The field trips were designed to facilitate a shift in teachers' orientation towards science teaching and exposure to topic-specific instructional strategies. For example, teachers investigated the reproductive success of lake trout in Lake Champlain, the history of ocean basin opening and closing and the formation of the Appalachian Mountain chain, and optimization of animal forging behavior. Teachers also investigated how big data informs quantitative reasoning and analysis in the context of these questions.

The summer institute experiences were bridged to academic year programming by engaging teachers in content-focused workshops in chemistry, ecology, and geology; facilitating field trips to Lake Champlain and local geology and stream sites; and hosting lesson studies at participating schools that focused on, for example, school-based composting efforts or local bird population studies. Coupled with these professional learning experiences were opportunities for teachers to reflect upon ways to meaningfully integrate the NGSS, as well as project-based and place-based principles or *touchstones* into their teaching practice. As part of program requirements, teachers kept a reflective journal of VSTEM experiences, developed and implemented a long-term project aligned to the NGSS and VSTEM touchstones, participated in school-based lesson studies and the VSTEM spring conference, and facilitated STEM professional learning communities (PLCs) in their home schools during the academic year.

Participants

During the period between 2015-17, thirty (30) K-12 teachers from rural, urban, and suburban school districts in Vermont participated in the VSTEM program. In Year 1, sixteen (16) teachers representing five school districts spanning grades K-12 participated in the program. Ten first-year cohort teachers returned to the program joined by ten new teachers in Year 2. Four of the five participating school districts are high-need designated school districts as defined by federal free and reduced lunch measures (U.S. Department of Agriculture, 2020). All of the VSTEM teachers are White. Teacher demographics aggregated by grade level and gender are represented in Table 1.

Table 1.

VSTEM Teacher Participant Demographics

	2015-16	2016-17
No. of Teachers	16 teachers representing 5 school districts	20 teachers representing 5 school districts
Grade/Gender	6 elementary – all female 6 middle school science – all female 4 high school – 3 male, 1 female (2 Biology, 1 Earth Science, 1 Physics)	7 elementary – all female 9 middle school science – 7 female, 2 male 4 high school – 2 male, 2 female (2 Biology, 1 Earth/Environmental Science, 1 Physics/Environmental Science)

Data Collection and Analysis

This mixed methods study examined changes in K-12 science teacher content knowledge and pedagogical content knowledge resulting from participation in the VSTEM program. Using a convergent parallel mixed methods design (Creswell & Plano Clark, 2011), qualitative and quantitative data were collected and analyzed separately over the two-year project (2015-2017), and then combined to answer the two interrelated research questions:

(1) What pre-post differences in teachers' science content knowledge were evident over the course of participation in VSTEM?
(2) What evidence of pedagogical content knowledge (PCK) did teachers demonstrate as an outcome of their participation in VSTEM?

Quantitative and qualitative data sources are illustrated in Table 2.

Table 2

Quantitative and Qualitative Data Sources

Research Question	Data Source
What pre-post differences in teachers' science content knowledge were evident over the course of participation in VSTEM?	• Pre-Post Assessments of Science Content Knowledge • Participant Project Plans • Post-Program Surveys
What evidence of pedagogical content knowledge (PCK) did teachers demonstrate as an outcome of their participation in VSTEM?	• Participant Project Plans • Classroom Observations • Post-Program Surveys • Reflection Journals

Quantitative pre-post assessments of science content knowledge were used as measures of change in content knowledge and ratings of classroom practice were used as evidence of pedagogical content knowledge (PCK). Qualitative notes from classroom observations, along with participant project plans, post-program surveys, and participant reflection journals provided additional evidence of both types of knowledge along with description and explanation. These data were collected and triangulated to gain a deeper understanding of knowledge change across multiple sources. Data from each source were analyzed separately and results were then merged to answer the research questions (Creswell & Plano Clark, 2011).

Pre-Post Assessments of Science Content Knowledge

Pre and post content assessments were used to measure change in participant content knowledge. The assessments were designed by project faculty to align closely with module learning objectives, and thus considered to have content validity. Participants completed pre and post assessments for each content specific module during the program. The pre and post assessments consisted of short and extended response questions primarily designed to assess basic knowledge of chemistry, geology, and ecology concepts. Most assessments contained too few items to establish reliability as measured by Cronbach's Alpha (Graham, 2006). When the data format allowed, results of pre and post assessments were analyzed using Wilcoxon signed rank tests as per project funder requirements.

Participant Project Planners

Development and implementation of an NGSS aligned project to be implemented as an instructional unit with their students was one of the key requirements for VSTEM participants. During the July institute, teachers were introduced to a project planner (see Appendix B) that served as a template for project design. During the summer institute, participants consulted with institute faculty and collaborated with VSTEM peers. As part of the project planning process, staff reviewed the principles of backward curriculum design (Wiggins & McTighe, 2005) and supported participants in project goal articulation, selection of standards, and development of enduring understandings and essential questions aligned to the overall project design. Completed planners were analyzed for evidence of content knowledge and content-specific instructional and assessment strategies.

Classroom Observations

To more fully examine the degree to which the VSTEM program impacted teacher instructional and assessment practices, classroom observations of the 10 teachers who participated in both Years 1 and 2 were conducted early, mid-way, and at the end of the VSTEM program utilizing the Diagnostic Classroom Observation Tool (DCO) (Saginor, 2008). The DCO was initially developed at The Vermont Institutes, subsequently validated by Mathematica, Inc. and the Northwest Regional Labs, and modified in 2014 to better align with new math and science standards. Utilization of the DCO allowed researchers to study both lesson implementation and lesson content. A summary of the 14 DCO indicators used in this study are listed in Table 3.

Table 3

Summary of Diagnostic Classroom Observation Indicators (Saginor, 2008)

Implementation Indicators	Content Indicators
Teacher Confidence Teacher demonstrates confidence as a facilitator of math/science learning and growth.	**Academic Standards** Academic standards are central to the instructional program.
Teacher – Student Interactions Periods of teacher-student interaction are probing and substantive.	**Teacher Content Knowledge** Teacher demonstrates an understanding of the concepts and content of the lesson.
Instructional Choices Instructional choices are effective in engaging students in active and thoughtful learning.	**Formative Assessment** Teacher collects and assesses evidence of student progress to enhance teaching and learning.
Opportunities to Construct Knowledge Students have opportunities to construct their own knowledge.	**Student Engagement** Students are intellectually engaged with concepts contained in the activities of the lesson.
Lesson Pace Lesson pace is appropriate for the developmental level of the students with adequate time for wrap-up.	**Content Connections** Concept connections and applications to the real world are made within and across lessons.
Student-Student Interactions Periods of student-student interaction are productive and enhance individual understanding of the lesson.	**Abstractions, Models, Theories** The lesson incorporates abstractions, theories, and models as appropriate.
Teacher Technology Integration Teacher models technology integration.	**Student Strategic Use of Tools** Students use appropriate tools strategically.

One complete science lesson per teacher was observed at each data collection point (fall 2015, spring 2016, and spring 2017). At each observation, each indicator was rated on a scale of 1 to 5 (no evidence to extensive evidence). Each DCO indicator includes a list of evidence that might be observed during the lesson. For example, "Instructional Choices" focuses on the connections between student engagement, clarity of learning objectives, and inquiry-based pedagogy. "Opportunities to Construct Knowledge" focuses on how the learning environment provided students with the opportunity to actively explore questions or concepts, and integrate new learning with prior experience and understanding. A detailed description of these two DCO indicators is found in Table 4. The observer noted whether any of these examples were observed, and took detailed notes of teacher and student actions during the lesson. The scale ratings were analyzed for shifts in frequencies and means across the three data collection points. At the end of the project, a paired sample t-test was used to test for statistically significant change in mean ratings for each of the 14 indicators. Field notes were used to describe the observed changes in more specific detail.

Table 4

Samples of DCO Indicators Used for VSTEM Observations (Saginor, 2008)

Indicator	Evidence	Examples of Evidence
Instructional choices are effective in engaging students in active and thoughtful learning.	1 - no 2 - limited 3 - moderate 4 - consistent 5 - extensive	• Students are engaged and excited about finding answers to questions posed by the activity. • Objectives are clearly stated. • Activities are likely to lead to student learning in the stated objectives. • Teacher does not dominate discussion. • Tasks are challenging; teacher sets high expectations. • Both teacher-directed instruction and constructivist methods are used as appropriate for task and diverse learning needs.
Opportunities to construct knowledge Students have opportunities to construct their own knowledge.	1 - no 2 - limited 3 - moderate 4 - consistent 5 - extensive	• Investigations are essential elements of the lesson. • Curiosity and perseverance are encouraged. • Students apply existing knowledge and skills to new situations and integrate new and prior knowledge. • Students make notes, drawings, or summaries in a journal or lab book that becomes part of their ongoing resources. • Students have opportunities to do more than follow procedures; they ask their own questions, choose their own strategies, or design investigations. • Students manipulate materials and equipment. • Teacher and students discuss which technologies to use for various products and processes and why.

Post-Program Surveys

At the end of each program year, each participant responded to an anonymous online survey about their program experiences. Survey topics included participants' perceptions of the impact of the VSTEM program on their knowledge of science content and pedagogy. Data analysis included creation of charts and tables from the raw data for each closed-response question and description of the results. Open-response items were analyzed for themes and patterns.

Reflection Journals

Each participant completed a daily journal reflection that prompted them to consider what they had learned about science content and pedagogy from VSTEM program activities. The journals were designed to provide evidence of participants' PCK for teaching the specific science topics addressed by the institute faculty and were analyzed for evidence of teachers' developing knowledge of instructional strategies for teaching science.

Research Results

The VSTEM program was built on two overarching foci pertaining to participating teachers' science content knowledge necessary to facilitate learning for all students and evidence of improved pedagogical content knowledge (PCK). A detailed summary of the analysis pertaining to changes in science content knowledge and PCK of participating teachers follows.

Science Content Knowledge

Pre-post content tests administered during workshops and field trips suggest a moderate increase in science content knowledge for teacher participants. For example, in Year 2 of the program, 13 of the 20 participants completed pre-post tests for the chemistry module. The pre-post data were analyzed using Wilcoxon signed ranks test which showed eight teachers posting significant gains (p=.006). It is important to note that the five teachers (mostly high school teachers) who did not score significant gains were already knowledgeable in the content area and completed the pre and post content tests with no errors. Fourteen teachers completed pre and post tests for the geology module. Test results were not in a format that allowed for use of Wilcoxon signed ranks (the standard MSP analysis); however, of the 14 teachers tested, 11 or 79%, showed positive gains in geology content knowledge from pre to post-test.

The ceiling effect observed in the pre-post content tests corresponds with participant responses to a question on the post-program survey about perceptions of increases in content knowledge. All survey respondents reported that participation in VSTEM deepened their knowledge of science content with increases ranging in degree from small to large. Comments suggested that this range is attributable to some participants having begun the project with deeper background in science, particularly those high school teachers who had STEM degrees.

That participants developed a deeper understanding of each of the VSTEM content areas is also evident in the analysis of their project planners. This analysis revealed that science content had been acquired and applied in a unit planned, taught, and evaluated by each of the teachers. Unit topics included forces and interactions, exploration of waves and sound, Earth science and engineering design, chemical processes and thermal energy, bridge design, and ecosystems and environmental change. Analysis of project planners also revealed an understanding of specific science content and the integration of content knowledge into meaningful science learning experiences. Table 5 represents examples of project planners designed by four of the VSTEM teachers.

Pedagogical Content Knowledge (PCK)

Our analysis of PCK focused on teacher knowledge of content-specific teaching strategies documented in participants' online journals, project planners, classroom observations, and online surveys. In our analysis, we explored evidence that teachers learned new strategies for teaching specific science content—for example, learning to use a local field site to teach students about human impacts on ecosystem biodiversity or learning novel ways for students to represent their understanding of energy conservation. To 'count' as PCK gained through this project necessitated evidence that teachers had learned these strategies through their participation in VSTEM activities specifically. For this reason, teachers' reflective journals—which prompted them to reflect on lessons learned from workshops and fieldtrips —were particularly useful.

Table 5

Teacher Designed Project Planner Descriptions

Title	Level	Essential Understandings	Project Experiences
Forces and Interactions	Middle School	Relationships between force, energy, and mass	Explore forces on encapsulated egg dropped from the roof and apply learning to the design of a helmet to prevent brain injury.
Exploration of Waves and Sound	Middle School	Properties of simple waves Sound transmission	Explore sound waves and apply learning to the design of musical instruments made from everyday materials.
Local Community Recreational Trail Project	High School	Water's movement causes weathering and erosion. Humans can negatively impact the environment. Models can generate data for iterative testing.	Using a local recreational area as an outdoor laboratory, observe weathering, collect data, build models, and experiment with trail design.
Bridge Design	Elementary School	Relationship between balance and force. Engineers consider materials, setting, purpose, and motion when designing bridges.	Students use the engineering design process to design a bridge for their school campus.

Reflective Journals and Project Planners as Evidence of PCK

Teachers' reflective journals revealed that the VSTEM workshops and fieldtrips —where university faculty modeled content-specific teaching strategies—were a primary source of VSTEM teachers' PCK. For example, multiple instances were found of energy-related PCK that resulted from a 2016 summer institute workshop led by chemistry faculty. Several VSTEM participants mentioned learning two new strategies—*Energy Theater* (Daane et al., 2014) and *Energy Tracking Diagrams* (Scherr et al., 2016)—for modeling energy transfers and transformations within systems and assessing students' understanding of energy types. Other participants mentioned learning to use water as an agent for demonstrating the relationship between temperature and kinetic energy while simultaneously addressing the common misconception among students that energy is only transferred through objects. The following excerpt from a high school teacher's journal denotes the energy-related PCK that resulted from this particular workshop:

> *I learned lab activities that will get students thinking about energy (mass and heating of water, electrolysis of water, and a variety of other activities mentioned by other teachers in the class). I also started to think more about total vs. average energy in a system and how students might think about that. I also got many ideas about how students could modify the lab activities that we did today (salt water, different energy sources, etc.) to turn these activities into individual investigations.*

Additional instances of PCK were found where teachers reported learning new strategies for teaching ecology and Earth science topics. For example, teachers reported learning from environmental science faculty how to model food webs, graphically represent population density, and investigate the effect of species size on ecosystem functioning. For example, several teachers wrote in their reflective journals about learning new strategies for modeling fish predation and the idea that big fish can only eat little fish.

> *What I found fascinating today—and I had never thought of it before—is that fish can only eat what fit in their mouth. They do not have hands or paws to push things in. They do not have a way to make their food smaller. They cannot chew. They just open and swallow. Totally amazing and quite obvious, but I never thought about it. I love the idea of sorting-by-size because third graders can do it and understand it and understand that little things need to eat littler things.*

A middle school teacher mentioned learning the same topic-specific strategy.

> *Today I learned about the ecology and food webs of Lake Champlain. It was interesting to learn that certain fish will eat the largest food available to them and how this might affect the populations of other organisms in the lake. I thought that the activity we participated in would be useful in the instructional sequence that I am building about ecology.*

Another VSTEM participant reported learning a multi-stage sequence for teaching science from watching environmental science faculty move from engaging students through videos, to using small toys to represent key concepts, to conducting hands-on experiments to solidify learning. Other participants reported learning from geology faculty on the use of student drawings of rock faces to teach Steno's laws of stratigraphy and how to test for calcite to demonstrate the connection between chemistry and geology content.

There were several instances in which the teaching strategies that participants reported learning during the program also appeared in the projects they designed. For example, two high school science teachers collaborated in the development of an NGSS-aligned project that focused on the impact of non-point source pollution on stream health. The project entailed students collecting, analyzing, and comparing data from water and macroinvertebrate samples at multiple local stream sites over time. Similarly, a middle school teacher designed a project that utilized local hiking and mountain bike trails as a context for teaching the topic of erosion. The fundamental idea that underlies this project is that wind and water can change the shape of the land, a concept that first appears in her summer institute journal following the VSTEM geology field trip. In both projects, students in these classes designed potential solutions to each problem. Teachers used these designs to assess students' understanding of underlying science content and scientific practices as suggested by the NGSS.

Another example where a teacher applied topic-specific teaching strategies learned during the program to their project design involved an elementary teacher who participated in VSTEM for 2 years. This participant designed a project for elementary students that applied the concept of biomimicry to mutualism between humans and natural systems—a strategy the teacher reported learning from VSTEM engineering faculty during a summer institute workshop. In this project, students are invited to use their observations of seed dispersal in nature to design innovative solutions to human problems associated with mobility and transportation.

Classroom Observations as Evidence of PCK

Classroom observation data provided additional evidence of knowledge of instructional strategies for teaching science for the 10 teachers who participated in both years of VSTEM. As summarized in Figures 1 and 2, the mean of all the DCO indicators shifted from moderate levels at the initial observation conducted in fall 2015 toward consistent levels by the third observation conducted in spring of 2017.

Figure 1

Classroom Observation Data – DCO Implementation Indicators

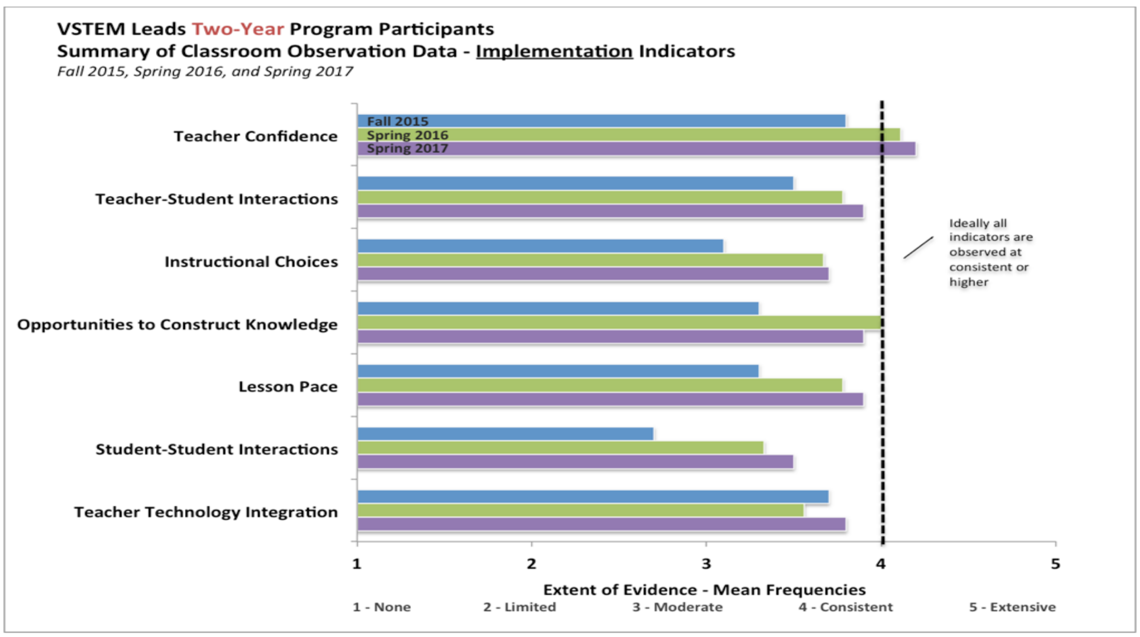
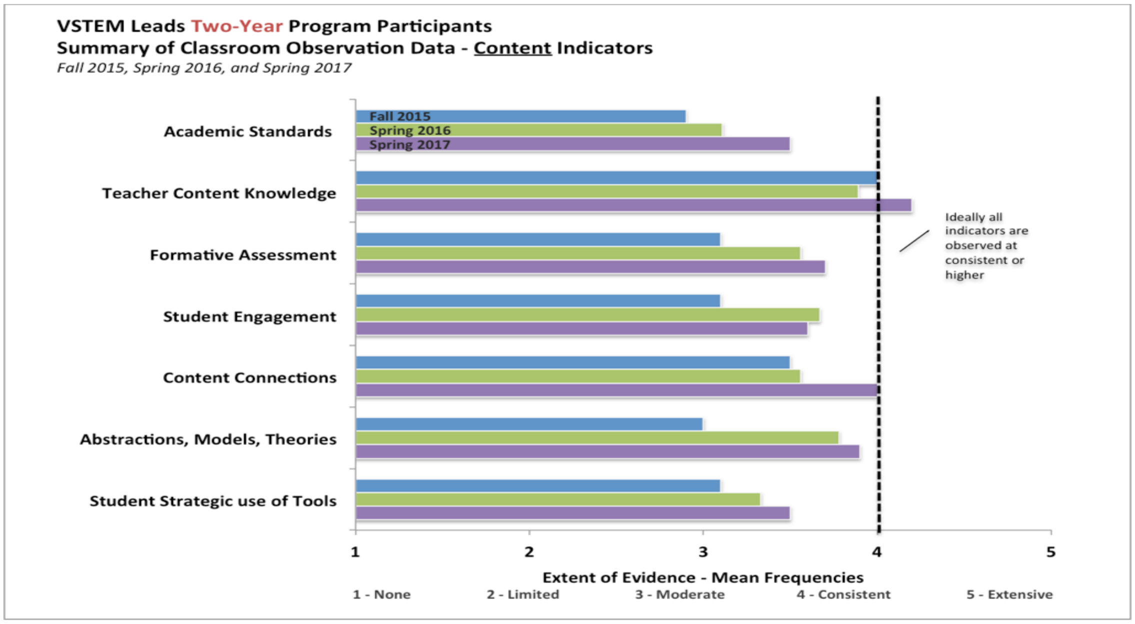


Figure 2

Classroom Observation Data – DCO Content Indicators



A paired sample t-test for each of the 14 DCO indicators (see Table 6) revealed statistically significant increases in the mean ratings for four of the DCO indicators including implementation indicators (instructional choices, opportunities to construct knowledge and student-student interactions) and content indicators (abstractions, theories, and models).

Table 6

Results of Yr. 2 Paired Samples T-Test on DCO Indicators

DCO Indicator	*t*	Sig. (2-tailed)
Teacher Confidence	-1.406	.193
Student-Teacher Interactions	-1.406	.193
Instructional Choices	-3.000	.015 *
Opportunities to Construct Knowledge	-4.583	.001*
Lesson Pace	-1.861	.096
Student-Student Interactions	-2.250	.051*
Teacher Technology Integration	1.000	.343
Academic Standards	-1.500	.168
Teacher Content Knowledge	.557	.591
Formative Assessment	-1.078	.309
Student Engagement	-1.861	.096
Content Connections	-.231	.823
Abstractions, Models, Theories	-2.333	.045*
Student Strategic Use of Tools	-1.000	.343

Demonstrated growth between the first and third classroom observations related to teacher instructional choices, student opportunities to construct knowledge, and productive student-student interactions reflects VSTEM's emphasis on scientific inquiry. While factors within school systems unrelated to VSTEM may have encouraged or inhibited change in teacher PCK, this shift suggests that teachers who participated across two years of the program embraced the STEM constructivist strategies modeled and supported throughout the VSTEM program.

At the time of initial observations, approximately two months after the week-long summer institute, most teachers were beginning to implement place-based or project-based learning strategies and some had already begun teaching the NGSS-aligned projects that they had developed during the previous summer. Most teachers were already familiar with the NGSS practices and some were skilled at engaging students in active and collaborative learning at the onset of the program. Much of the observed lesson content was linked to local place-based issues such as Lake Champlain conservation and energy efficiency in the local community.

Regardless of the instructional content, many of the initial observed lessons were didactic in nature characterized by explicit instruction and steps for engaging in STEM investigations by the teachers. In these instances, students were provided little opportunity to construct their own understanding of science concepts or collaborate in their scientific investigations with one another. Students generally followed teacher directions, and in some classrooms, they appeared far more compliant than engaged in their learning. The majority of the teachers tended to give direct answers to student questions rather than probe for understanding or respond with questions designed to encourage and motivate students to arrive at their own answers. Teachers were also more likely to present models than have students generate them. For example, this approach was evident in an elementary classroom where the teacher presented a model of a living cell and then demonstrated how a pizza and its various ingredients represented cell structures or organelles. Students were primarily engaged in observing the process but seemed more focused on tasting the pizza rather than how the various ingredients might represent cell organelle structure and function.

By the final observation point, lesson content continued to emphasize place-based and project-based learning with a shift towards more student-directed investigations. For example, one elementary class was engaged in an engineering design project that involved testing various materials for a new helmet design. During the first observation point, students were instructed in every phase of the project by the teacher, with little room for exploration and surprise. During the final observation, however, after testing materials that students chose and dropping helmet prototypes from the roof of the school, the teacher appeared to demonstrate genuine enthusiasm and surprise at some of the prototype results.

In a middle school classroom, teams of students worked at stations to investigate the movement of sound waves through various substances. Students made predictions and recorded observations that were later utilized as evidence in a claim-evidence-reasoning discussion. Similarly, in a high school biology class, students gathered evidence from experiments, readings, and mini-lectures to prepare for a debate on the use of genetically modified organisms in local agriculture.

Teachers at all levels were also more likely to engage students in developing and revising their own models in response to essential questions (e.g. How is the Earth organized? How does sound travel?) posed in the initial stages of the unit of study. The elementary teacher who had earlier modeled a cell by building a pizza was now using a story board to record and track students' evolving conceptions and representations about waves and energy transfer.

At the end of Year 2, participating teachers were more likely to ask probing questions such as "How do you know that?" "What tells you that?" "What is your evidence?" or "Is this type of graph a useful representation for this type of data?" When students raised content or process questions, teachers were more likely than at the initial observation point to respond with probing questions and reminders to utilize other resources such as their fellow students, thereby encouraging students to socially construct their own understanding of scientific concepts. By the third observation point, many teachers had created more contexts for students to ask their own questions, use evidence to make claims, and engage in genuine discussion and reasoning about their findings.

Online Surveys as Evidence of PCK

Detailed reports of teacher responses to an anonymous online program survey documented teacher perceptions of the ways in which program participation changed and improved their STEM classroom practice. See Table 7 for a sample of survey comments.

Table 7

Post-program Teacher Survey Data

Teacher	Comment
1	I think more about the scientific practices and what skills I want the students to master and therefore what projects I am going to have them demonstrate their proficiency in those skills.
2	I feel that I have assimilated the learning from VSTEM directly into my everyday teaching both with daily lesson structure and overall unit design.
3	I have always wanted this (projects and place) to be part of my practice but now I see how doable it is.
4	I have worked to make my class much more project-based and I present a great deal less information as 'an expert' and allow ideas to emerge from data and evidence.

Most teachers reported moderate to large changes in how they supported student learning that included the development of clearer learning targets, new attention to real-world connections, implementing place-based units, incorporating engineering design, and focusing on all three dimensions of the NGSS. They also reported facilitating new opportunities for students to develop their own experiments and engage in scientific discourse with each other. In the surveys, teachers also reported numerous challenges associated with implementing curricular and pedagogical changes that included insufficient planning time, limited time for science instruction, the amount of time needed for inquiry and engineering design, limited supplies and physical space, and uncertainty when facilitating student-led investigations.

Discussion and Conclusions

Creating multiple opportunities for teachers to experience authentic scientific research through place and project-based models was foundational to changes in teaching practice in this study. Comprehensive analysis of VSTEM program data and artifacts revealed that teachers' science content knowledge and pedagogical content knowledge were enhanced by VSTEM program participation with moderate to strong indications about place-based education, project-based learning, and the importance of engaging students in authentic scientific research. Evidence from a variety of data sources demonstrated that VSTEM participants learned new content-specific teaching strategies and implemented standards-based lessons and projects that aligned with constructivist theories of teaching and learning. The VSTEM touchstones—authentic inquiry, place-based and project-based learning, NGSS standards, personal connection, and backward design—served as guiding principles for these shifts in teachers' thinking, content knowledge, pedagogical content knowledge, and overall teaching and practice over time.

Interactions with VSTEM faculty during the summer institute and throughout the school year provided inspiration and technical support for the teachers as they continued to apply their STEM content and pedagogical content knowledge to their evolving NGSS projects and lessons. Faculty facilitated sessions during the VSTEM summer institute and school year workshops were readily available as a resource to participants throughout the academic year. In turn, university VSTEM faculty gained new understandings about the NGSS, as well as the school and cultural context for K-12 STEM education. Project leaders reported a higher volume of communication between university faculty and teacher participants in Year 2 compared to Year 1. This included requesting clarification about specific content and pedagogical questions, suggestions for accommodating special needs students, feedback on project plans, or sharing articles and information about other STEM professional development opportunities. As a direct outcome of their VSTEM participation, two middle school teacher participants collaborated with one of the project leaders to mentor a teacher intern during their student teaching experience.

Professional relationships within higher education and between the participating teachers were also reinforced. A strong synergy between project leaders from The College of Education and Social Services and The College of Engineering and Mathematical Sciences has been extended beyond the life of the program as these individuals continue to develop new projects and mentor and challenge each other to become ardent leaders for STEM education. Participants, too, were reaching out to each other directly to share lessons, projects, and units or to share information about upcoming STEM education events. Within each school district team, teachers continued collaboration beyond the timeframe of the VSTEM project.

The variety of professional learning opportunities such as those described in this study have worked to build teachers' capacity to offer more authentic and engaging STEM education to their students. As Vermont and other states increasingly aim to provide high-quality STEM education for *all* students, the VSTEM Leadership Program offers a framework, through its touchstones, curriculum, and modeling, to advance and support these conversations.

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References

Atkinson, R. D. & Mayo, M. J. (2010). *Refueling the U. S. innovation economy: Fresh approaches to science, technology, engineering and mathematics (STEM) education.* Information Technology & Innovation Foundation. https://itif.org/files/2010-refueling-innovation-economy.pdf

Banilower, E. R., Heck, D., & Weiss, I. (2007). Can professional development make the vision of standards a reality? The impact of the National Science Foundation's Local Systemic Change Through Teacher Enhancement initiative. *Journal of Research in Science Teaching*, *44*, 375-395.

Bayram-Jacobs, D., Henze, I., Evagorou, M., Shwartz, Y., Aschim, E. L., Alcaraz-Dominguez, S., Barajas, M., & Dagan, E. (2019). Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials. *Journal of Research in Science Teaching*, *56*, 1207-1233.

Berry, A., Friedrichsen, P., & Loughran, J. (Eds.). (2015). *Re-examining pedagogical content knowledge in science education*. Kluwer.

Beyer, C. J. , & Davis, E. A. (2012). Learning to critique and adapt science curriculum materials: Examining the development of preservice elementary teachers' pedagogical content knowledge. *Science Education*, *96*, 130-157.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palinscar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*, 369-398.

Buck Institute of Education. (n.d.). *Project design rubric.* PBL Works. https://my.pblworks.org/resource/document/project_design_rubric

Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical content knowledge: An integrative model for teacher preparation. *Journal of Teacher Education*, *44*, 263-272.

Cochran, K. F. (1997). Pedagogical content knowledge: Teachers' integration of subject matter, pedagogy, students, and learning environments. *Research Matters—to the Science Teacher*, *9702*. https://www.narst.org/publications/research/pck.cfm

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). SAGE.

Daane, A. R., Wells, L., & Scherr, R. E. (2014). Energy theater. *The Physics Teacher*, *52*, 291-294.

Demarest, A. B. (2015). *Place-based curriculum design: Exceeding standards through local investigations.* Routledge

Duckworth, E. (2006). *"The having of wonderful ideas" and other essays on teaching and learning* (3rd ed.). Teachers College Press.

Falk, A. (2012). Teachers learning from professional development in elementary science: Reciprocal relations between formative assessment and pedagogical content knowledge. *Science Education*, *96*, 265-290.

Fitzgerald, M., Danaia, L., & McKinnon, D. H. (2019). Barriers inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters. *Research in Science Education*, *49*, 543-566.

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching*, *45*, 922-939.

Graham J. (2006). Congeneric and (essentially) tau-equivalent estimates of score reliability: What they are and how to use them. *Educational and Psychological Measurement*, *66*, 930-944.

Graves, S. M. (1999). *Alternative conceptions in science and science teaching self-efficacy* [Unpublished doctoral dissertation]. University of Idaho.

Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education*. Teachers College Press.

Ingvarson, L., Meiers, M. & Beavis, A. (2005). Factors affecting the impact of professional development programs on teachers' knowledge, practice, student outcomes & efficacy. *Education Policy Analysis Archives*, *13*(10), 1-28. https://epaa.asu.edu/ojs/article/view/115/241

Julyan, C., & Duckworth, E. (2005). A constructivist perspective on teaching and learning science. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (2nd ed., pp. 61-79). Teachers College Press.

Kahle, J. B., Meece, J., & Scantlebury, K. (2000). Urban African-American middle school science students: Does standards-based teaching make a difference? *Journal of Research in Science Teaching*, *37*, 1019-1041.

Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education*, *45*, 169-204.

Kind, V. (2015). On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedgaogical content knowledge in education* (pp. 178-195). Routledge.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative model for helping middle grade science teachers learn project-based instruction. *Elementary School Journal*, *94*, 483-497.

Krajcik, J. S., Czerniak, C. M., & Berger, C. F. (2007). *Teaching science in elementary and middle school classrooms: A project-based approach* (3rd ed.). Routledge.

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education*, *92*, 1-32.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S. E., & Hewson, P. (2003). *Designing professional development for teachers of science and mathematics* (2nd ed.). Corwin Press.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Kluwer.

Meiers, M. & Ingvarson, L. (2005). *Investigating the links between teacher professional development and student learning outcomes.* (Vol. 1). Australian Department of Education, Science and Training.

Merrill, C., & Daugherty, J. (2010). STEM education and leadership: A mathematics and science partnership approach. *Journal of Technology Education*, *21*, 21-34.

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K-12 teachers. *Science Education*, *97*, 936-972.

National Center for Education Statistics. (2019). *National Assessment of Educational Progress.* National Center for Education Statistics, Institute of Education Sciences, U.S. Dept. of Education.

National Governors Association Center for Best Practices. (2010). *Common Core State Standards for Mathematics*. National Governors Association Center for Best Practices, Council of State School Officers.

NGSS Lead States. (2013). *The Next Generation Science Standards: For states, by states*. National Academies Press.

O'loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching*, *29*, 791-820.

Palinscar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology*, *49*, 345-375.

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*, 261-284.

Prawat, R. S., & Floden, R. E. (1994). Philosophical perspectives on constructivist views of learning. *Educational Psychologist*, *29*, 37-48.

Rice, L. H. (2012). *Courage to teach—touchstones.* The educator's room. https://theeducatorsroom.com/courage-to-teach-touchstones

Saginor, N. (2008). *Diagnostic classroom observation: Moving beyond best practice*. Corwin Press.

Scherr, R. E. , Harrer, B. W., Close, H. G., Daane, A. R., DeWater, L. S., Robertson, A. D., Seeley, L., & Vokos, S. (2016). Energy tracking diagrams. *The Physics Teacher*, *54*, 96-102.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*, 4-14.

Shulman, L. S. (2015). PCK: Its genesis and exodus. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 3-13). Kluwer

Solomon, J. (1987). Social influences on the construction of pupil's understanding of science. *Studies in Science Education*, *14*, 63-82.

Tal, T., Krajcik, J. S., & Blumenfeld, P. C. (2006). Urban schools' teachers enacting project-based science. *Journal of Research in Science Teaching*, *43*, 722-745.

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education*, *4*, 99-110.

U.S. Department of Agriculture. (2020). *Food and Nutrition Service Child Nutrition Programs: Income Eligibility Guidelines*. https://www.govinfo.gov/content/pkg/FR-2020-03-20/pdf/2020-05982.pdf

Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagogical content knowledge. *Science Education*, *86,* 572-590.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). Macmillan.

Wiggins, G. & McTighe, J. (2005). *Understanding by design*. Association for Supervision and Curriculum Development.

Appendix A

Vermont STEM Leadership Institute
Goals, Objectives and Outcomes

Course Description and Goals:
The VSTEM Leadership Program (VSTEM Leads) will engage K-12 teachers in an exploration of the Next Generation Science Standards through authentic research and investigations pertaining to Vermont's ecology and geology and related energy issues, as well as an exploration of engineering design principles and projects. Coupled with these experiences will be opportunities to reflect upon ways to meaningfully integrate project-based, proficiency-based, and place-based experiences into formal and informal learning environments.

VSTEM Leads program activities are aligned with the Next Generation Science Standards (NGSS), the Common Core State Standards (CCSS) in ELA and Mathematics, and the Vermont Transferable Skills Standards. Workshops and activities will commence with the VSTEM Leads Institute (July 11-15th) and continue throughout the school year with follow-up workshops and lesson studies (dates to be determined with input from teachers). During the academic year, teachers will work in school-based teams to lead NGSS Professional Learning Communities (PLCs) at their schools. Teachers will participate in the VSTEM Conference to share and present the results of their project implementation and NGSS PLC work.

VSTEM Learning Objectives:
VSTEM professional learning experiences will emphasize three primary learning objectives:
1. Teachers will demonstrate an understanding of STEM knowledge and concepts necessary to respond to the learning needs of all students. This includes a deep understanding of:
   - NGSS core knowledge and practices and VT Transferable Skills Proficiencies.
   - Common misconceptions that students hold in regard to fundamental science concepts.
   - Science as a way of thinking by engaging in Science and Engineering Practices.
   - Engineering as the practical application of mathematics and science.
   - Ways to integrate the knowledge of content, instruction, assessment, and technology.
   - Ways to integrate CCSS in Math and ELA into meaningful science learning opportunities.
2. Teachers will demonstrate improved teaching skill and effectiveness with a focus on project, place, and proficiency-based teaching and learning.
3. Teachers will develop leadership skills that include an understanding of the effective use of resources and tools to support the implementation of the Next Generation Science Standards.

Program Outcomes:
As part of VSTEM Leads program outcomes and requirements, participating teachers will:
1. Develop a project and instructional sequence with appropriate performance assessments aligned to NGSS, CCSS in Math and ELA, and VT Transferable Skills standards.
2. Develop and present a poster of project implementation at the VSTEM Leads Conference.
3. Participate in 3 lesson studies at participating schools followed by a critical friends reflection and discussion.
4. Draft and implement a plan for conducting a monthly PLC at their school about NGSS

implementation with monthly online reporting/discussion board of the successes/challenges during the academic year.

Essential Question for the VSTEM Institute:
How can authentic research, local investigations, and scientific and engineering design practices inform my pedagogy and deepen my students' understanding of key STEM principles and concepts?

Driving Questions:
1. How do local ecosystems, watersheds, and landscapes change over time?
2. How are evidence and data analysis used in the research and teaching process?
3. How are models used in the research and teaching process?
4. How do key educational theories and practices (i.e. project-based, proficiency-based, inquiry-based, and placed-based practices) inform my developing curriculum and pedagogy?
5. How do the NGSS, CCSS in Math and ELA, and the VT Transferable Skills Standards inform my ability to develop curriculum?
6. How does an emphasis on responsive teaching, student efficacy, and issues of equity promote success for ALL K-12 students?

Module Objectives:

Exploring Vermont Geology
A field trip to Lessor Quarry will provide participants with the opportunity to explore how the geology of Vermont can be used to teach some basic concepts in the geosciences. Participants will examine sedimentary rocks with fossils and engage in an investigation on determining relative geologic timing. Activities include making observations about the type of rocks and geologic structures, fossil identification, making sketches of a rock face, and using a geologic compass.

Moving Energy
Energy comes in many forms and is transferred in numerous, often subtle ways. Participants will examine how different forms of energy are transferred to and from common substances. Using temperature, participants will investigate relationships between energy transfer, average kinetic energy, mass, and types of matter.

Optimal Forging
Optimal foraging theory explains how animals effectively gather resources given tradeoffs of the time it takes to search and capture food, uncertainty in food location, and energetic value of food. Participants will become familiar with basic experimental design, understand the different tradeoffs animals face when trying to secure resources, apply math to animal behavior concepts, and collect, analyze, and graphically represent data.

Appendix B

VSTEM PROJECT PLANNER[1]

GOAL: To apply your knowledge of science content and pedagogical practices as you develop a place-based education (PBE) project to be implemented in your classroom during the academic year.

DESCRIPTION AND GOALS OF PBE PROJECT: What is the background and context of the project and instructional sequence? What is the relevance and importance of the project? What is the authentic problem being addressed? How are the principles and practices of PBE incorporated in your project?
STANDARDS/PROFICIENCIES: Identify the essential content standards and proficiencies that drive your project. (Consider multiple subjects and standards).
Big Ideas/Enduring Understandings (EUs): What big ideas or enduring understandings will students know and understand over time and drive your place-based project? Write the EU's in student friendly language.
Essential/Driving Questions: What essential questions will drive the project/sequence? Be sure to address how societal and cultural issues (preferably local issues that are meaningful to students) will be integrated into the place-based project.

OBJECTIVES: KNOWLEDGE, PRACTICES & DISPOSITIONS: What key knowledge, practices and dispositions will students know, understand and do (KUDs) as a result of engaging in this place-based project?		
Content & Concepts: What will students <u>know</u> and <u>understand about the place of study and PBE</u>?	Practices: What specific practices/skills will students develop and be able to <u>do</u> over time?	Dispositions: What important attitudes, habits of mind, ethics, and/or beliefs will students develop over time about place and PBE?

PROJECT DESIGN - Develop a hand-out for students that describes the following: What are the project goals? How will the project be developed and sequenced over time? What are the milestones and due dates for completion of various project activities and investigations? How will the project be assessed?
I. Project Description: Describe the goals, objectives and outcomes of the place-based project. **In your project description, consider the following elements:** 1. Authentic Research and Place-based Learning: What research questions and practices or inquiry skills are integral to the project? How does the project incorporate a sense of "place"? 2. Anchoring Events: How will you hook and sustain student interest? Develop an **anchoring event** that engages students in a motivating activity that can be referred to throughout the project. 3. Fieldtrips and Experts: What experts can students contact? What kinds of fieldtrips directly align with project goals? What businesses, non-profits, agencies**, experts,** and colleges can inform project goals? 4. Pedagogical Considerations: What kind of skills and practices do you intend for the students to learn? How will you differentiate and accommodate for various student needs? How will you integrate the background and culture of your students in the project? How does your project apply to the real world and life beyond secondary education?

[1] Adapted from the Buck Institute of Education (n.d.) Project Design Rubric and Wiggins and McTighe (2005). *Understanding by Design. Expanded Edition.* Association for Supervision and Curriculum Development.

- Discussion and Argumentation: How will you hold students accountable to the project tasks and each other? What kinds of discussion protocols (e.g. pair-share, four corners, listening triads, fishbowl) will support students in the project?
- Differentiated Instruction/IEP/504/SST: How will the project accommodate various student needs and interests? Consider ELL and special-needs students as well as the diverse learning styles/interests of all students.
- Social Justice and Multicultural Considerations: How is the background, culture, gender and SES of all students integrated into the project? What strategies will you implement so that all points of view are heard throughout?
- College and Career Readiness: What transferable skills will you emphasize that prepare students for life after high school? What careers will you highlight that pertain to the project?

II. Design a Project Timeline: Outline specific lessons, tasks, and milestones that students will complete throughout the duration of the project that align to your goals and objectives for the project:

- <u>Pre-Project:</u>
- <u>Project:</u>
- <u>Post-Project</u>

III. Reflection and assessment strategies: How will you and your students reflect on and assess (formative and summative) understanding <u>over time</u>? (e.g. Class discussion, fishbowl, surveys, student-facilitated formal debrief, peer/group evaluations).

Develop tasks, activities and rubrics that assess learning outcomes and proficiencies.

PROJECT RESOURCES		
Student Literature	Materials & Field Trips	Web sites & Technology
• What texts (fiction, non-fiction), newspapers & journal articles will support student learning?	• What materials do you need? • Who will you contact? • Where will you go? • What support do you need? • What are the logistics and for the field trip or activities?	• What technology and web resources will you utilize?
PLAN LEARNING OPPORTUNITIES AND SEQUENCE INSTRUCTION: Outline the essential learning experiences that sequence the key knowledge and practices for this project?		
Week 1 Standards: EUs/EQs: Objectives: Activities/Tasks:	Week 2 Standards: EUs/EQs: Objectives: Activities/Tasks:	Week 3 (or more) Standards: EUs/EQs: Objectives: Activities/Tasks:

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Articulating the Barriers in the Online Learning Engagement in Chemistry of Junior High School Students: A Photovoice Study

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ABSTRACT

Understanding the challenges and preferences perceived by learners is crucial in helping institutions devise strategies to support the continuum of learning during the COVID-19 pandemic. This study used photovoice to examine the barriers in the online learning engagement in chemistry of junior high school students in the lens of their experiences in the online education during the health crisis. The inquiry uncovered four themes: difficulty in understanding the nature of chemistry as a subject matter; lack of intrinsic motivation towards online learning; difficulty in accommodating academic responsibilities in an online platform; and technical challenges associated with online learning. As a participatory mode of research, the students were engaged in a root cause analysis through focus group discussion to account for the causes of their challenges and their perceived solutions to the factors identified. The utilization of photovoice as the platform of inquiry was able to capture the chemistry learning experiences of students and the barriers that hinder their optimum engagement.

Keywords: photovoice, online learning engagement, chemistry education, chemistry online learning, online learning engagement factors

Introduction

Amidst the crisis in many aspects of society brought about by COVID-19, education continues to do its role by embracing different modalities of instructional delivery as it affected almost 98% of the student population worldwide (UNESCO, 2020). This pandemic caused a sudden shift in the face of education worldwide. With the foremost concern for the safety of the school community stakeholders, the disruption in the sphere of education paved the way to embrace a new space of learning through distance education. With indefinite time as to when it would end, the shift to online teaching and learning was a manageable option (Martinez, 2020) with varying degrees of integration and infusion in the educational systems (Starkey, 2020). There is an urgency to rethink, revamp and redesign the educational system and respond to the demands of disruption (Mishra et al., 2020).

In the Philippines, the pandemic became a turning point for its educational system (Toquero, 2020) as the country needed to respond, to alleviate digital divides and racial disparity, and offer an inclusive education adhering to the mantra that no students will be left behind. Among the areas of interest that can be explored is in terms of how the ongoing crisis of learning is perceived by the learners who are at the core concern of the entire educational system. The process of understanding the challenges and preferences perceived by the learners can help institutions devise strategies in which remote learning will be a feasible option (Aguilera-Hermida, 2020). Notwithstanding the combination of the health crisis, social isolation and associated problems brought by the pandemic that affect students' mental health and can hinder the optimization of their learning (Singh et al., 2020), it is crucial to understand where the students are coming from and how they respond to instructional delivery in the implementation of online education. Mourlam et al. (2020) affirmed that children have a right to be heard and they are considered their own experts in describing their experiences and their impact on their well-being. Kalman et al. (2020) examined the views of students on the learning process in the online platform during the pandemic and concluded that due to the restrictions on the conduct of conventional face-to-face instruction, teachers need to become aware of the learners' needs and passions and devise ways on how to motivate them amidst the crisis.

This qualitative inquiry was explored in the context of chemistry online education of junior high school students. Previous research highlighted the challenges perceived by both teachers and learners in teaching chemistry online, such as familiarity with internet-based technologies and application tools, adjustment of teaching methods, maintaining student interest and engagement (Huang, 2020); effect of synchronous problem-solving exercises in organic chemistry classes on student's attendance rate and learning (Sunasee, 2020); impact of internet affordances and financial burden affecting chemistry students' engagement (Tigaa & Sonawane, 2020); inequity to chemistry education between urban and rural areas (Soares et al., 2020); and limitations on communications and socialization among learners (Lansangan, 2020). This study used an unconventional way of soliciting the responses from the learners with regards to their online learning experiences: the photovoice methodology.

Caroline Wang and Mary Ann Burris are credited to the inception of photovoice methodology. Their work is rooted in Paulo Freire's critical pedagogy, feminism and visual research (Wang & Burris, 1994). Photovoice is an example of participatory action research in which informants use cameras to take photographs of persons, contexts, or situations they consider representative of a particular aspect of their individual and/or social life (Sutton-Brown, 2014) and document reality and interpret it (Malka, 2020). Photovoice supports participants, who might be unexpressive of their perceptions in some research experiences and issues (Harkness & Stallworth, 2013), reflecting their interests instead of fulfilling the agenda of researchers (Lam et al., 2020). Through photovoice, participants can share their lived experiences in dealing with difficulties and problems within a dialogic group space making them feel empowered and are capable of promoting changes (Malka, 2021a).

Initially, the use of Photovoice mushroomed in social science research works (Liebenberg, 2018), more specifically on promoting public health, and eventually extended into different groups of people such as the youth (Ho et al., 2011) and the community (Suffla et al., 2012). While its nature was explored as a research methodology, some researchers attempted to note its pedagogical applications (Latz et al., 2016). It was adapted in an educational atmosphere and was used to provide insights into students' unique lives and their experiences in classrooms (Harkness & Stallworth, 2013). Photovoice was used to explore various aspects of teaching and learning, such as the genuine participation of high school students as learners (Warne et al., 2013). Ciolan and Manasia (2017) suggested the utilization of photovoice as an enrichment tool in diagnosing the way learners engage in learning and support communications on how learning takes place and what the students think of the process.

In the field of science education, some research works have explored the use of photovoice methodology in the science learning experiences of students. Cook (2015) affirmed this methodology as a way of reconceptualizing science knowledge, practitioners of science, and science education at large. Stroud (2014) effectively employed photovoice as a student-centered learning activity in undergraduate introductory chemistry while making the subject matter relevant. Cuansing (2018) used photovoice as a source of qualitative data on students' understanding of some topics in physics thereby developing positive appreciation as they reflect on the photos that they took. Behrendt and Machtmes (2016) utilized photovoice to account for biology students' illustration of their learning experiences in attending field trips. Feldman (2005) applied photovoice to science teacher education.

Other researchers used photovoice to document the online learning experiences of learners. Some of these include Tanhan (2020) who developed Online Photovoice (OPV) to reach diverse participants with the purpose of allowing participants to express the factors that facilitate or complicate a particular problem. Bunga et al. (2021) examined youth's online learning experiences in synchronous and asynchronous classes while Doyumğaç et al. (2021) explored the facilitators and complicators in distance learning using this visual data collection technique. In addition, Raza et al. (2021) documented the journey of undergraduate students in the early months of the pandemic while Malka (2021b) used photovoice as a coping tool with the pandemic crisis in the practical training of social work students.

It is in this perspective and theoretical underpinning that this study would like to explore the different barriers affecting students' online learning engagement in chemistry using photovoice as the platform of inquiry. Dumford and Miller (2018) emphasized the importance of learners' engagement in online learning, which Sun and Rueda (2012) defined as the quality of efforts the learners make to perform well and achieve desired outcomes. Miltiadous et al., (2020) identified engagement as a predictor of success in online chemistry learning. This paper envisions to highlight students' voices and their lived experiences in learning the subject matter as a basis for the improvement of instructional practices and policy formulations towards a reflective and responsive chemistry online learning and teaching.

Methods

Participants and Research Locale

The participants of this research consisted of 45 Grade 9 students, 20 male and 25 female, aged 15-16 years old, enrolled in a private sectarian institution in Metro Manila, Philippians. The school adopted an enriched virtual mode of instruction during the school year 2020-2021 in response to the learning crisis brought by the pandemic.

Context

The school used Cloud Campus (CC), a cloud-based infrastructure powered by Blackboard, a world-class learning management system (LMS), maintained by the school's Educational Technology Center and enhanced by Google for Education. The students attend chemistry classes twice a week, 1 hour synchronous per day and 3 hours asynchronous sessions per week. Four days in a week are allotted for the different academic subjects and another day is allotted for consultation and other school activities. The school follows a discipline-based curriculum in science, having chemistry as the focus of the science instruction for the ninth grade.

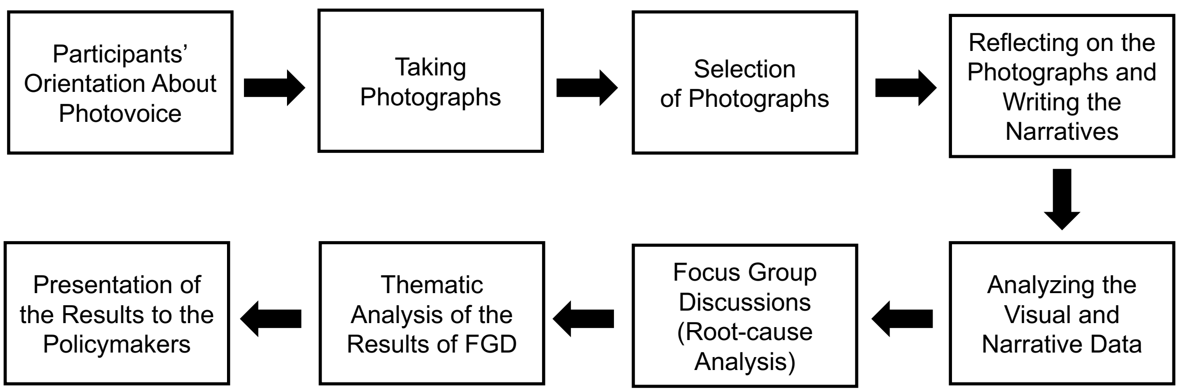
Data Gathering Procedure

The investigation started by obtaining parental consent and child assent forms before implementing a photovoice methodology in the context of their experiences in participating in chemistry classes in an online platform. A letter was sent to the parents of the students bearing the description of the research, the mechanism of upholding the confidentiality of the process, and the associated risks and benefits in the participation of the learners. The request for informed consent was submitted through the learning management system (LMS). Photovoice as a visual data collection technique was used in conjunction with focus group discussion on the issue at hand. As part of their year-end reflection in chemistry, orientation about the use of photovoice was done to inform the learners about the expectations and objectives of the activity. The diagram in Figure 1 summarizes the employed procedure.

A standard three-staged approach in conducting photovoice methodology (Wang & Burris, 1997) was employed in the entire analysis. First was the selection of photographs. Students were asked to take a picture that best represented the challenges they encountered in learning chemistry in an online platform. Their narratives on the pictures were also included. Second was the contextualization and discussion of photographs. According to Tsang (2020), analysis of findings in a photovoice methodology includes analyzing both visual data (participants' voice) and narrative data (interview data) based on the perspectives of the participants to establish a more credible way of theorizing the phenomenon. After the submission of the photos, students were asked to group themselves based on their perceived category of their photos depicting their challenges in learning chemistry. The categorization was used as the basis in the conduct of a series of group discussions that revolve around the root-cause analysis of their perceived challenges in online learning.

Figure 1

Photovoice Procedures



Data Analysis

The learners' narratives and the transcript of the focus group discussion were analyzed through thematic analysis which involved extracting significant responses adhering to the variables being explored; formulation of codes from significant statements; converting them into themes; and validation of the findings through member checking. As cited from the work of Lofton and Grant (2020), the key component of this kind of participatory research is to engage stakeholders to influence policy. After tabulating the themes for the perceived causes and solutions identified by the students, it was shared with authorities which involved a guidance counselor, science teacher, level head teacher, learning area coordinator, and members of the school council. Their comments and suggestions were noted and further coded and analyzed.

Results and Discussion

This discussion covers the various barriers affecting students' online learning engagement in chemistry culled from the photos the students provided. From the perceived challenges, root cause analysis was discussed and analyzed, and the corresponding solutions were outlined as a result of the participatory discussion with the learners.

Barriers Affecting Students Online Learning Engagement in Chemistry

Table 1 presents the categorization of the students' perceived barriers that affect their learning of chemistry in an online platform.

Table 1

Barriers Affecting Students Online Learning Engagement in Chemistry (N = 45)

Barriers	Categories	N	Excerpts Culled from the Students' Narratives
Difficulty in Understanding the Concepts of the Subject Matter	Difficulty in Problem Solving	7	*"I chose an unsolved Rubik's cube as this symbolizes that before you solve a problem you must first know the principles of the problem. You cannot solve a Rubik's cube just by turning and twisting it without fully knowing how it works, and just like in chemistry you cannot just solve and answer the problem, you must first understand it's idea and fundamentals before you can truly solve the problem. My problem in chemistry is that I just solve and answer blindly without understanding the problem first. I rush too much resulting in me making mistakes after mistakes."* (S6)
	Lack of Imagination and Concrete Learning Experience	3	*"I chose this picture because the dead flowers represent the lack of imagination. Imagination is a strong brain builder because it encourages you to think in unconventional ways. Your imagination can assist you in finding solutions that your brain may find unexpected, but it may also create situations that address problems in the most efficient manner. Chemistry requires imagination especially during class when the teacher asks to picture a scenario in your head, or when they ask you a specific question that requires this. This picture can also symbolize the confusion and things we forget along the way. Chemistry has a lot of terms that are new to most students & requires a lot of solutions and numberings for other lessons. Some students, like me, tend to forget some of these after some time and these specific solutions might be needed later."* (S4) *"I feel like Chemistry is easier to understand when you can do experiments. I feel like it's a very hands-on topic and we can't do it that way right now because of the pandemic."* (S41)
	Difficulty in Understanding the Concepts	3	*"This toy sword represents my overall experience through Chemistry this year. The toy itself represents the easiness of some parts of Chemistry for me personally. I found some parts of all the lessons fairly simple and straightforward. However, it wasn't all sunshine and rainbows for me, thus my second representation, the sword the toy represents. It means that despite it being a toy, it is a representation of a real-life sword, much like how Chem is a double-edged sword."* (S2)
Lack of Intrinsic Motivation Towards Online Learning	Frustration in the Set Up for Learning	3	*"The picture provided above represents my frustration and confusion not only in this certain subject but this whole school year. This leaves a question on my mind if there is still hope left for our education system. I am frustrated because this whole school year we students weren't given the experience and face-to-face education that we deserved."* (S15)

Table 1 Continued

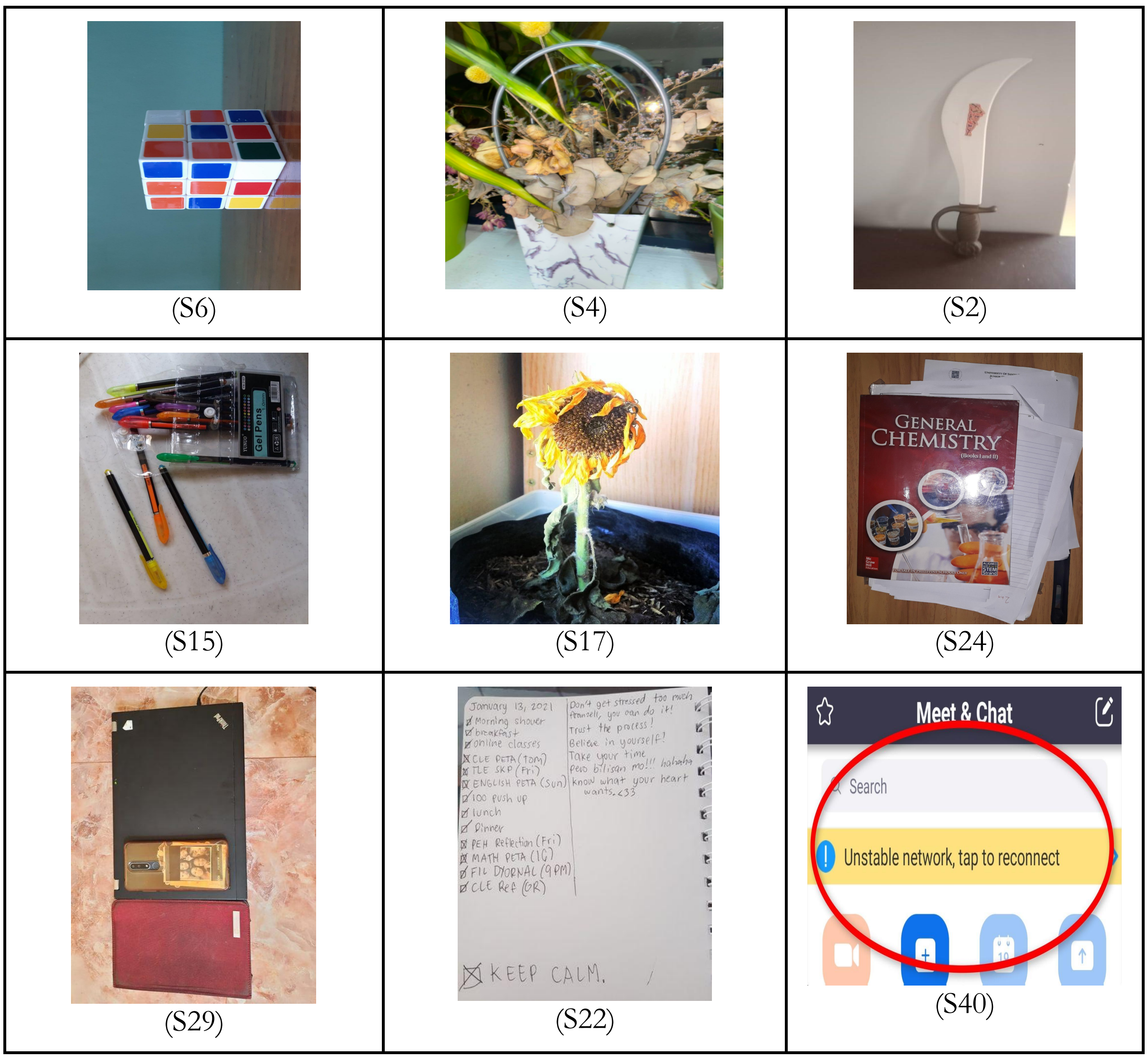
Barriers Affecting Students Online Learning Engagement in Chemistry (N = 45)

Barriers	Categories	N	Excerpts Culled from the Students' Narratives
Lack of Intrinsic Motivation Towards Online Learning	Lack of Interest and Motivation in Studying Online	3	*"Sunflowers usually symbolize joy and prosperity. The flower's bright yellow petals are reminiscent of the bright sun, and as the name of the flower suggests, it usually points to the direction of the sun. But despite its bright yellow petals, my sunflower is slowly withering away. It's kind of like me and my problems and challenges, not just in Chemistry, but in the whole online learning itself. Sometimes I'm bright and cheerful and I'm able to face the challenges of learning in an online setting, however as time goes on, I slowly lose motivation and energy to participate in class. Sunflowers usually grow in a field together, being bright and facing the sun together, but the sunflower in the picture is all alone and isolated. Back then, even if it was challenging, learning Chemistry and other subjects was still enjoyable to learn, mostly because of the actual face to face interactions with classmates, friends and teachers, but now because we are learning in an online setting, there are less interaction and it makes learning it demotivating and tiring instead." (S17)*
Difficulty in Accommodating Academic Responsibilities Online	Academic Overloads	6	*"In identifying and classifying all the challenges I went through, in this online environment in my Chemistry class this year, I took into account all the pressures and insecurities I felt, during the year. With this said, I would describe my challenges and problems this year, like a jam-packed book, in which, I would describe myself as a strong and bold Chemistry book that keeps on receiving tons and loads of information, everyday of my life, so much so, that the amount of information passed unto me is already more than enough, for my taste. This "too much info" I am referring to is of course the papers hidden within the book, in which the book can be seen as filled to the brim or even nauseatingly full, that is how I feel with the information given to me in this Chemistry subject, that sometimes all the concepts and learnings that I gain from this class, can sometimes prove to be too much, for myself. Basically, the problem I am referring to is the Chemistry subjects lack of awareness that sometimes all this information and insights that it brings us can sometimes be a little too much for us, as students, so much so that it is very hard to digest, even for me. With that said, the challenge that I identify within this school year is of course, the jam-packed amount of information given for us to digest and consume, which I for one think gives the student body nauseatingly too much information." (S24)*
	Distractions	5	*"I chose this because I tend to get distracted and tempted to open my other gadget whenever there's a class. Because of this, I can't really give my whole attention in class and that leads me to not fully understand the lessons given." (S29)*
	Time Management and Setting Priorities	9	*I chose a photo of my personal to-do list which I used in this school year, because I had difficulties managing my time. I was so overwhelmed with requirements that I couldn't focus entirely. (S22)*
Technical Challenges	Technical Affordances	6	*"I honestly think that the biggest and the only problem that I have faced during my Chemistry experience for this school year is the unstable internet connection that is present in my current home; I honestly though that I was able to properly adapt to each topic that came in my way from the first topic of 4.1 up until the last topic of 4.9, however, adjusting to find a proper internet provider so that my online classes will be stable without disconnections during an important part of the zoom meetings have been the greatest dilemma of my entire school year." (S40)*

From the pool of submitted pictures, learners were asked to categorize their chosen picture as to what factor it conveys. From their categorization, pictures were coded into 11 categories and further thematized into 4 major themes. Figure 2 conveys sample photos associated with Table 1. Twenty-nine percent of the learners had difficulty in understanding the concepts of the subject matter; 13% considered lack of intrinsic motivation towards online learning as the major factor affecting their learning; 44% conveyed their difficulty in accommodating academic responsibilities in an online medium; and another 13% perceived technical challenges associated with online learning. To account for the organic responses of the learners under each perceived challenge, significant responses were culled and analyzed. Pictures of the sample excerpts were also included in the discussion.

Figure 2

Sample Photos Associated with Table 1



(S6) (S4) (S2)
(S15) (S17) (S24)
(S29) (S22) (S40)

The first theme that hinders students' engagement in learning chemistry online revolves around its nature as a subject matter. The challenges perceived by students under this theme are coded in terms of the nature of the chemistry concepts, problem-solving, and the microscopic nature of the subject, which for them, are difficult to comprehend. S2 modeled the difficulty associated with chemistry concepts into a double-edged sword. The student acknowledged the balance between the easy and difficult chemistry concepts he learned in the school year. S6 used Rubik's cube to convey the difficulty he encountered in solving chemistry problems which is common among learners especially in basic education, as the work of Yuriev et al. (2017) contends that it can be associated with the lack of knowledge on the concept embedded in the problems, presence of alternative conceptions, and lack of appropriate strategies in approaching a chemistry problem. Due to the microscopic nature of the subject, the lack of imagination in comprehending the concepts was affirmed by S4 as dead flowers. Having specialized jargon in terms of chemical formulas and equations is one of the hurdles that may hinder learners' optimum understanding of chemistry concepts which is what Lim (2019) affirmed that for students to learn and understand the nature of chemistry, they must believe that they can see, touch, or taste the concepts embedded in the subject. As they explore the concepts, they find difficulty in understanding the interrelationships of the contents because they need to consider different levels of representations ranging from the macroscopic to microscopic. S41 highlighted the usefulness of conducting experiments to fully comprehend concepts in chemistry. Positive engagement towards science is associated with practical experiments (Hampden-Thompson & Bennett, 2013), and students find it uninteresting if not being incorporated in the lessons (Barmby et al., 2008).

The second theme deals with lack of intrinsic motivation in learning the subject matter in the online platform. It has always been emphasized in educational research how motivation significantly impacts the learning and performance of students (Bandura, 1993). For instance, S17 took withered sunflowers representing the lack of interest and motivation in studying chemistry online. It can be deduced from this photo narrative an intrinsic aspect of the learner's motivation, which is what Priniski et al. (2018) equates to learners' satisfaction and capacity to have personal value for the learners.

The way students deal with this more abstract cognition is affected by both teaching and the learning atmosphere (Corno, 2009), in this case, migration of instruction to the online platform. Aside from lack of motivation, S15 used colored pens to convey his frustration in the current set up of learning chemistry online. As they coped with the feeling of isolation and loneliness due to lack of socialization (Besser et al., 2020), it has been underscored in some studies how learners experience boredom, anxiety, and frustration (Aristovnik et al., 2020). Since the learners under study are used to the conventional way of learning through face-to-face platforms for many years, they find frustrations in the current set up which can be associated with lack of actual interaction with their friends and absences of school activities they are used to experiencing before.

The third theme corresponds to the difficulty of the students in accommodating their academic responsibilities associated with online learning. S24 took a book conveying the feeling of academic overload; S29 represented the distractions through a gadget; and S22 portrayed a to-do-list note for lack of time management. Chen (2021) described these aspects as academic stressors that change learners' behavior against some environment, social or internal demands. Learners are taking several subjects, not only chemistry, and they need to conform to the demands of all these disciplines. Workload conundrum was believed to be one of the dilemmas confronting learners in the beginning of mainstreaming the online platform during the pandemic. In the context of the learners, several academic ease were requested by the student body calling school administration to lessen the academic workloads of the students.

The fourth theme corresponds to the challenge associated with technical affordance, as exemplified by S40 as a screenshot of unstable internet connection. Due to the rapid utilization of online platforms to deliver education, many students were caught unprepared to account for the needed technical requirements associated with remote learning such as stable internet connection and gadgets. All the learning experiences of the students depend on their internet connection, thereby affecting their learning engagement when confronted with poor connectivity.

Root Cause Analysis of the Perceived Barriers

After categorizing the perceived challenges of the learners, group discussions were completed with students to articulate the causes of these challenges. This was also done to account for the learners' perceived solution to the problem hindering their engagement in the online learning platform. For this part of the study four batches of focus group discussions for the root cause analysis were conducted. Figure 3 shows the summary of the results of the root cause analysis while the specific items are reflected in Table 2.

Figure 3

Root Cause Analysis of the Perceived Barriers

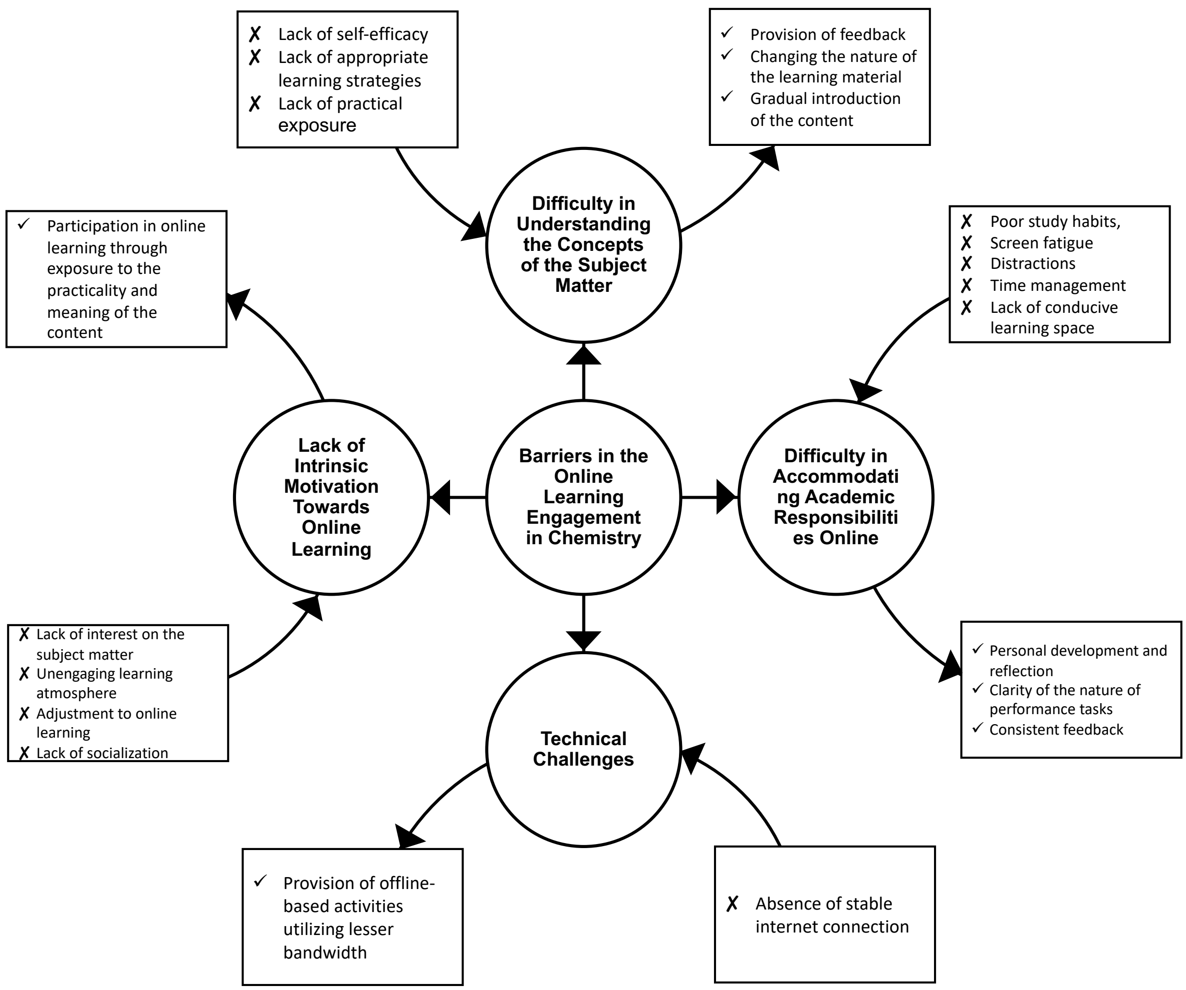


Table 2

Anecdotes Culled from the Root Cause Analyses Drawn from the Focus Group Discussions

Barriers	Learners' Perceived Causes	Learners' Perceived Solutions
Difficulty in Understanding the Concepts of the Subject Matter	F1C1 - Carelessness (S12) F1C1 - Lack of focus to the lessons (S3) F1C1 - Lack of self-confidence (S1) F1C2 - Poor memorization (S2) F1C2 - Lack of appropriate strategies in problem solving (S6, S11) F1C2 - Difficulty in abstracting the concepts (S4, S7, S8) F1C2 - Lack of analytical skills (S4, S7, S8) F1C3 - Lack of practical experience (S5, S9, S43)	F1S1 - More follow ups and formative exercises (S5, S11) F1S1 - Consistent feedback (S7) F1S2 - Provision of fun-related and engaging learning material (S11) F1S3 - Lessen the academic workload of the different subjects (S1, S6) F1S3 - Gradual introduction of the content (S2)
Lack of Intrinsic Motivation Towards Online Learning	F2C1 - Inability to see the sense of the lessons (S16, S18) F2C1 - Lack of interest on the subject (S16, S18) F2C2 - Monotonous learning atmosphere (S19) F2C2 - Time allotted for the subject (S14) F2C3 - Overwhelming feeling during online classes (S13) F2C3 - Unpreparedness for the demands of online learning; has not yet adjusted to online platform (S15, S41, S42) F2C4 - Lack of social interaction (S17, S14, S16)	F2S1 - Solicit students' profile in terms of their interest where they can connect (S19) F2S2 - Provision of the practical applications and connections of the lesson into real life setting such as in career and profession (S19) F2S2 - Provision of varieties of activities other than the traditional seatwork (S18) F2S2 - Provision of more student-centered activities that call for active participation (S17) F2S2 - More encouragement to participate (S16) F2S2 - Provision of student-to-student interaction and collaboration (S14)
Difficulty in Accommodating Academic Responsibilities Online	F3C1 - Overthinking (S23) F3C1 - Impulsiveness (S30) F3C1 - Laziness and Irresponsibility (S26, S34) F3C1 - Procrastination (S22, S39) F3C2 - Screen fatigue (S27, S31, S36) F3C2- Information overload (S20, S24) F3C2 - Excessive school works (S24, S25, S33) F3C3 - Visiting social media platforms during synchronous classes (S21, S29) F3C3 - Frequent use of cellular phones during online classes (S32, S39) F3C4- Lack of enough time to study the lesson (S24) F3C4 - Lack of time management (S37, S38) F3C4 - Lack of balance between curricular and extra-curricular involvement (S28) F3C5 - Absence of conducive online learning space (S39)	F3S1 - Personal development on time management, self-discipline, way of learning, goal setting (S24, S26, S27, S35, S30, S36, S29, S21, S20, S38) F3S2 - Reasonable deadline and nature of the requirements in consideration to other subjects (S26) F3S2 - Setting clear expectation and instructions to performance tasks (S39) F3S3 - Consistent open communication between students and teachers/ and between students (S33, S35, S39, S29) F3S3 - Continue the practice of having consultation day in a week (S36)
Technical Challenges	F4C1 - Unstable internet connection (S35) F4C1 - Current subscription to internet plan (S40, S45) F4C1 - Financial problem (S44) F4C1 - Not enough gadgets at home (S44) F4C1 - Home location (S45)	F4S1 - Lessening the kind performance tasks that require high bandwidth (S40) F4S1 - Provision of more offline activities (S44) F4S1 - Consistent uploading of class recording that the students can review (S42) F4S1 - Lessening of the kind of requirements that simultaneously require internet (S42)

Note: F = factor, C = causes, S = perceived solutions

Discussion 1: Difficulty in Understanding the Concepts of the Subject Matter

The first group discussion included learners who identified the difficulty in understanding chemistry concepts as the dominant barrier affecting their online learning engagement in chemistry. From the anecdotes culled from their narratives, causes of this challenge can be thematized into lack of self-efficacy, lack of appropriate learning strategies, and lack of practical exposure to the subject. However, students had a consensus that their perceived difficulty is not entirely due to the nature of the subject matter, but also because of the other external factors affecting their sense of focus in understanding the subject. Table 3 includes excerpts of the significant statements drawn during the first group discussion with the students.

Table 3

Excerpts from the Group Discussion on the Students' Perceived Solution in Addressing the Difficulty in Understanding the Concepts of the Subject Matter

Student	Comment
S1	*"For me, this past school year in chemistry is ok. But because we need to comply with the different requirements of the subjects, it affects how we perform in the subject. Though I get the point why teachers need to give the requirements, I suggest making it reasonable especially when it comes to the time allotted to complete it."*
S2	*"I cannot really speak for everyone here. We all have our own difficulties, personal problems, strengths and weaknesses, especially in chemistry Sir, so, I am not really sure of the definite or most universal solution. There was a quarter where there were a lot of concepts to study. Because of my lack of experience and strategies, I think that concepts need to be introduced one at a time, little by little."*
S6	*"I think, I agree with S1 regarding the allotment of reasonable time to complete the different requirements of the subject to give us enough time to study the lesson."*
S11	*"I actually don't have a problem in chemistry but I personally find more practice exercises to be helpful in understanding the subject. I think it will also become helpful if chemistry will add fun-related activities because it can help us become more active in dealing with the subject."*
S5	*"Similar to the answer of S11, I think the interest of the students can also be considered in the materials that the students use in the subject. I think it seems that everything becomes mechanical just for the sake of compliance. I think there should be more reinforcement or follow up activities to check our learning."*
S7	*"I have to agree with my classmates most especially when it comes to doing practice in understanding chemistry. It is important to have self-discipline in understanding this kind of subject. However, consistent giving of feedback is helpful for us to know if we are on the right track. I also agree with the aspect of providing reasonable time to complete the requirements not only in chemistry."*

Their perceived solutions include the provision of feedback, changing the nature of the learning material, and gradual introduction of the content. S5 and S11 agreed that the provision of more follow-ups and formative exercises can help them better understand the content of the lesson. For them, these mechanisms will reinforce their understanding of the content and scaffold the complex concepts that they are studying. In fact, Leenknecht et al. (2021) opine that these modes of assessments are associated with learners' autonomy, competence, and motivation. As they participate in the online platform of learning, their independence to self-study the content can be best supported by providing them with the learning materials that remediates their conceptual understanding. S11 pointed out the utilization of materials that are engaging to them to keep them motivated to study the lesson. In connection to this, S7 affirmed the role of consistent feedback on them to be informed about their progress and as to whether they are on the right track or not. However, S2 pointed out the complicated nature of chemistry concepts based on his experience and that these concepts need to be introduced gradually. Literature termed this mechanism as content chunking (Miller, 1956), a process of breaking content into smaller manageable pieces that would ease students' challenges with processing it. Heath and Shine (2021) identified it as one of the teaching techniques to facilitate time management as well in online teaching. Despite their consensus to provide these kinds of mechanisms to support their learning, S1 and S6 believed that lessening their academic workload among the different subjects could help them focus on a deeper understanding of the contents.

Table 4

Excerpts from the Group Discussion on the Students' Perceived Solution in Addressing the Lack of Intrinsic Motivation Towards Online Learning

Student	Comment
S19	*"The overwhelming feeling in online learning… Chemistry has a lot of technical terminologies to comprehend. It affects my motivation to study it. The solution that I can think of is to consider the individual interest of the students. I think it would be better to integrate areas we are interested and that we can easily connect with."*
S18	*"Regarding the monotonous learning atmosphere, I think as compared to the normal face to face school, our online activities now usually only have seatworks, answer them, that's it. I think we should try changing the way we give learning activities, make it interesting to make it more inspiring. Yes Sir, variety of activities."*
S17	*"I think there should be more activities that require class participation even if it is online. Since we are not in the classroom, we are easily distracted at home when we are just simply listening to lectures."*
S16	*"I usually think that the lack of interest is mostly my personal problem. But my mom told me that just because the subject is boring, doesn't mean that you are not going to give it your best because you will encounter them in real life. I try to make myself interested in chemistry class by participating even if I am shy. Because I learned when I participated in the classes. If I don't participate the lessons will just simply go over my head and I will suffer in the quizzes. Encouraging me to participate really works for me."*
S14	*"Regarding the lack of social interaction and monotonous learning atmosphere, unlike in the face to face before, it would be better if there are more collaborations with our classmates to validate as to whether we are on the right track especially when learning a complex lesson. It gives me a sense of relief knowing that you have the same experience."*
S19	*"Most students like me don't have the opportunity to see the importance of the subject. I think it would be better that chemistry lessons must also integrate its actual connections in reality such as in terms of career opportunities."*

Discussion 2: Lack of Intrinsic Motivation Towards Online Learning

In the second group discussion pertaining to the lack of intrinsic motivation towards online learning, the primary causes of the challenge that students identified are lack of interest in the subject matter, unengaging learning atmosphere, adjustment to online learning, and lack of socialization. In solving such, student participants dwelled mainly on the role of students' active participation in online learning through exposure to the practicality and meaning of the content as the solution to boost their motivation. Leading the unanimous perceived solution is from S19 student's disposition that varieties of activities other than the traditional seatwork must be provided. In doing so, S19 suggested the solicitation of their interest where they can connect, such as the practical applications and connections of the lesson into real-life settings, such as in career opportunities. The students also suggested that the lesson be student-centered to allow them to actively participate, as shared by S17. S16 emphasized that encouraging learners to participate can help them be motivated in online chemistry learning. These resolutions are consistent with the work done by Tan et al. (2020), that appropriate digital tools in the online teaching of chemistry are a predictor in achieving engagement and active learning among students. Table 5 presents the excerpts from the second group discussion.

Consistently, in the study of Broman and Simon (2015) on students' ideas to improve chemistry education, learners contented to make it relevant to everyday life, more practical, and student-centered. Among the commonly utilized way of igniting the relevance of chemistry to learners' context include the use of real-world applications and socio-scientific issues (George et al., 2021), sustainability-oriented socio-scientific issues (Gulacar et al., 2020); and project-based learning (Hugerat, 2020).

Table 5

Excerpts from the Group Discussion on the Students' Perceived Solution in Addressing the Difficulty in Accommodating Academic Responsibilities Online

Student	Comment
S24	*"Personally, in terms of the difficulty in accommodating academic responsibilities online, I am affected with procrastination, laziness and screen fatigue. It delays my tasks. I think we have to develop some sort of personal clock on better time management for oneself. I am encouraging personal development on ourselves, on our part."*
S26	*"I have a lot of insights about this actually. Starting from the extra-curricular activities and my goals in academics, I need to always consider the two. I need to learn to manage my time well whenever tasks are given in each role. With regards to excessive activities given by the teachers, I understand their motives, but I think teachers need to consider not only the bulk of activities being given in the individual subject but all the subjects. This should be planned well especially in terms of the deadlines."*
S33	*"Based on my experience, I actually improved on time management this school year. And I think the best solution that I did was to communicate with my teachers about my academic concerns. I also hope that teachers should also have this sense of communication with each other where they can give feedback about the learners."*
S36	*"I think rest is important. The idea of having Day 5 for consultation in our school is good. It is a way for us to take some rest after synchronous and asynchronous sessions. Being tired onscreen affects our performance in school. I remember during the third quarter where there were almost no Days 5, it was tiring. That extra day in a week can help us reset."*
S39	*"I procrastinate when I do not know how to start doing a particular task. I agree with S33 about open communication between students and teachers to clarify instructions and expectations…"*
S38	*"My problem lately is time management and overthinking. The root of my time management is lack of motivation and low self-esteem...I find it a lot harder this school year. I find myself getting insecure because others find it easier staying at home…As a way of fixing this problem is by having new habits, coping mechanisms…people should have personal development, self-discipline and having time for themselves as well..."*

Discussion 3: Difficulty in Accommodating Academic Responsibilities Online

Themes that emerge as primary causes of difficulty in accommodating academic responsibilities in online learning include lack of study habits, screen fatigue, distractions, time management, and lack of conducive learning space. To orient learners on how to accommodate academic responsibilities in online learning, the group affirmed the importance of personal development and reflection, clarity of the nature of performance tasks, and consistent feedback. The group unanimously agreed with S24 that learners need to become reflective on their responsibilities with the guidance of the school. To relay their concerns regarding their online engagement, maintaining open communication between the teachers and the students was perceived by S33. Like the main agenda of the second group discussion, some of the solutions nominated by the participants are associated with how academic requirements in the form of learning activities and performance tasks are being given. Performance tasks, which are the major requirement of the different subjects, must have clear instructions and expectations (S39) and a reasonable deadline of submission must be considered (S26). In addition, S36 affirmed the benefits of having the consultation day as part of the weekly schedule for them to take some rest free from academic-related stress. The excerpts of significant transcripts culled from the third group discussion are included in Table 5.

Discussion 4: Technical Challenges

In the last group discussion, participants affirmed the notion that problems with internet connectivity cannot be resolved instantly, and that is a given and common problem associated with online learning. However, the student participants suggested that teachers may also consider this learning dilemma when it comes to giving learning activities that require students to have a stable internet connection. S40 pointed out lesser bandwidth associated with performance tasks; more offline activities for S44, and consistent provision of the session recordings as emphasized by S42. For them, their experiences can still be optimized if the said aspects will be provided to support their learning. Similarly, recent studies on online learning during the pandemic explored other alternatives to solve students' problems on poor internet connection, including the use of social media (Perguna et al., 2021), and conversion of high-definition media and other large-size files into smaller ones (Octaberlina et al., 2020).The excerpts of significant transcripts culled from this discussion are included in Table 6.

Table 6

Excerpts from the Group Discussion on the Students' Perceived Solution in Addressing the Technical Challenges

Student	Comment
S40	*"For me, I honestly think that we can't do anything about this problem on internet connection since our medium is really online. But it would be better if subjects will give performance tasks that are doable but at the same time utilizes lesser bandwidth or use of internet connection."*
S44	*"I agree with S40 that we can't do anything with technical challenges on internet connectivity. I think more offline activities can be provided. Based on my experience, whenever teachers ask us to do something, it always allows us to stay longer in front of the screen."*
S42	*"For me, I noticed that not all subject teachers upload their class recordings. I wish it will become mandatory to upload class recordings. Another is when there are a series of scheduled long tests and other activities to be done, it becomes difficult if our internet connection is not that stable…"*

Comments from School's Policy Makers on Learners' Perceived Solutions

Using in vivo coding, the comments and suggestions of the stakeholders involved in policymaking were tallied in Table 7. The remarks given are classified as affirmations and suggestions.

Table 7

Anecdotes Coded from the Responses of the Invited School Stakeholders (N = 5)

Barriers	Affirmations	Comments/ Suggestions
Difficulty in Understanding the Concepts of the Subject Matter	• Provision of feedback and constructive criticisms (P1, P2) • Provision of fun-related and engaging learning material (P1, P2, P3) • Content chunking of lessons (P1, P2, P3)	• F1S1 - Provide feedback using sandwich method (P2) • F1S1 - Provision of personalized feedback (P3) • F1S2 - Finding out the rationale of the given outputs/ requirements (P2, P4)
Lack of Intrinsic Motivation Towards Online Learning	• Allow students to learn individually and collectively (P1, P2, P3) • Incorporating students' likes and interests (P2 and P3) • Employing various means to elicit reactions and participation (P2)	• F2S1- Engagement in meaningful dialogue and independent learning (P1) • F2S1 - Giving recitation that calls for practical applications (P2) • F2S1 - Teachers should not just ask-ask, but ask-do (P2) • F2S1 - Contextualization of the lessons (P1) • F2S1 - Incorporation of current events in the class (P2, P3) • F2S2 - Optimizing HRO sessions as communication opportunities (P1, P4) • F2S3 - Teacher himself or herself exhibits the needed level of energy in the OL class (P2) • F2S4 - Provision of repository of students' interest (P3) • F2S4 – Utilization of guidance data (P4) • F2S4 - Introduction of applications that students' find interesting (P2) • F2S5 – Provision of refresher webinar for faculty on latest online approaches (P4)
Difficulty in Accommodating Academic Responsibilities Online	• Learners' challenges in the online platform for learning (P1)	• F3S1 - Teachers' careful planning of expected outputs and submissions (P1, P4) • F3S1 – Maximize the use of Weekly Instructional Schedule (WIS) • F3S2 - Orientation to family members about their roles in assisting the learners (P2) • F3S2 - Building home-school collaboration program (P2, P4) • F3S3 - Communication with guidance counselor (P3, P4) • F3S4 - Teachers should identify students for consultation (P3, P4)
Technical Challenges	• Allowing learners to do some off-screen time (traditional pen-and-paper activities) (P2, P4)	• F4S1 - Developing modules (P1) • F4S1 - Provision of lessons in advance and consistent recordings of the lesson (P3, P4) • F4S2 - Setting up individual consultations to students with problems in connectivity (P1)

Note: F = factor, C = causes, S = perceived solutions

All concerns raised by the Grade 9 students were positively regarded and are considered essential in the improvement of the institutional practices in the context of online teaching and learning. In terms of the conceptual understanding of the students, the provision of feedback and rationalizing the content was given emphasis. To improve learners' intrinsic motivation, the stakeholders highlighted contextualization of the lessons, communication opportunities, teachers' modeling, profiling of learners' interest, and further professional development for teachers. In regulating students' academic workloads that result in difficulty in accommodating academic responsibilities, suggested actions are revisiting the monitoring of existing policies, the building of home-school collaboration, and maximizing consultation periods. Lastly, the provision of flexible and alternative learning materials is suggested to support learners who have problems with internet connectivity.

The items reflected in Table 7 provide opportunity for the policymakers to recalibrate the existing practices in online learning using the empirical evidence gathered from the voices of the learners. This may address some gaps and further improve the learning engagement of the students not only in chemistry, the context of this study, but also in other learning areas.

Conclusion

Aside from being used as a research method, the study considered photovoice as a pedagogical tool in terms of fostering dialogue with learners regarding how their learning experiences can be improved. Latz et al. (2016) and Harkness and Stallworth (2013) support this approach in an educational atmosphere and have shown the potential for photovoice to provide insights into students' experiences. As a form of reflective inquiry to both the teacher and the students, this photovoice study was able to capture and articulate the chemistry learning experiences of junior high school students and the barriers affecting their engagement in learning the subject on an online platform like what Tanhan and Strack (2020) explored as way of reaching out to participants' expression even in the virtual platform.

The factors drawn from the photovoice inquiry were capped into four themes, identified as (1) difficulty in understanding the nature of the subject matter; (2) lack of intrinsic motivation towards online learning; (3) difficulty in accommodating academic responsibilities in an online platform; and (4) technical challenges associated with online learning. Through participant-led discussion, the conduct of root cause analysis was able to bring out the perceived causes of their encountered barriers and solutions which they think are significant in studying the subject matter. Identified causes of their challenges range from the cognitive aspect of learning chemistry, personal disposition in approaching chemistry as a subject, and social aspect in dealing with the other factors that affect their online learning. In addition, the students' perceived solutions encompassed personal development based on the factors that they identified, consistency of the existing policies on online learning, and consideration of the provision of appropriate materials that can help and support them in their learning process. The challenges and opportunities outlined in this work supports the investigation done by Warne et al. (2013). The aforementioned themes transpired in the context of pandemic is also consistent to Malka (2021b)'s work in which the use of photovoice served as a coping tool among students.

Implication and Recommendations

Considering the findings drawn from this study, four implications can be deduced. First, this approach offers active participation among the learners by empowering them to be part of understanding a particular problem and extracting the solutions from their perspectives. Photovoice gives them a sense of value while highlighting the significant role that they have in the process of learning, especially for those who are unexpressive about their perceptions (Harkness & Stallworth, 2013). Second, this approach gives a new platform and style of communication between the teacher and the learners that gives a premium not only to verbal forms of responses, but in a different way on how students convey the meaning of their values and lived experiences, while at the same time leading the researcher to find solution to the identified problem (Lam et al., 2020). Third, as a participatory learning exercise, photovoice fosters socialization among learners by exchanging ideas and perspectives through the root cause analysis of the problem. Finally, the policy-making process in the field of education becomes participatory and consultative while considering the voices of the learners with regard to the impact of the existing policies on their learning experiences. This may further cascade into promoting changes (Malka, 2021b) in improving teachers' instructional practices, being more reflective, and offering direction to innovations.

Regarding further research, it can be recommended for future work to explore the utilization of the photovoice methodology on the aspect of the learners' attitude and efficacy in learning other disciplines. Responses to the limitations on this work can also be done as this is limited to the online learning experiences solely in the context of the school of the students. Since the exploration was done as part of the year-end reflection of the students and that the time allotted in immersing the participants in the protocols of photovoice is short, it can also be suggested to formalize the work in a much longer period. Finally, while this work documented the factors affecting learners' engagement in the online set-up, it is crucial to point out that these experiences are dependent on the context of the participants. Therefore, the insights gathered from the entire research procedure cannot be accounted as true and applicable to all students.

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References

Aguilera-Hermida, A. P. (2020). College students' use and acceptance of emergency online learning due to Covid-19. *International Journal of Educational Research Open, 1*, 100011. https://doi.org/10.1016/j.ijedro.2020.100011

Aristovnik, A., Keržič, D., Ravšelj, D., Tomaževič, N., & Umek, L. (2020). Impacts of the COVID-19 pandemic on life of higher education students: A global perspective. *Sustainability, 12*(20), 8438. https://doi.org/10.3390/su12208438

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educational Psychologist, 28*(2), 117-148. https://doi.org/10.1207/s15326985ep2802_3

Barmby, P., Kind, P. M. & Jones, K. (2008). Examining changing attitudes in secondary school science. *International Journal of Science Education, 30*(8), 1075–1093. https://doi.org/10.1080/09500690701344966

Behrendt, M., & Machtmes, K. (2016). Photovoice as an evaluation tool for student learning on a field trip. *Research in Science & Technological Education, 34*(2), 187-203. https://doi.org/10.1080/02635143.2015.1124410

Besser, A., Flett, G. L., & Zeigler-Hill, V. (2020). Adaptability to a sudden transition to online learning during the COVID-19 pandemic: Understanding the challenges for students. *Scholarship of Teaching and Learning in Psychology.* Advance online publication. https://doi.org/10.1037/stl0000198.

Broman, K., & Simon, S. (2015). Upper secondary school students choice and their ideas on how to improve chemistry education. *International Journal of Science and Mathematics Education, 13*(6), 1255-1278. http://dx.doi.org/10.1007/s10763-014-9550-0

Bunga, B. N., Adu, A. A., Damayanti, Y., Takalapeta, T., Pello, S. C., & Kiling, I. Y. (2021). Synchronous vs. Asynchronous: Photovoice study on Indonesian youth's online learning experience. *Child & Youth Services,* 1-14. https://doi.org/10.1080/0145935X.2021.1901572

Ciolan, L., & Manasia, L. (2017). Reframing photovoice to boost its potential for learning research. *International Journal of Qualitative Methods, 16*(1), 1-15. https://doi.org/10.1177/1609406917702909

Cook, K. (2015). Grappling with wicked problems: exploring photovoice as a decolonizing methodology in science education. *Cultural Studies of Science Education, 10*(3), 581–592. https://doi.org/10.1007/s11422-014-9613-0

Corno, L., & Mandinach, E. B. (2009). The role of cognitive engagement in classroom learning and motivation. *Educational Psychologist, 18*(2), 88-108. https://doi.org/10.1080/00461528309529266

Cuansing, J. (2018). An Action Research: Enhancing Learning in Undergraduate Introductory Course Physics Courses Using Photovoice. In Proceedings of the 4th International Conference on Education (Vol. 4, No. 2, pp. 68-75). http://tiikmpublishing.com/data/conferences/doi/icedu/24246700.2018.4209.pdf

Doyumğaç, İ., Tanhan, A., & Kiymaz, M. S. (2021). Understanding the most important facilitators and barriers for online education during COVID-19 through online photovoice methodology. *International Journal of Higher Education, 10*(1), 2021. https://doi.org/10.5430/ijhe.v10n1p166

Dumford, A. D., & Miller, A. L. (2018). Online learning in higher education: Exploring advantages and disadvantages for engagement. *Journal of Computing in Higher Education, 30*, 452–465. https://doi.org/10.1007/s12528-018-9179-z

Feldman, A. (2005). *Photovoice in science teacher education.* Paper presented at the North East Regional Meeting of the Association of Science Teacher Education.

George, A., Zowada, C., Eilks, I., & Gulacar, O. (2021). Exploring chemistry professors' methods of highlighting the relevancy of chemistry: Opportunities, obstacles, and suggestions to improve students' motivation in science classrooms. *Education Sciences, 11*(1), 13. https://doi.org/10.3390/educsci11010013

Gulacar, O., Zowada, C., Burke, S., Nabavizadeh, A., Bernardo, A., & Eilks, I. (2020). Integration of a sustainability-oriented socio-scientific issue into the general chemistry curriculum: Examining the effects on student motivation and self-efficacy. *Sustainable Chemistry and Pharmacy, 15,* 1-8. https://doi.org/10.1016/j.scp.2020.100232

Hampden-Thompson, G. & Bennett, J. (2013). Science teaching and learning activities and students' engagement in science. *International Journal of Science Education, 35*(8), 1323–1343. https://doi.org/10.1080/09500693.2011.608093

Harkness, S. S., & Stallworth, J. (2013). Photovoice: Understanding high school females' conceptions of mathematics and learning mathematics. *Educational Studies in Mathematics, 84*(3), 329–347. https://doi.org/10.1007/s10649-013-9485-3

Heath, S., & Shine, B. (2021). Teaching techniques to facilitate time management in remote and online teaching. *Journal of Teaching and Learning with Technology, 10*(1), 164-171. https://doi.org/10.14434/jotlt.v10i1.31370

Ho, W. C. , Rochelle, T. L. , & Yuen, W. K. (2011). 'We are not sad at all': Adolescents talk about their 'city of sadness' through photovoice. *Journal of Adolescent Research, 26*(6), 727–765. https://doi:10.1177/0743558410391255

Huang, J. (2020). Successes and challenges: Online teaching and learning of chemistry in higher education in China in the time of COVID-19. *Journal of Chemical Education, 97*(9), 2810-2814. https://doi.org/10.1021/acs.jchemed.0c00671

Hugerat, M. (2020). Incorporating sustainability into chemistry education by teaching through project-based learning. In S. O. Obare, C. H. Middlecamp, & K. E. Petterman (Eds.), *Chemistry education for a sustainable society volume 1: High school, outreach, & global perspectives* (pp. 79-96). American Chemical Society. https://doi.org/10.1021/bk-2020-1344.ch007

Kalman, R., Macias Esparza, M., & Weston, C. (2020). Student views of the online learning process during the COVID-19 Pandemic: A comparison of upper-level and entry-level undergraduate perspectives. *Journal of Chemical Education, 97*(9), 3353-3357. https://doi.org/10.1021/acs.jchemed.0c00712

Lam, G. Y. H., Holden, E., Fitzpatrick, M., Raffaele Mendez, L., & Berkman, K. (2020). "Different but connected": Participatory action research using photovoice to explore well-being in autistic young adults. *Autism, 24*(5), 1246-1259. https://doi.org/10.1177/1362361319898961

Lansangan, R.V. (2020). Teaching junior high school chemistry during the COVID-19 community quarantine season: Lessons, challenges, and opportunities. *KIMIKA, 31*(1), 20-37. https://doi.org/10.26534/kimika.v31i1.20-37

Latz, A. O., Phelps-Ward, R., Royer, D., & Peters, T. (2016). Photovoice as methodology, pedagogy, and partnership-building tool: A graduate and community college student collaboration. *Journal of Public Scholarship in Higher Education, 6,* 124–142. https://doi.org/10.1163/25902539-00201008

Leenknecht, M., Wijnia, L., Köhlen, M., Fryer, L., Rikers, R., & Loyens, S. (2021). Formative assessment as practice: the role of students' motivation. *Assessment & Evaluation in Higher Education, 46*(2), 236-255. https://doi.org/10.1080/02602938.2020.1765228

Liebenberg, L. (2018). Thinking critically about photovoice: Achieving empowerment and social change. *International Journal of Qualitative Methods, 17,* 1–9. https://doi:10.1177/1609406918757631

Lim, K. F. (2019). Education: A picture is worth a thousand words. *Chemistry in Australia,* 34. http://chemaust.raci.org.au/article/marchapril-2019/picture-worth-thousand-words.html

Lofton, S., & Grant, A. K. (2020). Outcomes and intentionality of action planning in photovoice: a literature review. *Health Promotion Practice*, 22(3), 318-337. https://doi:10.1177/1524839920957427

Malka, M. (2021a). Real-time lived experience of social work students in their field training during the coronavirus crisis: Insights from photovoice-based research. *The British Journal of Social Work*, *52*(1), 311-333. https://doi.org/10.1093/bjsw/bcaa240

Malka, M. (2021b). Photovoice as a creative coping tool with the COVID-19 crisis in practical training seminar for social work students. *Qualitative Social Work, 20*(1-2), 544-552. https://doi.org/10.1177/1473325020973309

Malka, M. (2020). Photo-voices from the classroom: Photovoice as a creative learning methodology in social work education. *Social Work Education,* 41(1), 4-20. https://doi.org/10.1080/02615479.2020.1789091

Martinez, J. (2020). Take this pandemic moment to improve education. EduSource. https://edsource.org/2020/take-this-pandemic-moment-to-improve-education/633500

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81-97.

Miltiadous, A., Callahan, D. L., & Schultz, M. (2020). Exploring engagement as a predictor of success in the transition to online learning in first year chemistry. *Journal of Chemical Education, 97*(9), 2494-2501. https://doi.org/10.1021/acs.jchemed.0c00794

Mishra, L., Gupta, T., & Shree, A. (2020). Online teaching-learning in higher education during lockdown period of COVID-19 pandemic. *International Journal of Educational Research Open, 1*. https://doi.org/10.1016/j.ijedro.2020.100012

Mourlam, D. J., DeCino, D. A., Newland, L. A., & Strouse, G. A. (2020). "It's fun!" Using students' voices to understand the impact of school digital technology integration on their well-being. *Computers & Education, 159,* 1-11. https://doi.org/10.1016/j.compedu.2020.104003

Octaberlina, L. R., & Muslimin, A. I. (2020). EFL students perspective towards online learning barriers and alternatives using moodle/google classroom during covid-19 pandemic. *International Journal of Higher Education, 9*(6), 1-9. https://doi.org/10.5430/ijhe.v9n6p1

Perguna, L. A., Apriyanti, N., & Kurniasih, D. (2021). Alternative online learning using social media as a panacea. *International Journal of Emerging Technologies in Learning, 16*(7), 257-264. https://doi.org/10.3991/ijet.v16i07.21209

Priniski, S. J., Hecht, C. A., & Harackiewicz, J. M. (2018). Making learning personally meaningful: A new framework for relevance research. *The Journal of Experimental Education, 86*(1), 11-29. https://doi.org/10.1080/00220973.2017.1380589

Raza, M. H., Khatri, N., Intikhab, S., & Iqbal, R. (2021). The new normal in urban Pakistan: A journey of undergraduate students through photovoice. *Journal for Undergraduate Ethnography, 11*(1), 108-131. https://doi.org/10.15273/jue.v11i1.10870

Singh, S., Roy, D., Sinha, K., Parveen, C., Sharma, G., & Joshi, G. (2020). Impact of COVID-19 and lockdown on mental health of children and adolescents: A narrative review with recommendations. *Psychiatry Research, 293*, 1-10. https://doi.org/10.1016/j.psychres.2020.113429

Soares, R., De Mello, M. C. S., Da Silva, C. M., Machado, W., & Arbilla, G. (2020). Online chemistry education challenges for Rio de Janeiro students during the COVID-19 pandemic. *Journal of Chemical Education, 97*(9), 3396-3399. https://doi.org/10.1021/acs.jchemed.0c00775

Stroud, M. (2014). Photovoice as a pedagogical tool: Student engagement in undergraduate introductory chemistry for nonscience majors. *Journal of College Science Teaching, 43*(5), 98-107.

Suffla, S. , Kaminer, D. , & Bawa, U. (2012). Photovoice as community engaged research: The interplay between knowledge creation and agency in a South African study on safety promotion. *Journal of Psychology in Africa, 22*(4), 517–528. https://doi.org/10.1080/14330237.2012.10820563

Sutton-Brown, C. (2014). Photovoice: A methodological guide. *Photography & Culture, 7,* 169–186. https://doi.org/10.2752/175145214X13999922103165

Starkey, L. (2020). A review of research exploring teacher preparation for the digital age. *Cambridge Journal of Education, 50*(1), 37–50. https://doi.org/10.1080/0305764X.2019.1625867

Sun, J. C.-Y., & Rueda, R. (2012). Situational interest, computer self-efficacy and self regulation: Their impact on student engagement in distance education. *British Journal of Educational Technology, 43*(2), 191–204. https://doi.org/10.1111/j.1467-8535.2010.01157.x

Sunasee, R. (2020). Challenges of teaching organic chemistry during COVID-19 pandemic at a primarily undergraduate institution. *Journal of Chemical Education, 97*(9), 3176-3181. https://doi.org/10.1021/acs.jchemed.0c00542

Tan, H. R., Chng, W. H., Chonardo, C., Ng, M. T. T., & Fung, F. M. (2020). How chemists achieve active learning online during the COVID-19 pandemic: Using the community of inquiry (CoI) framework to support remote teaching. *Journal of Chemical Education, 97*(9), 2512-2518. https://doi.org/10.1021/acs.jchemed.0c00541

Tanhan, A. (2020). COVID-19 sürecinde online seslifoto (OSF) yöntemiyle biyopsikososyal manevi ve ekonomik meseleleri ve genel iyi oluş düzeyini ele almak: OSF'nin Türkçeye uyarlanması. [Utilizing online photovoice (OPV) methodology to address biopsychosocial spiritual economic issues and wellbeing during COVID-19: Adapting OPV to Turkish.] *Turkish Studies, 15*(4), 1029-1086. https://doi.org/10.7827/TurkishStudies.44451

Tigaa, R. A., & Sonawane, S. L. (2020). An international perspective: teaching chemistry and engaging students during the COVID-19 pandemic. *Journal of Chemical Education, 97*(9), 3318-3321. https://doi.org/10.1021/acs.jchemed.0c00554

Toquero, C. M. D. (2020). Emergency remote teaching amid COVID-19: The turning point. *Asian Journal of Distance Education, 15*(1), 185-188. https://doi.org/10.46661/ijeri.5113

Tsang, K. K. (2020). Photovoice data analysis: Critical approach, phenomenological approach, and beyond. *Beijing International Review of Education, 2*(1), 136-152. https://doi.org/10.1163/25902539-00201009

UNESCO. (2020). Education: From disruption to recovery UNESCO. https://en.unesco.org/covid19/educationresponse

Wang, C., & Burris, M. A. (1997). Photovoice: Concept, methodology, and use for participatory needs assessment. *Health, Education & Behavior, 24*(3), 369–387. https://doi.org/10.1177/109019819702400309

Warne, M., Snyder, K., & G. Gådin, K. (2013). Photovoice: An opportunity and challenge for students' genuine participation. *Health Promotion International, 28*(3), 299–310. https://doi.org/10.1093/heapro/das011

Yang C, Chen A, & Chen Y (2021) College students' stress and health in the COVID-19 pandemic: The role of academic workload, separation from school, and fears of contagion. *PLoS ONE 16*(2), e0246676. https://doi.org/10.1371/journal.pone.0246676

Yuriev, E., Naidu, S., Schembri, L. S., & Short, J. L. (2017). Scaffolding the development of problem-solving skills in chemistry: Guiding novice students out of dead ends and false starts. *Chemistry Education Research and Practice, 18*(3), 486-504. http://doi.org/10.1039/C7RP00009J

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Science Teachers' Self-Efficacy Perceptions on Acid-Base Subject Related to Daily Life in a Science Course

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ABSTRACT

The study aims to investigate the level of science teachers' self-efficacy perceptions on the topic of acid-base chemistry in terms of some variables (gender, the place where the teacher works, and the frequency of using the science laboratory). In this study, a survey method was used, and the sample of the study consists of 138 science teachers. 'Acid-Base Self-Efficacy Perception Scale (ABSPS)', a five-point Likert type, was used as a data gathering tool. The validity and reliability of the ABSPS were calculated for the data obtained from the science teachers in this study. Descriptive and inferential statistics were carried out in examining the data obtained in this research. Results of the study showed that according to mean scores on items, it can be said that the acid-base self-efficacy perception of science teachers is generally at a high level. Also, results show that there was no significant difference in science teachers' self-efficacy perceptions on the topic of acid-base chemistry in terms of gender and the place where the teacher works. On the other hand, it was determined that the teachers had a positive correlation between the frequency of using science laboratories and the acid-base self-efficacy perception level.

Keywords: acid-base, daily life, self-efficacy perception, science teachers, science laboratory

Introduction

The self-efficacy perception is one of the concepts mentioned in the 'Social Learning Theory' belonging to Bandura (1977), who expresses that individuals acquiring behavior are affected by external and internal factors. The self-efficacy perception, different from the inabilities and abilities of individuals, can be defined as the belief regarding whether the individual can deal with any matter (Bandura, 1977). The self-efficacy perception has an impact on a person's approach, behavior, and effort towards events and circumstances (Lee, 2003). Patterson (2011) explains that individuals with a high self-efficacy perception are more successful since they believe deeply in their ability to fulfill the requirements of work. In this context, self-efficacy perception at a low level may complicate dealing with the problems for people (Bussey & Bandura, 1999).

In the study by Bandura (1997), it was stated that the self-efficacy belief has four sources. These are direct experiences, indirect experiences, verbal persuasion, and emotional state. Direct experiences mean an individual's assessment of his/her own behaviors' results, and are the most effective factor on the self-efficacy perception (Bandura, 1997). Vicarious experiences are a type of learning through modelling oneself on the surrounding people (Bandura, 1997; Pajares, 1996). Verbal persuasion refers to the impact of the surrounding people's comments on an individual's motivation in doing a job (Bandura, 1997; Golightly, 2007). If an individual is persuaded by verbal comments of others about that person's deficiency in some abilities, that individual stays away from expending effort because of the decrease in his/her self-efficacy perception (Bandura, 1994).

Finally, being anxious and stressed, in the context of individuals' emotional state, influences the self-perception manner, and this creates negative effects on coping with a problem (Lewis, 2006). Bandura (1977) analyses the self-efficacy perception as "personal efficacy" and "outcome expectation". Personal efficacy is the belief in one's own abilities regarding the encountered problems, while outcome expectation expresses the beliefs and perceptions about the coping capability before encountering a problem (Ozenoglu Kiremit, 2006).

The literature on self-efficacy shows that research exists to investigate the self-efficacy of teachers (Azar, 2010; O'leary, 2005; Ustuner et al., 2009). Tschannen- Moran et al. (1998) define the self-efficacy of teachers as teachers' belief and judgement on their capability to fulfill professional requirements. In other words, the self-efficacy perception of teachers is their individual judgement on their ability to influence the learning process (Tschannen-Moran & Woolfolk-Hoy, 2001). Several studies have emphasized that the self-efficacy perception of teachers has an impact on the teaching-learning process and the students' development (Miller et al., 2017; Tschannen-Moran et al., 1998; Uzuntiryaki & Aydın, 2009). As the self-efficacy perception of teachers rises, the probability of coping with failures increases (Goddard et al., 2004).

In the literature, the studies on self-efficacy are conducted in the fields of science teaching self-efficacy, perceived self-efficacy and academic self-efficacy (Adetoro et al., 2010; Niehaus et al., 2012). The science teaching self-efficacy belief can be explained as the opinions regarding the abilities to teach science in an effective and efficient way (Dede et al., 2017). Bandura (1977) explained that academic self-efficacy was "personal judgments of one‘s capabilities to organize and execute courses of action to attain designated types of educational performances" (p. 203). Also, Pintrich and Schunk (1996) maintained that academic self-efficacy is a strong predictor of academic performance. In this aspect, perceived self-efficacy according to Bandura (1994) is "concerned with people‘s beliefs in their capabilities to exercise control over their own functioning and over events that affect their lives" (p. 13).

The concepts of self-efficacy perception and self-esteem are frequently confused. Pajares and Schunk (2001) referred that the self-efficacy perception is related to a particular field, to explain the basic difference between those two concepts. The self-efficacy perception of teachers may differ depending on their field (Bandura, 1986). High or low self-efficacy perception is related to an individual's self-perception level in terms of efficacy rather than an individual's efficacy or inefficacy in a specific field. Thus, an individual's self-efficacy perception is not the same for all domains. An individual with a high self-efficacy perception on a specific issue may have a low self-efficacy perception in another one. Therefore, the concept of self-efficacy perception is far from generalizability.

Teachers not only provide instruction on science/chemistry concepts but also provide education. They are responsible for the development of their students in the affective field. In this respect, teachers themselves are expected to have competencies in the affective field. Teachers need to have high self-efficacy beliefs.

Science Teaching Efficacy Belief Instrument (STEBI) developed by Riggs and Enochs (1990) is one of the first measurement tools that reveal self-efficacy beliefs about science e-teaching and learning. Studies on self-efficacy about science are generally studies on a lesson/course or teacher/teaching field (Chemistry, biology, etc.). Studies have been carried out in the fields of self-efficacy in teaching science (Ilhan et al., 2015), chemistry self-efficacy (Uzuntiryaki & Çapa-Aydin, 2009), and biology self-efficacy (Baldwin et al., 1999). However, no scales and survey studies have been found, taking into account science/chemistry subjects and concepts. The present study is important in this respect.

Some subjects/concepts in Science/Chemistry courses include activities, such as laboratory experiments and theoretical information, and the lessons are taught according to these contents. In this case, it is thought that self-efficacy beliefs may change in terms of subjects and concepts. In this respect, it is important to measure self-efficacy beliefs by considering science/chemistry subjects and concepts. Teachers can spend more time on some topics and prefer participating in the activities corresponding to the field they consider themselves to be efficient, according to their self-efficacy perception. Laboratory use has an important place in science education in terms of learning and teaching (Hofstein, 2017; Hofstein & Kind, 2012; Uzuntiryaki & Aydın, 2006). Many studies emphasize the relationship between science laboratory activities and self-efficacy belief (Alkan, 2016; Lee et al., 2019; Uzuntiryaki & Aydın, 2006). In the current study the relationship between the frequency of using the science laboratory by teachers, and their perception of self-efficacy belief, is considered to be an important issue to be investigated.

In recent years, the number of studies determining the self-efficacy perception of teachers and candidate teachers reveal that how self-efficacy perceptions changes concerning certain demographic variables rises (Gercek et al., 2006; Ilhan et al., 2015; Ozdemir, 2008; Saracaloglu & Yenice, 2009). In addition, multiple studies are discovering that self-efficacy perception is affected by some demographic variables (Calıskan et al., 2010; Yalcın, 2011). O'leary (2005) found that the science self-efficacy perception of female teachers was significantly lower than that of male teachers. Cetin (2008) investigated that the science teaching self-efficacy belief of students does not differentiate concerning the gender variable. This situation shows us that science teaching self-efficacy perception can also change according to the cultural contexts or course and subjects. In this respect, it is important to measure the acid-base self-efficacy perception in the present study. Moreover, teachers' working in City center/District center/Village/Rural area and regional differences, their school facilities, and use of course materials may affect their participation in seminars. For these reasons, considering that this situation may also affect science teaching self-efficacy perception, the location of the school is considered as a variable in this study. Teachers' self-efficacy perceptions can change with their teaching experience years by considering Bandura's (1997) theory about their direct experiences as a source of self-efficacy perception. Therefore, in this study, years of teaching experience was also considered as a variable in the current study.

Although certain studies investigate self-efficacy in terms of a specific field, such as science teaching self-efficacy perception (Azar, 2010; Dede et al., 2017; Denizoglu, 2008; Morgil et al., 2004), no study examining the self-efficacy perception in terms of the acid-based topic is found for the teacher. Science teaching self-efficacy belief determined according to certain subjects of science/chemistry; years of teaching experience, gender, teachers use of the laboratory, and location of the school, will contribute to the field. In this respect, it is important to carry out the present study.

The current study investigates the level of self-efficacy perception of science teachers on the topic of acid-base in chemistry. The reason to choose the topic of acid-base for the research is the inability to connect adequately this topic with daily life despite its close connection with the latter (Ayas & Ozmen, 1998; Yildiz et al., 2006), and the existence of misconceptions about this topic (Ozmen & Demircioglu, 2003; Rahayu et al., 2011). Although there are various studies on teaching the topic of acid-base chemistry (Cetin Dindar, 2012; Ozeken & Yildirim, 2011), none of those studies reveals the self-efficacy perception.

Aim

The present study aims to analyze the self-efficacy perception level of science teachers in teaching the topic of acid-base chemistry with certain variables. In this context, the self-efficacy perception of teachers is examined according to gender, the location of the school (city, district, and village) and the frequency of using science laboratories.

Based on these aims, the research questions of the present study investigated the following:

1) What is the self-efficacy perception level of science teachers in teaching the topic of acid-base chemistry?
2) Are there any significant differences in the acid-base self-efficacy perceptions of science teachers about the gender variable and the location of the school (city, district, and village)?
3) Is science teachers' acid-base self-efficacy perception level correlated to the frequency of using the science laboratory by teachers?

Methods

This research was conducted by the survey method which is used for gathering data from mass groups and presenting the data (Buyukozturk, 2012; Gravetter & Wallnau, 2016). The reason for using the survey method is because of the aim and research questions of the study required comparative data and correlations.

Sample and Data Collection

The study sample consists of a total of 138 science teachers, 78 of which are female and 60 are male, who worked in public schools in the fall term of the 2015-2016 academic year and were voluntarily involved in the research. Some demographic attributes of the participating teachers and certain information about the schools the teachers work in are identified through the demographic information form the teachers are asked to fill. The teachers involved in the study work in secondary schools and teach science lessons (subjects of physics, chemistry and biology) at the 5th, 6th, 7th and 8th grade levels. The demographic information about the sample is presented in Table 1. 56.52% of teachers (78 teachers) comprising the sample were female, 43.48% (60) were male. Of the teachers, 44.20% (61 teachers) work in the city center, 40.58% (56 teachers) in district, and 15.22% (21 teachers) in village/rural area. In Gaziantep and Kilis, the majority of the population lives in the city center of the province and a very small part in the villages. The population was taken into account in data collection.

Table 1

Demographic Characteristics of the Sample

Gender		n	%
	Female	78	56.52
	Male	60	43.48
	Total	138	100
Location of School		n	%
	City center	61	44.20
	District center	56	40.58
	Village/Rural area	21	15.22
	Total	138	100
Teacher' years of teaching experience		n	%
	1-5 Year	97	70.29
	6-10 Year	21	15.22
	11-15 Year	17	12.32
	16-20 Year	3	2.17
	Total	138	100

"Acid-Base Self-Efficacy Perception Scale (ABSPS)" was applied to teachers by either contacting one-to-one (79 teachers) or through an online survey by Google Form (59 teachers). The data collected through one-to-one contact were obtained from the teachers working in Gaziantep province (40) and Kilis province (39) from Turkey. The researchers of the present study went to the middle schools to administer the scale to the teachers. Also, data gathered by online contact was taken from 59 teachers working in cities. Convenience sampling was used to collect data and sample the138 science teachers working in City center/District center/Village school in Turkey. Gaziantep and Kilis are two provinces in the south of Turkey. Due to the fact that the second author is a researcher in the Kilis province, data were gathered from Gaziantep and Kilis. The researchers of the present study went to the schools to administer the scale, gather the demographics information from teachers, and collect the data. Participants have been informed that their data will be collected for scientific research purposes only and evaluated anonymously.

Data Gathering Tool

The research data was obtained through 'Acid-Base Self-Efficacy Perception Scale (ABSPS). For this study, the reliability and validity procedures of ABSPS were developed by Ilhan and Cicek (2017). ABSPS is comprised of 14 items with a five-point Likert type (strongly disagree, disagree, neutral, agree, and strongly agree). ABSPS consists of two dimensions entitled "Relating to Daily Life" and "Knowledge on topic and scientific explanation". In the current study, the reliability and validity of the scale were examined again for science teachers. The present study is aimed at determining the science teachers' perception of self-efficacy related to acid-base subjects of science/chemistry. In this respect, the scale used in this study was developed for the study.

Reliability and Validity for Data and Scale

In a previous study, ABSPS developed by Ilhan and Cicek (2017) was used with preservice teachers. In this study, the reliability and validity of the data obtained from the science teachers was assessed. For all of the data in this research (from 138 science teachers), the Cronbach's Alpha reliability coefficient is calculated as 0.827 in the data for all of the items of ABSPS. In addition, the Cronbach's Alpha reliability coefficient is calculated as 0.672 for the sub-dimension of 'Relating to daily life' and 0.742 for the sub-dimension of 'Knowledge on topic and scientific explanation'.

To assess the reliability of data in this study, differences between mean values of data obtained by the researchers by contacting one-to-one and online contact were investigated. Independent samples t-test, used to test differences between mean, showed that a significant difference was not found between the two groups of data ($t(136) = -0.587$, $p>.05$). Thus, the data gathered online was accepted as reliable and is analyzed after being combined with other data.

Confirmatory Factor Analysis (CFA) for Data and Scale

Confirmatory factor analyses for validity were carried out. CFA is a method used for determining the goodness of fit for the model (Tabachnick & Fidell, 2001). In the data of this research, the CFA was performed by the program of Lisrel 8.7 (Linear Structural Relation Statistics Package Program, Joreskog & Sorbom, 2001). CFA results are displayed in Table 2.

In this study, among the most frequently used fit indexes within CFA, root mean square error of approximation (RMSEA), root mean square residual (RMR), standardized root mean square residual (SRMR), the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), normed fit index (NFI), comparative fit index (CFI) are considered (Joreskog & Sorbom, 2001).

Table 2

Index Values of the Fit Statistics

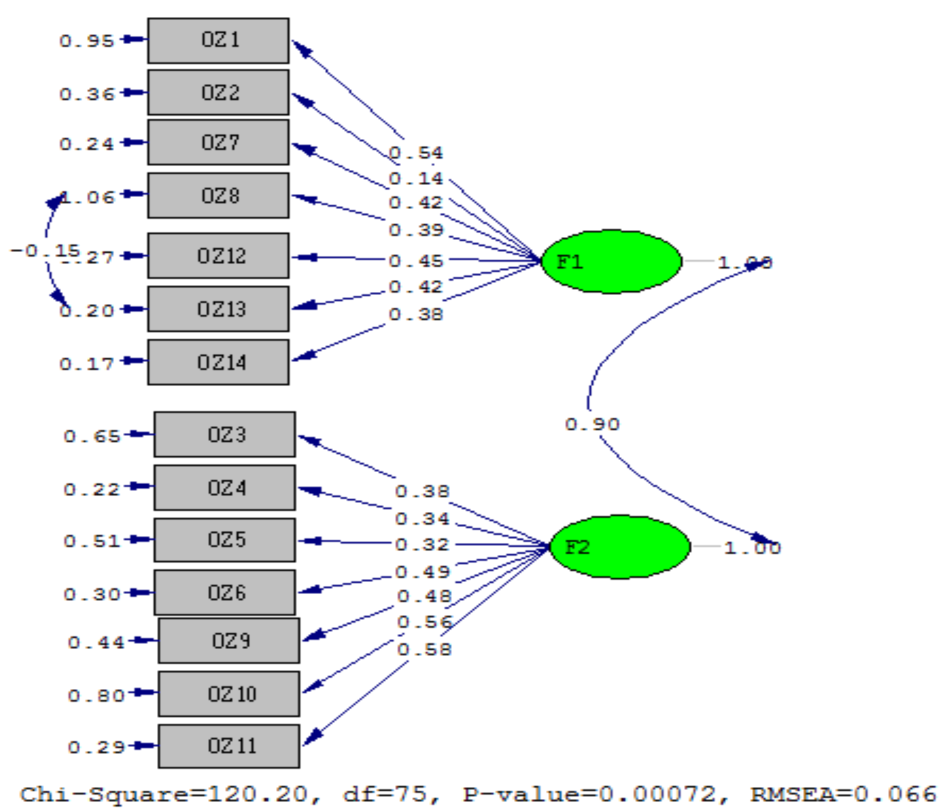
X2	X2\ df	RMSEA	RMR	SRMR	GFI	AGFI	NFI	CFI
120.2	1.60	0.066	0.047	0.064	0.89	0.84	0.90	0.96

As it is shown in Table 2, the value acquired through dividing the chi-square value (120.20) by the degrees of freedom (75) is 1.60. Kline (2005) accepts that a value below 3 is a perfect fit. The value found by this research indicates the perfect fit.

It can be claimed that all the values of RMSEA (0.066), RMR (0.047), SRMR (0.064), GFI (0.89), AGFI (0.84), NFI (0.90), CFI (0.96), among the goodness of fit indexes, for Acid-Base Self-Efficacy Perception Scale are at an acceptable level. The Path Diagram of confirmatory factor analysis for ABSPS is shown in Figure 1.

Figure 1

Path Diagram of CFA for ABSPS



Data Analysis

Statistical data analysis methods were chosen by the purpose and research questions of the present study. The descriptive statistical calculations were carried out in examining the data obtained in this research to detect the variables' distribution according to the sample attributes. For the analysis of the data for mean scores, independent sample t-test and one way variance analysis were used. Correlation analyses were used to describe the relationships between variables. Independent sample t-test was used in analyzing the acid-base self-efficacy perception of science teachers concerning the gender variable. For its examination concerning the location of school (city, district, village), one way variance analysis (ANOVA) is employed. The correlation analysis was used for examining the relationship between the acid-base self-efficacy perception of science teachers and the frequency of using science laboratories. The data analysis was carried out by using the SPSS statistical program.

Findings

The descriptive statistical values of total scores for the data obtained with ABSPS are given in Table 3. The minimum score is 44 and the maximum is 70. Furthermore, the average score was 60.09, standard deviation was 6.27, kurtosis coefficient was -.37, and skewness coefficient was -0.35. The fact that these values and the kurtosis-skewness coefficient are within -1/+1, indicates that the values have a normal distribution (Buyukozturk, 2012).

Table 3

Descriptive Statistics for Data Gathered with ABSPS

***N*=138**	**Value**
Mean	60.09
Standard Deviation	6.27
Skewness	-.35
Kurtosis	-.37
Range	26
Minimum	44
Maximum	70

Within the data obtained in this research, according to the teaching expressions of science teachers, the mean (M) of items in the ABSPS range between 3.76 and 4.77. For the scale items of ABSPS, the mean of items and standard deviation values are displayed in Table 4. The items on which the teachers have the highest self-efficacy perception are Item two 'I can make interpretation on the acidic/basic substance for consumer products used in daily life (soap, shampoo, wet towel, cosmetics etc.) according to pH values on packages' (*M*=4.77), Item 14 'I can classify the substances I encountered in daily life to their acidic or basic features' (M=4.61). Those on which teachers have the lowest, are Item 8 'I can explain the correlation between temperature and the acidity of coke' (*M*=3.76), and Item 11 'I feel self-efficacious in scientific discussions related to acid-base substances' (*M*=3.86).

Mean scores of acid-base self-efficacy perception level of both male and female teachers in Table 5 show that female teachers' mean score (*M*=60.50, *Sd*= 6.34) is higher than that of male teachers (M=59.57, Sd= 6.20). However, no significant difference was observed between the acid-base self-efficacy perceptions of science teachers about the gender variable (t(138)= .866, p>.05).

As it is observed in Table 6, the mean score of teachers working in villages, among the teachers comprising the sample, on the acid-base self-efficacy perception (*M*= 61.29, *Sd*= 6.78) is higher than those of teachers working in cities (*M*= 60.64, *Sd*= 5.81) and of teachers working in districts (*M*= 59.05, *Sd*= 6.52).

Table 4

Descriptive Statistics for Items in ABSPS

		Items	*M*	*Sd*	Reliability
Relating to Daily Life	1	I can determine whether the solution formed by the interaction of water with the substances such as Carbon dioxide (CO2), Ammoniac (NH3) is acidic or basic.	4.06	1.12	0.672
	2	I can make interpretations on the acidic/basic substance for consumer products used in daily life (soap, shampoo, wet towel, cosmetics etc.) according to pH values on packages	4.77	0.62	
	7	I can apply the precaution required for safety and health while using acidic and basic substances (bleach, drain opener).	4.51	0.64	
	8	I can explain the correlation between temperature and the acidity of coke.	3.76	1.10	
	12	I can use in daily life my knowledge about the topic of acid-base I learned at school.	4.40	0.69	
	13	I know the storage conditions of the acid-base substances I encountered in daily life (hydrochloric acid, vinegar, bleach).	4.49	0.62	
	14	I can classify the substances I encountered in daily life to their acidic or basic features.	4.61	0.56	
Knowledge on topic and scientific explanation	3	I can explain the features of chemical substances used in order to remove the calcification of kitchen tools and rust on metal wares.	4.20	0.89	0.742
	4	I have enough knowledge about the features of acid-base substances.	4.51	0.58	
	5	I can scientifically explain the reason for color change appearing when red cabbage juice is dripped over lemon, vinegar, tooth paste, and carbonate.	4.47	0.78	
	6	I can scientifically explain how the stomach and teeth are damaged by acidic food and drink.	4.43	0.73	
	9	I can explain the essential use areas of acidic and basic substances in the industry (food, water purification, petrol).	3.99	0.81	
	10	I know how to conduct an experiment in the laboratory for measuring the pH values of an aqueous solution of salt.	4.00	1.05	
	11	I feel efficacious in scientific discussions related to acid base substances.	3.86	0.79	
		Total	4.29	0.45	0.827

Table 5

Self-efficacy Perception According to Gender Variable

Gender	N	M	Sd	Df	T	P
Female	78	60.50	6.34	136	.866	.566
Male	60	59.57	6.20			

Table 6

Science Teachers' Acid-base Self-efficacy Perception According to Location of School

Location of School	N	M	Sd
City center	61	60.64	5.81
District center	56	59.05	6.52
Village/Rural	21	61.29	6.78
Total	138	60.09	6.27

The results of a one-way ANOVA performed to determine whether the differences between the mean scores of science teachers on acid-base self-efficacy perception were significant about the place of schools are shown in Table 7.

Table 7

One-way ANOVA Test Results According to Location of School

Source	Sum of square	Df	Mean square	*F*	*p*
Between groups	108.585	2	54.292	1.388	.253
Within groups	5279.191	135	39.105		
Total	5387.775	137			

The assessment of Table 7 reveals that there is no significant difference between the acid-base self-efficacy perception of science teachers concerning the place of schools (city, district, village) ($F(2\text{-}135) = 1.388$, $p>.05$).

The teachers are asked to determine their frequency of using the laboratory weekly during science classes within one academic year by assigning it a grade between 1 (I quite rarely use it) and 5 (I always use it). Of the teachers, 6.52% (9 teachers) express that they quite rarely use it, 13.04% (18 teachers) that they always use it, and 27.54% (38 teachers) that they never use it (see Table 8).

Table 8

The Frequency With Which the Teachers Use the Weekly Laboratory

Using the weekly laboratory	Frequency (f)	%
1	9	6.52
2	18	13.04
3	31	22.46
4	24	17.40
5	18	13.04
Not using	38	27.54
Total	138	100

Also, it can be observed in Table 9 that there is a positive significant correlation between the frequency of using the science laboratory by teachers and their acid-base self-efficacy perception level ($r = .364$, $p<.01$).

Table 9

Correlation between the Frequency of Using the Laboratory and Self-efficacy Perception

Variables	1	2
Frequency of using laboratory	-	.364**
Self-efficacy perception	.364**	-

Note. N=138. **p<0.01. **Correlation is significant at the.01 level (two-tailed).

Results and Discussion

This study investigated the acid-base self-efficacy perception of science teachers about gender, the place of school (city, district, village), and the frequency of using the science laboratory. Within the framework of the study, the data was collected through the ABSPS. The validity and reliability of the ABSPS was calculated for the data obtained from the science teachers in this study. Also, the value of Cronbach's Alpha reliability coefficient of the ABSPS demonstrated the reliability. The results of confirmatory factor analysis show that the ABSPS has two dimensions ('Relating to Daily Life' and 'Knowledge on topic and scientific explanation'). These findings acquired from the reliability and validity analyses for science teachers are in congruence with the findings of the scale developed for preservice teachers (Ilhan & Cicek, 2017).

The mean scores were calculated for each item on the ABSPS within the study. The examination of mean scores on items shows that the mean score of teachers on the acid-base self-efficacy perception range is between 3.76 and 4.77, and the overall mean of items is 4.29. According to these scores, it can be said that the acid-base self-efficacy perception of science teachers is generally at a high level. In the study made on the acid-base self-efficacy perception of preservice science teachers by Ilhan & Cicek (2017), it was detected that the mean scores on the items of ABSPS differentiate between 3.28 and 4.14. The comparison of the present study to the study of Ilhan & Cicek (2017) may lead that the acid-base self-efficacy level of teachers is higher than that of preservice teachers. This state may be connected with the fact that teachers are more experienced than the preservice teachers, by considering Bandura's (1997) theory about the direct experiences as a source of self-efficacy perception.

The results of this study reveal that the mean score of female science teachers on the acid-base self-efficacy perception is higher than that of male teachers. However, no significant difference was found between the average scores of teachers on the acid-base self-efficacy perception concerning the gender variable. So, it can be concluded that the gender variable is not influential on the acid-base self-efficacy perception of teachers.

In the study made by Ilhan and Cicek (2017), it was revealed that levels of self-efficacy perceptions on the acid-base topics of the female pre-service science teachers were significantly higher than the male pre-service science teachers. In terms of levels of self-efficacy perceptions, it differs between the results of this study, conducted with science teachers and the results of the study conducted by Ilhan and Cicek (2017) with pre-service science teachers. O'leary (2005) examined the science self-efficacy perception level of science teachers about the gender variable and found that the science self-efficacy perception of female teachers was significantly lower than that of male teachers. Smist (1993) revealed that females have a lower self-efficacy perception on the experimental studies about general chemistry than males, according to the data obtained from the working group aged 17-48. Cetin (2008) investigated that the science teaching self-efficacy belief of students in the department of teaching does not differentiate concerning the gender variable in terms of the aspects of personal science teaching and outcome expectation in science teaching. While certain studies found a difference in terms of the science teaching self-efficacy perception, others did not. This situation shows that science teaching self-efficacy perception can also change according to the cultural contexts or course and subjects. It can be said that measuring the perception of self-efficacy according to the course and subjects is important in this respect. Since no other studies investigating the self-efficacy perceptions of the subject concepts of science/chemistry exist, such discussions have not been given much consideration. In this respect, it is important to measure the acid-base self-efficacy perception in the present study. It is considered that measuring the self-efficacy perception in similar chemistry topics would contribute to the literature.

As the mean scores on the acid-base self-efficacy perception level of science teachers working in a city, district or village are examined, it was found that the mean score of teachers working in a village is higher than that of teachers working in a city or district according to the results of the study. This finding shows that the place of school (city, district, and village) is not a determinant for the acid-base self-efficacy perception of science teachers.

Furthermore, it was identified that there is a significant positive but weak correlation between the frequency of using science laboratories and the acid-base self-efficacy perception of science teachers. After starting their professional life, teachers make lessons on acid-base chemistry in a laboratory and their experiments enhance the learning experience. The direct experiences about acid-base chemistry, provided in these ways, may have a positive impact on the self-efficacy perception of teachers.

Many studies emphasize that science methods courses improve pre-service teachers' science teaching self-efficacy (Menon, 2020; Naidoo & Naidoo, 2021). These courses can be taught as optional or compulsory courses in teacher education programs. It is important to examine the effects of science teaching methods courses that will prepare science teachers and teacher candidates by arranging them in relation to science subjects (such as acid-base).

In the present study, the relationship between using the laboratory and science teaching self-efficacy perception were revealed. Although the relationship between laboratory use and self-sufficiency is emphasized in the literature (Alkan, 2016; Lee et al., 2019; Uzuntiryaki & Aydın, 2006), studies that reveal the relationship have not been found. In this respect, new results that contribute to the field have been revealed. When evaluated from the point of view of teachers, this discloses the importance of enriching the courses and their contents for the use of laboratories in science teacher preparation programs.

Limitations and Suggestions

One of the limitations of this study was that the sample was not very large. As it is known, it is difficult to make an appointment and go from school to school to collect data from teachers. However, the study may be a resource for researchers studying the self-efficacy perceptions of science teachers in various topics. High self-efficacy of teachers is important, since it leads to high motivation and better performance. The results obtained in this research may provide an insight for researchers, teachers, managers, and teachers training programs concerning the things to do to develop the self-efficacy perception of teachers. Moreover, the environments can be created or activities can be organized to improve the self-efficacy perception level of teachers in various topics, by measuring it frequently.

In Turkey, the subjects in middle/secondary science programs/courses can be covered by use of the laboratory. Although there are laboratories in schools, the use of laboratories is not compulsory. The present study results show that there is a relationship between the use of laboratories in science teaching and acid-base self-efficacy perception of science teachers. In teacher training programs and in-service training programs, more emphasis should be placed on increasing teachers' laboratory skills.

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References

Adetoro, N., Simisaye, A. O. & Oyefuga, A. B. (2010). Relationship between perceived self-efficacy and information literacy among library and information science undergraduates in a Nigerian university of education. *IFE PsychologIA: An International Journal, 18*(2), 172-191. https://doi.org/10.4314/ifep.v18i2.56758

Alkan, F. (2016). Development of chemistry laboratory self-efficacy beliefs scale. *Journal of Baltic Science Education, 15*(3), 350-359.

Ayas, A. & Özmen, H. (1998, October 23-25). *Asit-baz kavramlarının güncel olaylarla bütünleştirilme seviyesi: bir örnek olay çalışması* [The level of integration of acid-base concepts with current events: a case study]. 3rd National Symposium of Science Eduation, Karadeniz Technical University, Trabzon, Turkey.

Azar, A. (2010). In-service and pre-service secondary science teachers' self-efficacy beliefs about science teaching. *ZKU Journal of Social Sciences, 6*(12), 235-252.

Baldwin, J., Ebert-May, D., & Burns, D. (1999). The development of a college biology self-efficacy instrument for non-majors. *Science Education, 83,* 397–408.

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

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall.

Bandura, A. (1994). *Self-Efficacy*. In V. S. Ramachauran (Ed.)., *Encyclopedia of Human Behaviour,* (pp. 71-81). Academic Press.

Bandura, A. (1997). *Self efficacy: the exercise of control.* Freeman.

Bussey, K., & Bandura, A. (1999). Social cognitive theory of gender development and differentiation. *Psychological review*, *106*(4), 676.

Buyukozturk, S., (2012). *Sosyal bilimler için veri analizi el kitabı[Data analysis handbook for social science]*. Pegem A: Ankara

Calıskan, S., Selcuk, G. S., & Ozcan, Ö. (2010). Self-efficacy beliefs of physics student teachers': Effects of gender, class level and academic achievement. *Kastamonu Education Journal*, *18*(2), 449-466.

Cetin Dindar, A. (2012). *The effect of 5E learning cycle model on eleventh grade students' conceptual understandıng of acids and bases concepts and motivation to learn chemistry* [Unpublished doctoral dissertation]. Middle East Technical University.

Cetin, B. (2008). The effect of science teaching lesson on the self efficacy beliefs of 3rd grade primary school teaching department students' science teaching. *Dokuz Eylul University The Journal of Graduate School of Social Sciences, 10*(2), 55-71.

Dede, H., Yilmaz, Z. A. & Ilhan, N. (2017). Investigation of the self-efficacy beliefs of pre-service science teachers in terms of following and using the innovations in the field of education. *Journal of Education and Training Studies, 5*(2), 21-30.

Denizoglu, P. (2008). *The assessment of the relation between self-efficacy belief levels, learning styles of science teacher candidates towards science teaching and their attitudes towards science* [Unpublished master thesis]. Cukurova University.

Gercek, C., Yilmaz, M., Koseoglu, P. & Soran, H. (2006). Biology teaching self-efficacy beliefs of the teacher candidates. *Ankara University Journal of Faculty of Educational Sciences, 39*(1), 57-73.

Goddard, R. D., Hoy, W. K. & Hoy, A. W. (2004). Collective efficacy beliefs: theoretical developments, empirical evidence, and future directions. *Educational Researcher, 33*(3), 3–13.

Golightly, T. R. (2007). *Defining the components of academic self-efficacy in Navajo American Indian high school students* [Unpublished doctoral dissertation], Brigham Young University.

Gravetter, F., & Wallnau, L. (2016). *Statistics for the behavioral sciences*. Cengage Learning.

Hofstein A. (2017) The role of laboratory in science teaching and learning. In K. S. Taber & B. Akpan (Eds.), *Science education: New directions in mathematics and science education*. Sense Publishers. https://doi.org/10.1007/978-94-6300-749-8_26

Hofstein A., Kind P.M. (2012) Learning in and from science laboratories. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second international handbook of science education*. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9041-7_15

Ilhan, N. & Cicek, O. (2017). The development of acid-base self-efficacy perception scale and the investigation of pre-service science teachers' self-efficacy perceptions on acid-base. *Sakarya University Journal of Education, 7*(1), 123-141. https://doi.org/10.19126/suje.307068

Ilhan, N., Yilmaz, Z. A. & Dede, H. (2015). Attitudes of pre-service science teachers towards educational research and their science teaching efficacy beliefs in Turkey. *Journal of Baltic Science Education*, *14*(2), 183-193.

Joreskog, K. & Sorbom, D. (2001). *Lisrel 8: User's reference guide.* Scientific Software International.

Kline, R. B. (2005). *Principles and practice of structural equations modeling.* Guilford.

Lee, E. E. (2003). *Cultural mistrust, university alienation, academic self-efficacy and academic help seeking in african american college students* [Unpublished doctoral dissertation]. University of Nebraska.

Lee, M., Liang, J., Wu, Y., Chiou, G., Hsu, C., Wang, C., et al. (2020). High school students' conceptions of science laboratory learning, perceptions of the science laboratory environment, and academic self-efficacy in science learning. *International Journal of Science and Mathematics Education, 18*(1), 1–18. https://doi.org/10.1007/s10763-019-09951-w

Lewis, C. A. (2006). *Academic motivation among college students* [Unpublished doctoral dissertation]. Wayne State University.

Menon, D. (2020). Influence of the sources of science teaching self-efficacy in preservice elementary teachers' identity development. *Journal of Science Teacher Education, 31*(4), 460-481. https://doi.org/10.1080/1046560X.2020.1718863

Miller, A. D., Ramirez, E. M., & Murdock, T. B. (2017). The influence of teachers' self-efficacy on perceptions: Perceived teacher competence and respect and student effort and achievement. *Teaching and Teacher Education, 64,* 260–269. https://doi.org/https://doi.org/10.1016/j.tate.2017.02.008

Morgil, I., Secken, N. & Yucel, A. S. (2004). Based on some investigation of self-efficacy beliefs of preservice chemistry teachers variables. J*ournal of Balıkesir University Graduate School of Nature and Applied Sciences, 6*(1), 62-72.

Naidoo, K. & Naidoo, L. J. (2021). Designing teaching and reflection experiences to develop candidates' science teaching self-efficacy. *Research in Science & Technological Education*. https://doi.org/10.1080/02635143.2021.1895098

Niehaus, K., Rudasill, K. M., & Adelson, J. L. (2012). Self-efficacy, intrinsic motivation, and academic outcomes among latino middle school students participating in an after-school program. *Hispanic Journal of Behavioral Science, 34*(1), 118-136. https://doi.org/10.1177/0739986311424275

O'Leary, M. (2005). *A comparison of female and male teacher's self-efficacy in science and a comparison of science motivation beliefs in students with high science self-efficacy vs. low science self-efficacy teachers* [Unpublished doctoral dissertation]. Kean University.

Ozdemir, S. M. (2008). An investigation of prospective primary teachers' self-efficacy beliefs regarding teaching process in terms of certain variables. Educational Administration: *Theory and Practice, 54*, 277-306.

Ozeken, O. F. & Yildirim, A. (2011). The effect of problem-based learning method in teaching acid-base subject on science teachers academic success. *Pegem Journal of Education and Instruction, 1*(1), 33-38.

Ozenoglu Kiremit, H. (2006). *Preservice science teachers' self-effcacy beliefs in teaching biology* [Unpublished doctoral dissertation]. Dokuz Eylul University.

Ozmen, H. & Demircioglu, G. (2003). The effect of conceptual change texts on the elimination of misunderstandings by students on the subject of acids and bases. *Journal of National Education, 159*, 111-119.

Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research*, *66*(4), 543–578.

Pajares, F., & Schunk, D. H. (2001). Self-beliefs and school success: Self-efficacy, self-concept, and school achievement. In R. Riding & S. Rayner (Eds.), *Perception* (pp. 239–266). Ablex Publishing.

Patterson, D., (2011). *Can I graduate from college? the influence of ethnic identity, ethnicity, academic self-efficacy and optimism on college adjustment among community college students* [Unpublished doctoral dissertation]. Alliant International University.

Pintrich, P. R., & Schunk, D. H. (1996). *Motivation in education: Theory, research, and applications.* Prentice-Hall.

Rahayu, S., Chandrasegaran, A. L., Treagust, D. F., Kita, M., & Ibnu, S., (2011). Understanding acid–base concepts: Evaluating the efficacy of a senior high school student centred instructional program in Indonesia. *International Journal of Science and Mathematics Education*, *9*(6), 1439-1458.

Riggs, I. M., & Enochs, G. (1990). Toward the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education, 74,* 625–637.

Saracaloglu, A. S., & Yenice, N. (2009). Investigating the self-efficacy beliefs of science and elementary teachers with respect to some variables. *Journal of Theory and Practice in Education, 5*(2), 244-260.

Smist, J. M. (1993, August). *General chemistry and self-efficacy* [Paper presentation]. National Meeting of the American Chemical Society, Chicago, IL.

Tabachnick, B. G. & Fidell, L. S. (2001). *Using multivariate statistics.* Allyn & Bacon.

Tschannen-Moran, M. & Woolfolk-Hoy, A. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education, 17*, 783–805.

Tschannen-Moran, M., Woolfolk-Hoy, A., & Hoy, W. K. (1998). The teacher efficacy: Its meaning and measure. *Review of Educational Research, 68*, 202–248.

Ustuner, M., Demirtas, H., Comert, M. & Ozer, N. (2009). Secondary school teachers' self-efficacy beliefs]. *Mehmet Akif Ersoy University Journal of Education Faculty, 9*(17), 1-16.

Uzuntiryaki, E., & Aydın, Y. Ç. (2009). Development and validation of chemistry self-efficacy scale for college students. *Research in Science Education*, *39*(4), 539-551.

Yalcın, F. A. (2011). Investigation of science teacher candidates' self-efficacy beliefs of science teaching with respect to some variables. *International Online Journal of Educational Sciences, 3*(3), 1046-1063.

Yildiz, V. G., Yildirim, A. & Ilhan, N. (2006, September 7–9). *Üniversite kimya öğrencilerinin asitler ve bazlar hakkındaki bilgilerini günlük hayatla ilişkilendirebilme düzeyleri [Chemistry student teacher' levels of thinking their knowledge with daily life about acid and base concepts].* Seventh National Science and Mathematics Education Congress, Ankara, Turkey.

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An Empirical Study on the Evolution of Students' Perceptions in Basic Concepts of Physics of Primary and Secondary Education in Cyprus

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ABSTRACT

In recent years, more and more systematic research has been conducted in science fields, focusing on identifying alternative ideas that the students have for essential concepts and principles of physics. This has resulted in the production of essential and valuable international bibliographic information in various science fields, including mechanics. In the present paper, we focus on physics, particularly in classical mechanics, including key concepts such as weight, energy, force, action/reaction, and work. A multiple-choice questionnaire was given to senior students of primary school, middle school, and Cyprus's high school. We analyzed the percentage of correct and incorrect responses of the three survey groups to determine whether the responses were related to the group's age or representative of statistical fluctuations. For most questions, there was a statistically significant correlation with age, as opposed to gender, which does not appear to play a role in students' correct answers. In particular, our results suggest that the alternative conceptions of students, reflecting misconceptions and preconceptions, reduce with age or equivalently with the education level. Nevertheless, there are also many questions for which such a correlation cannot be established. Our study can be used in science teaching, on the design of curricula, and teachers' professional development.

Keywords: alternative ideas, physics sciences, mechanics, curriculum, professional development of teachers

Introduction

The constructivist learning approach advocates that learning materializes when new knowledge is associated with existing knowledge (Dysthe, 2002; Matthews, 2002; Taber, 2002). Research in the field of science education in the past years suggest that students enter the educational process while holding their ideas and conceptions on scientific principles. Such ideas reflect preexisting views and primary perceptions of physical phenomena and typically create obstacles in the learning process (Duit, 2004).

In the pertinent literature, one encounters many studies regarding students' alternative ideas on concepts such as force, motion, heat, temperature, power, and energy (Arslan & Kurnaz, 2009; Kurnaz & Arslan, 2011). Further studies worldwide have also reported and confirmed students' conflicting ideas on force, Newton laws, energy, weight, etc. (Ferreira et al., 2017; Kurnaz & Arslan, 2011; Villarino, 2018).

According to Taber (2014), prior knowledge of what learners already know and understand is a major determinant of what students will learn from their science classes. An abundance of research suggests that very frequently, students may hold ideas about science topics that are different and indeed often inconsistent with canonical scientific principles and theories (Abell, 2000). Bountiful studies have described students' ideas related to science subjects in diversified ways, including misconceptions, intuitive theories, and alternative conceptual frameworks. However, there are no widely agreed meanings for these different terms. These perceptions, which are found today under the term "alternative ideas," are an intrinsic part of the learning process, affecting it deeply. Researchers also accent that students' ideas vary in different dimensions that affect how vital students' thinking is to learning scientific ideas (Taber, 2009). As a result of this, research shows that students can often preserve different physics science ideas that are often incompatible with the correct scientific principles and theories (Abell, 2000). Since students' alternative conceptions are used as a starting point for advanced learning, recent studies have focused on students' alternative ideas (Calik & Kurnaz, 2008).

As stated in the bibliographic review carried out in the theoretical context of the present work, it appears that, in recent years, several kinds of research have been carried out on the exploration of students' alternative ideas in science. However, as the review shows, the literature mainly concerns the foreign educational community. Therefore, in the context of the Cypriot educational community, we do not find an appropriate response to this issue. This is where the interest in this research derives. This work investigates and highlights the possible alternative ideas of students in mechanics concepts, which will contribute to the broader research carried out in teaching, on the design of curricula, and the professional development of teachers in primary and secondary education in Cyprus.

Theoretical Background

"Conceptual understanding" invokes the construction of well-connected and hierarchically organized conceptual structures instead of incomplete and roughly connected knowledge pieces (Delgado et al., 2010). Notwithstanding, research has shown that developing scientific conceptual understanding is somewhat tricky due to the resilience of the alternative conceptions ingrained in larger conceptual frameworks (Skopeliti & Vosniadou, 2014; Treagust & Duit, 2008).

Alternative Conceptions (AC), as these ideas are commonly attributed to nowadays, turn out to be a primary ingredient in students' learning process (Driver & Easley, 1978). In particular, it has been pointed out that AC turn out to be remarkably more persistent and diverse than one would naively expect, eventually affecting students' critical thinking (Taber, 2009). Furthermore, students may also hold various views on scientific subjects, which are often inconsistent with the well-established theories that they are being taught (Abell, 2000). Thus, AC are being formed through mechanisms of empirical understanding. AC are usually developed through daily life experiences in the child's attempt to make sense of the world in which it lives. Hence, in some cases, AC are so deeply rooted that they cannot be abandoned or even slightly affected by the educational process (Driver, 1989). To this end, teachers and other professionals in education must know beforehand their students' various AC characteristics to prepare suitable teaching interventions. In this way, they can recant or critically confront these crucial aspects of children's considerations.

A large-scale factor in the implementation of the constructive model of teaching Physics Sciences is the educator. Ideally, educators must possess both a sufficient scientific background and the pedagogical abilities to impart their knowledge to their students. However, in many studies, it has been pointed out that primary school teachers often hold misconceptions in basic scientific principles similar to those of students. Recent research has extended this observation to secondary school teachers within Turkey in Bayraktar (2009) and international Taber (2008). It is reasonable to expect that the misconceptions of teachers are imprinted in the AC of students. The more these concepts deviate from the established scientific principles, the harder it becomes for students to alter and abandon their AC. Therefore, by studying the presence or absence of AC at different primary and secondary education levels, we can picture the teachers' educational backgrounds. Doubtless, as is usually the case in this research field, such an interpretation should be regarded with caution. Other variables can affect AC's relation with age, including the students' growing mental ability, new mathematical and logical tools at various education stages, cumulative experience, etc.

This study aims not to detect new forms of AC but instead investigate how much they change across the education levels. The survey for this study was an appropriate choice, due to the utilization of a multiple-choice questionnaire format with all questions focused on Classical Mechanics concepts. Classical Mechanics is an area of Physics with a prominent position among all others since it deals with phenomena one meets in daily life. Related concepts such as weight, force, and mass are widely used outside the classroom and in various activities. Additionally, these concepts are used directly or indirectly in almost all other physics areas, such as optics, thermodynamics, electromagnetism, etc. For instance, without the laws of motion, there can be no proper explanation for the kinetic theory of gases or the electromagnetic theory (Carson & Rowlands, 2005).

In the relevant literature, many multiple-choice questionnaires have been developed for investigating AC in Classical Mechanics (Huey-Por et al., 2007; Nieminen et al., 2010). Nevertheless, most of them are addressed to Middle and High School students and become unsuitable for our purpose here. To include Primary School students in the study, our questionnaire needs to involve only basic concepts with which all three groups are familiar. The questionnaire, which has been developed (Kotsis et al., 2002) for Primary School, has also been used (partially) in secondary education (Kotsis & Anagnostopoulos, 2006) and even with undergraduate university students (Stylos et al., 2008). After removing complex concepts targeted at bigger classes, the questionnaire was designed to address all our research groups based on the current curriculum and school textbooks.

Factors Affecting Students' Conceptions of Science

Students' misconceptions on several scientific concepts, including physics, might result from their misunderstanding of basic affairs. This may portray a shortage of skills embodied in scientific literacy, usually affected by several socio-demographic, cognitive, and motivational factors. These factors can be organized by student level, gender, etc. (Organization for Economic Co-operation Development, OECD, 2016). In the individual's socio-demographic level, gender is an alternative factor influencing students' achievement in science (Acar & Tuncdogan, 2018; Martin et al., 2016; OECD, 2016). In many scientific disciplines, males perform better than females in achievement tests (Miyake et al., 2010). The Programme for International Student Assessment survey also indicates that boys tend to demonstrate better performances than girls (OECD, 2016). Other factors that are not investigated in this research are classified in the cognitive domain, affecting students' achievements in their secondary-school specialization and past academic performance (De Clercq et al., 2012). In the affective domain, individuals' motivation towards scientific issues (OECD, 2016; Sun et al., 2012) like their interest (Hidi & Renninger, 2010) and confidence towards the subject (Kang & Im, 2019; Tsai et al., 2017), is positively correlated to science performance (OECD, 2016).

Students' Alternative Conceptions

Researchers have interpreted the evidence for the nature of students' conceptions in two distinct ways. Some researchers viewed students' conceptions as being theory-like, in that they are stable, coherent, persistent, and found helpful in a wide range of tasks (Blown & Bryce, 2007; Kalman, 2019). Others characterized students' conceptions as unstable, fragmented, transient, and context-bound (Tytler, 2007; Wood-Robinson & Clough, 2010). Therefore, students' simultaneous use of multiple alternative conceptions sometimes even coexist with scientific ones, as evidenced in their explanations of the same phenomenon. Such diverse and inconsistent explanations were often prompted by context and created in situ by operating various conceptual elements (Taber, 2008; Wood-Robinson & Clough, 2010). A limited number of studies have explored the consistency of students' conceptions concerning physical, chemical, and biological phenomena among different age groups (Alonzo & Steedle, 2009; Palmer, 1993; Pozo & López-Íñiguez, 2014; Nieminen et al., 2017; Treagust & Chu, 2014; Tytler, 2007). Findings from some studies indicated that few students utilized scientific conceptions across tasks with equivalent content. Numerous students inconsistently utilized different AC in response to different tasks (Alonzo & Steedle, 2009; Palmer, 1993; Treagust & Chu, 2014; Tytler, 2007).

Notwithstanding, teachers must acknowledge and comprehend their students' misconceptions to apply teaching techniques for their transformation (Slater et al., 2018). Nonetheless, it has been found that this is not happening, and students graduate from school and university with their former perceptions (Chu et al., 2012).

Selecting Physics Domain

In the context of our research, we focus on the field of Classical Mechanics to detect students' alternative ideas. It would be impossible to provide a questionnaire covering all areas of Physics. However, our specific choice is also motivated by the fact that

> "mechanics" is a physics field with a prominent place among its other fields, such as light, sound, heat, electricity, etc. That is true because these areas are defined by mechanics in the sense that, without the laws of motion, for example, there would be no kinetic theory of gases or there would be no electromagnetic theory. (Carson & Rowlands, 2005, p. 476)

The field of mechanics also declares that the ideas of weight, force, and mass comprise the foremost basic physics ideas and primarily concern physics general knowledge (Seker & Welsh, 2006). Also, Galili (1995) characteristically states that: "physics is thought as a particularly fertile ground" for students' perceptions (p. 371). An enormous structure that nowadays we tend to decision physics consists of many sectors. The importance of Mechanics is more significant than any single one in all these areas. It defines the "rules of the game," defines most physics tools, and presents nature's foremost universal laws. It introduces the basic strategies of physics that apply to all other areas. That is why mechanics continually guide each physics curriculum.

Purpose of the Study

In the context of the Cypriot educational reality, this study intended to examine how the progression and consistency of students' understanding of physics concepts in everyday contexts changed across grade levels. Subsequently, we tried to notice if a conceptual change takes place from tier to tier (educational) and which concepts of mechanics it focuses on. The main objective of this paper is to highlight the possible alternative ideas of students to the concepts of Mechanics, which will contribute to the broader research carried out in the field of didactics of Science, on the design of curricula, and the professional development of teachers in primary and secondary education in Cyprus. This research was prepared to investigate the following fundamental questions:

1) How consistent are students in their scientific and non-scientific (alternative) understandings of physical concepts across the different grade levels?
2) Is there a statistically significant difference in students' understanding across the concepts of Mechanics or based on their level of education?
3) Is there a statistically significant difference in students' understanding of the concepts of Mechanics based on gender?

The statistical criterion χ^2 test was applied through the SPSS program (Table 3) to achieve the first objective. That enables us to determine whether the answers given to the survey questions for each primary and secondary education class are independent of each other. For the second goal, the questions have been first grouped according to the relevant general concepts (i.e., Force, Action/Reaction, Weight, Energy, Work) (see Table 4). Besides, the average degree of correct answers has been calculated in each category (see Table 7). In the end, the average grades were compared both between classes, using the paired samples t-test, and between training levels, using the one-way ANOVA (see Table 6). In the case of multiple comparisons, the Bonferroni correction has been used. A t-test has been performed to achieve the third goal, associating the final score of correct answers with gender to determine if gender plays any role in the percentage of correct answers (see Figure 2).

Methodology

Initially, a Detailed Research Plan was submitted to the Ministry of Education and Culture of Cyprus (Directorate of Primary and Secondary Education). After approval and securing the required license, the investigation proceeded. Students, parents, teachers, and principals were primarily informed about the research aims and participated voluntarily. The research was conducted in May – June (2019) in primary schools and September – October (2019) in middle and high schools. The same questionnaire was used for data collection in all classes.

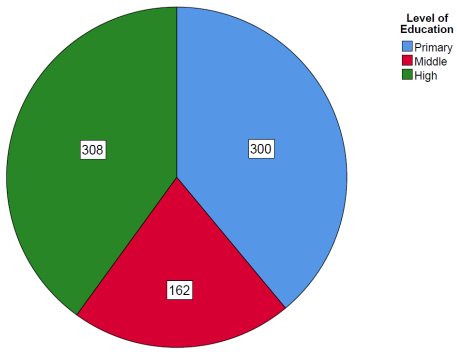
In this article, we investigate the AC of students related to Physics. Our survey sample consists of students attending primary and secondary education classes in Cyprus. According to their age/education level, candidates chosen from schools in five different cities were split into three groups. These included seniors in primary school (age 11), in middle school (age 14), and in high-school (age 17), following the standard 12-grade educational system of the country. All candidates were provided with a multiple-choice questionnaire of closed-form. It includes basic physical concepts such as weight, energy, force, action-reaction, and work. Statistical analysis based on their answers was performed with the use of the χ^2-test (Wagner, 2019) and with the help of the IBM SPSS Statistics 25 computer software (Field, 2013).This was a cross-sectional study (Zhou et al., 2015) involving students from three grade levels (primary school (6^{th} grade), middle school (3^{rd} grade), and high school (3^{rd} grade)) (Olsen & Diane, 2004). The methodology adopted for this study was quantitative in nature. Survey data were collected at a single time from students of three grade levels without any intervention or change to the learning environment.

Participants and Research Context

As aforementioned, our study targets populations in primary, middle, and high school. The total number of students in our sample is N=770 chosen from several public education facilities in five Cyprus cities: Limassol, Larnaca, Nicosia, Paphos, and Famagusta. The choice of schools was made using random sampling to avoid research bias. Students from each grade level were almost evenly distributed by gender. The survey groups corresponded to three specific education classes: the 6^{th} grade of Primary School (age 11), the 3^{rd} grade of Middle School (age 14), and the 3^{rd} grade of High School (age 17). The specific number of students in each group is given in Figure 1. Our analysis is based on a comparison of the answers received from the three groups. The survey was carried out in May-June (2019) in Primary Schools and September-October (2019) in Middle and High Schools.

Figure 1

Number of Students Participating in Each of the Three Survey Groups of the Study and Their Corresponding Education Level



Data Collection – Instrument

In the context of the investigation of students' alternative ideas, multiple-choice questionnaires tend to be a popular choice. Standard multiple-choice questions require students to choose the best answer to a given question from a given set of alternatives. Questionnaires are flexible, practical, objective, easy to use, and less influenced by a person's tendency to react in a specific way (Brancato et al., 2004). It was considered appropriate to use a multiple-choice questionnaire for research purposes. The questionnaire questions are simple conceptual understanding questions that can be answered by primary, middle school, and high school students.

Initially, the questionnaire contained 28 questions since it was also addressed to the pedagogical department's undergraduate students (Kotsis, 2005). However, because the present study also specializes in primary school students, some questions that contained complex concepts were removed to make the questionnaire more accessible. After the changes were made on the changing and differing educational policies, the differing aims, and needs of education, the questionnaire was formulated based on current data (school textbook, curriculum) into 20 questions. It should be noted that the questionnaire was given to a group of students and teachers of primary and secondary education to comment and check the clarity of the questions. The primary school teachers agreed that the questionnaire was within the capabilities of the final grades of primary school, while the secondary school teachers characterized it as easy (Kotsis, 2011, p. 40).

The questionnaire has been used in past in studies conducted in Greek schools (Kotsis, 2005). Each question is based on a scenario from familiar everyday environments followed by statements that include the scientific explanation and one or more alternatives (see Table 1). The data was collected using the revised closed type of multiple-choice questionnaire of 20 items mentioned previously. All questions were similar to examples from school textbooks. The questionnaire did not include graphic or pictorial representations to avoid any unwanted misinterpretations. Students could easily read the scripts given on the objects without using or knowing scientific terms. The questionnaire was tested with 770 students, and the reliability of the Cronbach alpha coefficient was 0.7. According to Nunnally & Bernstein (1994), a Cronbach alpha reliability coefficient greater than 0.7 indicates high reliability, while values in the range of 0.5–0.7 indicate moderate reliability and are acceptable in cognitive nature studies. Besides, the names of the five conceptual groups were modified in the current study, using analysis of variance (ANOVA), with Conceptual Group 1 being titled

Table 1

Questionnaire Based on a Scenario from Common Everyday Environments

Questions	**Available answers**			
	A	**B**	**C**	**D**
Q1. "What is the effect of force acting on a body"	*"Deformation"*	*"Change of kinetic state"*	*"Both"*	-
Q2. "In a high-five with a friend, what is the direction of the forces engaged by both boys' hands on the other's hands?"	*"Same direction"*	*"Opposite direction"*	*"Different direction"*	-
Q3." When is a force exerted?"	*"When pushing a bike"*	*"When pushing against a wall"*	*"In both cases"*	-
Q4. ''When is a force acting on a body?''	*''When we start moving a body''*	*''When we stop a moving body''*	*''In both cases''*	-
Q5. ''When does a football player exert a force on a ball?''	*''When the player shoots''*	*''When the player moves towards the nets''*	*''In both cases''*	*''In no case''*
Q6. ''A child throws a stone. When does the child exert a force on the stone? ''	*'' When it leaves the hand''*	*''When it's in the air''*	-	-
Q7. '' I stumble upon a stone that I move. The stone:''	*''Wields force on me, too''*	*''Doesn't wield force on me''*	-	-
Q8. ''I hit my hand on a table and my hand hurts, because: ''	*''I exerted force on the table''*	*''The table exerted force on me''*	-	-
Q9. ''When we swim, we push the water backwards with a force and this pushes us forward' with a force''	*''Correct''*	*''Incorrect''*	-	-
Q10. '' When we walk, we push the ground:''	*''Forward''*	*"Backward"*	-	-

Questions	Available answers			
	A	B	C	D
Q11. ''When can we drive a car more safely on an icy road? When it is: ''	*''Empty''*	*"Loaded"*	-	-
Q12. '' A small car and a heavy truck wait in front of a red light. After the green light turns, they develop the same speed. Which one will start faster?"	*''The small car will start faster''*	*''The heavy truck will start faster''*	-	-
Q13. ''The weight of the body is: ''	*'' A force''*	*"A property"*	*''Mass''*	-
Q14. ''Gravity on the moon is smaller than gravity on earth. The weight of a chocolate is: ''	*''Smaller on Earth than on the moon''*	*''Bigger on Earth than on the moon''*	*''The same on Earth and on the moon''*	-
Q15. '' When you are at sea and lift a stone inside water, the weight of the stone is:"	*''Bigger in the water''*	*''Smaller in the water''*	*''The same''*	-
Q16. '' An apple is hanging on the branch of an apple tree and another is falling to the ground. Which of the two produces work? ''	*"The falling apple''*	*"The hanging apple"*	*''Both apples''*	*''Neither of them''*
Q17. '' You go up to the second floor of your house, once empty, once loaded with stuff. When do you spend more work?"	*''When you're empty''*	*''When you're loaded''*	*''The same''*	-
Q18. ''Two athletes with the same weight and height run for 100 meters. Who consumes more energy?"	*''The one who finishes first''*	*''The one who finishes second''*	*''They consume the same energy''*	-
Q19. ''When does a truck have more energy?"	*''When it moves''*	*''When it's stationary''*	*''It always has the same''*	-
Q20. ''Two weightlifters lift the same weight. Who spends more energy?"	*''The one who's taller''*	*''The one who's shorter"*	*''The same both''*	-

"Weight," Group 2 "Energy," Group 3 "Work," Group 4 "Force," and Group 5 as "Action-Reaction" (see Table 4). Since the questions concerned five different physics fields, it was chosen to group them in this way. The participants responded to the questionnaire items within one class period (40 min). Before administering the test, the volunteer participants were informed that their responses to the questionnaire would not affect their course grades but would be used for research purposes to evaluate their understanding of physics (mechanics).

Data Analysis

Among the data from the 20-item questionnaire, items with 2, 3, or 4 (a, b, c, d) alternatives each were initially coded in SPSS by identifying the selected choice. For example, Choice A was coded as '1', and Choice B was coded as '2', and so on. If a student did not respond, it was coded as '0'. Then, the data were re-coded in SPSS, assigning '1' and '0' for each correct and incorrect response, respectively.

For research question RQ (1), using the re-coded data, the percentage of each group of students' scientific responses to each item was calculated (Table 3). The patterns of change in understanding each physics (mechanics) concept (e.g., force, energy, weight, Etc.) were compared across grade levels (Table 4). Also, all students' total standard questionnaire scores (20 items were included) were calculated.

Results

The questionnaire responses' processing was performed using the statistical package SPSS V.25 (Landau & Everitt, 2004). To investigate whether the answers to the survey questions depend on education, we used the χ^2-test as a statistical control criterion. Table 2 summarizes the results of the χ^2 test mentioned previously for each question separately.

Table 2

Comparisons of the Chi-square Test on the Correctness of the Responses Depending on the Education Level

Question	χ^2	*Df*	*P*		Pairwise
1	36.642	2	<0.001	Statistical difference	1<2<3
2	23.108	2	<0.001	Statistical difference	1<2=3
3	73.126	2	<0.001	Statistical difference	1<2<3
4	18.753	2	<0.001	Statistical difference	1=2<3
5	5.891	2	0.053	Random Variation	-
6	5.818	2	0.055	Random Variation	-
7	12.223	2	0.002	Statistical Difference	1<2<3
8	50.149	2	<0.001	Statistical difference	1<2<3
9	3.440	2	0.179	Random Variation	-
10	6.981	2	0.03	Statistical difference	1=2<3
11	7.816	2	0.02	Statistical difference	1=2<3
12	6.038	2	0.049	Statistical difference	1=2=3
13	40.820	2	<0.001	Statistical difference	1<2=3
14	1.762	2	0.414	Random Variation	-
15	5.556	2	0.062	Random Variation	-
16	5.854	2	0.054	Random Variation	-
17	2.929	2	0.231	Random Variation	-
18	32.700	2	<0.001	Statistical difference	1=2<3
19	4.513	2	0.105	Random Variation	-
20	4.527	2	0.104	Random Variation	-

Table 3 shows the percentages of students who provided scientifically correct responses to each questionnaire group at each grade level. From the statistical analysis of the data carried out, one can see a statistically significant difference in the respondents' level of education.

RQ (1) How consistent are students in their scientific and non-scientific (alternative) understandings of physics (mechanics) concepts across the different grade levels?

Table 3

Percentage of Students' Correct Answers Across Groups

Questions	*% Of Scientific Responses*		
	Group 1[a] (N =300)	Group 2[b] (N=162)	Group 3[c] (N=308)
Q1. "What is the effect of force acting on a body"	40.2	52.5	64.8
Q2. "In a high-five with a friend what is the direction of forces engaged by boys' hands on the other's hands?"	50.5	64.8	69.1
Q3." When is a force exerted?"	48.7	79	78.2
Q4. "When is a force acting on a body?"	45.5	48.1	62.2
Q5. "When does a football player exert a force on a ball?"	60.4	71.3	61.4
Q6. "A child throws a stone. When does the child exert a force on the stone?	87.5	93.8	91.9
Q7. "I stumble upon a stone that I move. The stone:'	66.7	82	72.6
Q8. "I hit my hand on a table and my hand hurts, because:"	40.1	74.1	56.4
Q9. "When we swim, we push the water backwards with a force and this pushes us forward' with a force"	88.9	90.7	85.3
Q10. "When we walk, we push the ground:"	78	77.2	85.3
Q11. "When can we drive a car more safely on icy road? When it is:"	71.8	68.5	79.3
Q12. "A small car and a heavy truck wait in front of a red light. After the green light turns, they develop the same speed. Which one will start faster?"	84.5	85.8	90.9
Q13. "The weight of the body is:"	30	49.4	55.1
Q14. "Gravity on moon is smaller than gravity on earth. The weight of a chocolate is:"	61.3	64.8	66.4
Q15. "When you are at sea and lift a stone inside water, the weight of the stone is:"	16.9	24.8	23.5
Q16. "An apple is hanging on the branch of an apple tree and another is falling to the ground. Which of the two produces work?"	58.8	62.1	51.5
Q17. "You go up to the second floor of your house once empty once loaded with stuff. When do you spend more work?"	82.5	76.1	81.6
Q18. "Two athletes with the same weight and height run for 100 meters. Who consumes more energy?"	37.7	44	60.5
Q19. "When does a truck have more energy?"	72.1	72.3	79
Q20. "Two weightlifters lift the same weight. Who spends more energy?"	30.7	23.9	33.4

Note. [a] Primary school (11), [b]Middle school (14), [c]High school (17)

From Table 2, it is observed that there is a statistically significant relationship between the level of education and the percentage of correct responses in eleven (11) questions out of twenty (20). This result indicates that the answers' correctness depends on the education level in most of the questions. Many variables can affect this phenomenon, such as mental development (Rapp, 2005), teaching method (Sperandeo-Mineo et al., 2006), experiential experience (Wallace & Brooks, 2014), and other factors that cannot be isolated in the present research (Hazari et al., 2010).

Nevertheless, it is interesting to investigate in detail by class pairs if and to what extent there is a statistically significant difference in the answers to each question's questions separately. Specifically, we collect groups from education classes, i.e., for the groups of primary-middle (pair1), middle-high (pair2), and primary-high (pair3) education.

To avoid listing multiple pages with shapes and relevance tables, we quote only a table that summarizes the values of χ^2, degrees of freedom (df), and the level of statistical significance (p). In the list of "pairwise," we distinguish per education pair, which pair is superior, depending on the students' percentage of correct responses (see Table 2).

As previously mentioned, the names of the five conceptual groups were modified in the current study, using analysis of variance (ANOVA), with Conceptual Group 1 being titled "Weight," Group 2 "Energy," Group 3 "Work," Group 4 "Force," and Group 5 as "Action-Reaction" (see Table 4). The percentages of scientific concepts that include five different physics concepts at different education levels can be seen in Table 4.

Table 4

Percentages of Students Who Consistently Provided Scientific or Nonscientific Responses Across Concepts

Concept Group	Item	% Of Scientific Responses		
		Group 1[a] (N=300)	Group 2[b] (N=162)	Group 3[c] (N=308)
Force	Q1, Q2, Q3, Q4, Q5, Q6, Q12	59.9	70.8	74.1
Weight	Q13, Q14, Q15	36.1	46.3	48.6
Work	Q16, Q17	70.8	69.8	66.7
Energy	Q18, Q19, Q20	46.9	46.8	57.9
Action/Reaction	Q7, Q8, Q9, Q10	68.5	81.4	75

Note. [a] Primary school (11), [b]Middle school (14), [c]High school (17)

Table 5 presents each question's meanings for the statistical or random variation of each education level's difference to overview all the research questions. The audit was performed by using the χ^2 criterion here as well. In Table 5, we give only the final aggregated results. The table displays, for each pair of education groups, only the information for each question's relevant physical concept and the statistical conclusion, namely whether the result reflects a Statistical Difference (SD) or a Random Variation (RV). In Table 5, one may notice several interesting patterns from the responses to the questionnaire. In questions 1,5,7,and 8, one observes a Statistical Difference for pairs of groups (1-2, 2-3), while in questions 9,12,14,17, and 19, one observes random variation instead. In questions 4,10,11,16,18, and 20, there is a random variation for "primary school-middle school" which changes into a statistical difference for "middle school-high school". Of course, such a pattern is also expected. It suggests that students remove slowly and gradually their AC for some physical phenomena through education (Gilbert et al., 2002). It also indicates that the educational system works effectively in this respect. However, we note that for questions 2,3,6,13, and 15, the reverse pattern is observed for groups (1-2, 2-3), suggesting no further improvement in the students' perception of those concepts in later education stages. In pair 1-3, the results are at expected levels, i.e., 11 out of 20 questions, the high school students did better than those of the primary school, of which they are mainly related to the concept of force and action-reaction, probably because the concepts are taught in middle and high school.

Table 5

Statistical Analysis of the Results Using the χ^2 Criterion for Pairs of Groups for the Levels of Education.

Question Concept	[1]Primary school [2]Middle school	[2]Middle school [3]High school	[1]Primary school [3]High school
Q1. Force	SD	SD	SD
Q2. Direction of Force	SD	RV	SD
Q3. Force - Motion	SD	RV	SD
Q4. Force - Motion	RV	SD	SD
Q5. Impact - Force	SD	SD	RV
Q6. Impact - Force	SD	RV	RV
Q7. Action / Reaction	SD	SD	RV
Q8. Action / Reaction	SD	SD	SD
Q9. Action / Reaction (Water)	RV	RV	RV
Q10. Action / Reaction (Ground)	RV	SD	SD
Q11. Friction	RV	SD	SD
Q12. Force - Mass	RV	RV	SD
Q13. Weight - Mass	SD	RV	SD
Q14. Weight - Gravity Field	RV	RV	RV
Q15. Weight - Levitation	SD	RV	SD
Q16. Work	RV	SD	RV
Q17. Work	RV	RV	RV
Q18. Energy	RV	SD	SD
Q19. Energy - Kinetic	RV	RV	RV
Q20. Energy	RV	SD	RV

Note. The Statistical Difference (SD) or Random Variation (RV) is displayed with a brief description of the relevant physical concept attributed to each question.

RQ (2) Is there a statistically significant difference in students' understanding across the concepts of Mechanics or based on their level of education?

Initially, having separated the questions based on concepts (Force, Action/Reaction, Weight, Energy, Work), the average score of the correct answers in each category was calculated separately. The mean scores were then compared between the categories using the paired samples t-test instead of correlation analysis (see Table 6). As is known, correlation analysis is used when the aim is to examine whether there is a correlation between two phenomena (Soh et al., 2010). For example, correlation analysis would be used if our objective was to examine whether students with a high score on "Weight" have a high or low score on "Force". However, that is not our objective. We want to examine whether the score on "Weight" differs or not from the score on "Force". Considering that the same students responded to these questions, a paired-samples t-test is an appropriate test in this research point (Ross & Willson, 2017). Afterward, a one-way ANOVA (see Table 7) analyzed the education levels (Yockey, 2007). In cases of multiple comparisons for the between training levels comparisons, a Bonferroni correction was used. The following tables list the results from the analyses.

Table 6

Comparisons Between the Scores of the Different Pairs of Concepts

Paired Sample Test
Paired Differences

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower.	Upper	t	df	Sig. (2-tailed)
Pair 1. Force / Action-Reaction	-0.05827	0.26460	0.00955	-0.03951	-0.03951	-6.099	766	0.000
Pair 2. Force / Weight	0.24627	0.30677	0.01108	0.22453	0.26802	22.233	766	0.000
Pair 3. Force / Work	-0.00995	0.36635	0.01322	-0.03590	0.01600	-0.753	767	0.452
Pair 4. Force / Energy	0.16464	0.31364	0.01135	0.14235	0.18693	14.500	762	0.000
Pair 5. Action - Reaction / Weight	0.30566	0.32588	0.01178	0.28253	0.32879	25.943	764	0.000
Pair 6. Action - Reaction / Work	0.04896	0.39596	0.01431	0.02087	0.07704	3.422	765	0.001
Pair 7. Action - Reaction / Energy	0.22544	0.35616	0.01292	0.20008	0.25080	17.450	759	0.000
Pair 8. Weight / Work	-0.25544	0.43946	0.01588	-0.28661	-0.22427	-16.087	765	0.000
Pair 9. Weight / Energy	-0.08004	0.38451	0.01395	-0.10742	-0.05266	-5.739	759	0.000
Pair 10. Work / Energy	0.17738	0.40357	0.01462	0.14868	0.20608	12.133	761	0.000

Table 7

Impact of the Education Level in the Score of Each Category of Physics Concepts

Question Concept	Group 1 Primary School (11)	Group 2 Middle School (14)	Group 3 High School (17)			
	M (SD)	M (SD)	M (SD)	F	p	Post-Hoc
Weight	0.35(0.26)	0.46(0.31)	0.48(0.30)	15.043	<0.001	2<1
Energy	0.47(0.27)	0.46(0.24)	0.57(0.26)	15.590	<0.001	3<2
Work	0.70(0.33)	0.68(0.33)	0.66(0.31)	1.172	.310	-
Force	0.59 (0.23)	0.70 (0.21)	0.74 (0.22)	34.168	<0.001	2<1
Action/Reaction	0.68 (0.25)	0.80 (0.23)	0.74 (0.26)	13.338	<0.001	1<3<2

RQ (3) Is there a statistically significant difference in students' understanding of the concepts of Mechanics based on gender?

A total score (score_total) of the correct answers was created depending on the gender of the respondents. From the total sample (N = 770), 375 students were boys and 395 girls. A t-test was performed with the final score of the correct answers per gender to determine if gender plays a role in the percentage of correct answers. Looking at the Mean Difference (see Figure 2), we notice that boys' average grade is 0.58 lower than girls, which practically shows us that there is no difference between students' sexes. This result contrasts with several studies (Kahle, 2004; Murphy & Elizabeth, 2006; Sjoberg & Imsen, 1998; Soerensen, 1991) that want boys to perform better in physics. This is not confirmed here.

Figure 2

Total Score of Correct Answers Depending to Gender

Independent Samples Test										
		Levene's Test Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig.(2-tailed)	Mean Difference	Std.Error Difference	Lower	Upper
score_total	Equal variances assumed	1.113	.292	-2.365	768	.018	-.57826	.24450	-1.05822	-.09830
	Equal variances not assumed			-2.367	767.755	.018	-.57826	.24428	-1.05780	-.09873

Discussion

The current study results provide evidence for the progression and consistency of students' conceptions about concepts in classical mechanics across distinct educational levels. There are no longitudinal studies in the Cyprus education system that record students' understanding of such concepts from primary to high school in an interpretative manner.

As our analysis shows, there is a correlation between AC and the age/education-level of the students concerning physical concepts. In eleven (11) out of twenty (20) questions, the results suggest that the AC reduces with students' age, as one would expect. Nevertheless, for the other nine (9) questions, such a correlation cannot be established with sufficient statistical significance.

This conclusion suggests that age/education, although a primary factor driving AC's suppression, is not solely responsible for their presence. As for the percentages of correct answers based on the concepts of physics, the results range in logical and expected contexts, i.e., primary school students in the lowest percentages of correct answers and high school students in the highest, except for the answers of the concept "work", mentioned previously. Also, it became clear that the "student gender" factor does not play a role in whether they will answer the questions of physics correctly or incorrectly.

Other factors related to the provided education such as teaching methods, quality of education, technology infrastructure, or related to the students like social environment and religious background, possibly particularly significant, need to be examined further. Together with other studies in this subject, the results presented here are expected to help teachers develop more effective educational methods, construct analytical programs, and design curriculum.

Conclusions

In conclusion, it should be emphasized that students rely primarily on their perceptions, which are sometimes intuitive and sometimes empirical. However, their education's scientific knowledge often results in contradictions and confusion between pre-existing and new knowledge. The research showed that there are alternative ideas of students in different concepts of physics in all classes. In most cases, there is a change in these ideas over time, and that this phenomenon may show some reduction. However, it does not cease to exist even at the highest education levels, which means that more emphasis should be placed on this issue.

The teacher's teaching approach should consider that children's alternative ideas cannot be ignored because teaching will not be linked to learning. It is a point that must be paid special attention by all actors in the education system so that from Primary School, the student begins to acquire scientific knowledge. Further research is needed that will include more detail and more variables that can affect the phenomenon and describe more accurately the root of the problem. Ideally, it will be possible to implement a teaching system where teachers will know the appropriate age that students should be ready to teach the relevant concepts of physics. The research conclusion deserves a special observation where the proper processing by various educational institutions (e.g., Universities, Pedagogical Institute, Ministry of Education and Culture) can be led to a qualitative improvement of students' learning performance in the course of Physics Science.

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References

Abell S.K. (2000). International perspectives on science teacher education. In Abell S.K. (Ed.), *Science Teacher Education* (pp. 3-6). Springer, Dordrecht.

Acar, O. A., & Tuncdogan, A., (2019). Using the inquiry-based learning approach to enhance student innovativeness: a conceptual model, *Teaching in Higher Education*, *24*(7), 895-909. https://doi.org/10.1080/13562517.2018.1516636

Alonzo, A.C., & Steedle, J.T. (2009). Developing and assessing a force and motion learning progression. *Science Education*, *93*(3), 389-421. https://doi.org/10.1002/sce.20303

Arslan, A., & Kurnaz, M. (2009). Prospective physics teachers' level of understanding energy, power and force concepts. *Asia-Pacific Forum on Science Learning and Teaching*, *10*(1), 1-18.

Bayraktar, S. (2009). Pre-service primary teachers' ideas about lunar phases. *Journal of Turkish Science Education*, *6*(2), 12-23.

Blown E. J., & Bryce T. G. K. (2006). Knowledge restructuring in the development of children's cosmologies, *International Journal of Science Education*, *28*(12), 1411-1462. https://doi.org/10.1080/09500690600718062

Brancato, G., Macchia, S., Murgia, M., Signore, M., & Simeoni, G. (2004). *Handbook of recommended practices for questionnaire development and testing in the European Statistical System*. Eurostat. European Commision.

Calik, M., & Kurnaz, M. (2008). Using different conceptual change methods embedded within 5E model: A sample reaching for heat and temperature. *Journal of Physics Teacher Education Online*, *5*(1), 3-10.

Carson, R., & Rowlands, S. (2005). Mechanics as the logical point of entry for the enculturation into scientific thinking. *Science & Education*, *14*(3), 473–492.

Chu, H., Treagust D. F., Shelley Y., & Marjan Z. (2012) Evaluation of students' understanding of thermal concepts in everyday contexts. *International Journal of Science Education*, *34*(10), 1509-1534. https://doi.org/10.1080/09500693.2012.657714

De Clercq, M., Galand, B., Dupont, S., Frenay, M. (2013). Achievement among first-year university students: an integrated and contextualized approach. *European Journal of Psychology of Education, 28*(3)**,** 641–662.

Delgado, C., Stevens, S., & Krajcik, J. (2010). Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching*, *47*(6), 687-715.

Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education*, *11*(5), 481-490. https://doi.org/10.1080/0950069890110501

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*(1), 61-84. https://doi.org/10.1080/03057267808559857

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287-312.

Duit, R., & Treagust, D. F., (2004). Conceptual Change – A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*(6), 671-688.

Dysthe, O. (2002). Professors as mediators of academic text cultures: An interview study with advisors and master's degree students in three disciplines in a Norwegian university. *Written Communication*, *19*(4), 493-544. https://doi.org/10.1177/074108802238010

Ferreira, A., Lemmer, M., & Gunstone, R (2017). Alternative conceptions: Turning adversity into advantage. *Research in Science Education*, *49*(3), 657-678.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. SAGE.

Galili, I. (1995). Mechanics background influences students' conceptions in electromagnetism. *International Journal of Science Education*, *17*(3), 371-387.

Gilbert, J., Treagust, D., Van Driel, J., De Jong, O. & Justi, R. (2002). *Chemical education: Towards research-based practice*. Kluwer Academic Publishers.

Hazari, Z., Sonnert, G., Sadler, P., & Shanahan, M. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978-1003.

Hidi, S., & Renninger, K. (2010). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111-127.

Huey-Por, C., Jun-Yi, C., Chorng-Jee, G., Chung-Chih,C., Ching-Yi, C., Shean-Huei, L., Wei-Jou, S., Kuen-Der, L., Shun-Yi, H., Jang-Long, L., Chin-Chang, C., Yi-Ting, C., Loung-Shyi, W. & Yaw-Teng, T. (2007) Investigating primary and secondary students' learning of physics concepts in Taiwan, *International Journal of Science Education*, *29*(4), 465-482. https://doi.org/10.1080/09500690601073210

Kahle, J. B. (2004). Will girls be left behind? Gender difference and accountability. *Journal of Research in Science Teaching, 41*(10), 961- 969.

Kang, M. & Im, T. (2019). Structural relationships of factors which impact on learner achievement in online learning environment. *International Review of Research in Open and Distributed Learning*, *20*(1), 111-124.

Kotsis, K. T. (2005). *Διδασκαλία Της Φυσικής και Πείραμα [Teaching Physics & Experiment*]. University of Ioannina Publications.

Kotsis, K. T. (2011). *Έρευνητικη προσέγγιση του διαχρονικού χαρακτήρα των εναλλακτικών ιδεών στη διδακτική της Φυσικής [A research approach to the timeless nature of alternative ideas in the teaching of Physics*]. University of Ioannina Publications.

Kotsis, K. T., & Anagnostopoulos (2006). Αντιλήψεις των μαθητών Α'Λυκείου για βασικές έννοιες και αρχές της Φυσικής, όπως ταχύτητα, επιτάχυνση, μάζα, βάρος και 2ος νόμος του Νεύτωνα. [Misconceptions of high school students for basic concepts and principles of physics, such as speed, acceleration, mass, weight, and Newton's 2nd law]. *Proceedings of the 3rd Panhellenic Conference of the "Association of the Didactics of Natural Sciences*". Volos, Greece.

Kotsis, K. T., & Kolovos, C. (2002). Οι εναλλακτικές αντιλήψεις των παιδιών, η εννοιολογική αλλαγή και η διάρκεια γνώσης από την διδασκαλία στο Δημοτικό στην έννοια της δύναμης. [The misconceptions of the Primary school students, the conceptual change, and the duration of knowledge from their teaching on the concept of force]. *Proceedings of the 3rd National Conference for "Didactics of Natural Sciences and New Technologies in Education"*. Rethymno, Grete.

Kotsis, K. T., & Vemis, K. (2002). Οι εναλλακτικές αντιλήψεις των παιδιών, η εννοιολογική αλλαγή και η διάρκεια γνώσης από την διδασκαλία στο Δημοτικό για φαινόμενα που στηρίζονται στον τρίτο νόμο του Νεύτωνα. [The misconceptions of the Primary school students, the conceptual change, and the duration of knowledge from their teaching about phenomena based on Newton's third law]. *Proceedings of the 3rd National Conference for "Didactics of Natural Sciences and New Technologies in Education"*. Rethymno, Grete.

Kurnaz, M. A., & Sağlam Arslan, A. (2011). A thematic review of some studies investigating students' alternative conceptions about energy. *International Journal of Physics & Chemistry Education*, *3*(1), 51–74.

Landau, S., & Everitt, B.S. (2003). *A handbook of statistical analyses using SPSS* (1st ed.). Chapman and Hall/CRC Press.

Martin, R., Matthew, K., Finn, A., Martin, R., Duckworth, A., Gabrieli, C., & Gabrieli, J. (2016). Promise and paradox: Measuring students' non-cognitive skills and the impact of schooling. *Educational Evaluation and Policy Analysis*, *38*(1), 148-170.

Matthews, M. R. (2002). Constructivism and science education: A further appraisal. *Journal of Science Education and Technology*, *11*(2), 121-134.

Miyake, A., Kost-Smith, L., Finkelstein, N., Pollock, S., Cohen, G., & Ito, T. (2010). Reducing the gender achievement gap in college science: A classroom study of values affirmation. *Science*, *330*(6008), 1234-1237.

Murphy, P., & Elizabeth, W. (2006). Girls and physics: continuing barriers to 'belonging'. *The Curriculum Journal*, *17*(3), 281-305. https://doi.org/10.1080/09585170600909753

Nieminen P., Savinainen A. & Viiri J. (2017) Learning about forces using multiple representations. In D. Treagust, R. Duit, & H. Fischer (Eds.), *Multiple representations in physics education: Models and modeling in science education* (pp. 163-182). Springer, Cham.

Nieminen, P., Savinainen, A., & Viiri, J. (2010). Force concept inventory-based multiple-choice test for investigating students' representational consistency. *Physical Review Physics Education Research*, *6*(2), 020109(1-12).

Nunnally, J., & Bernstein, H. (1994). *Psychometric theory*. McGraw-Hill, Inc.

Organization for Economic Co-operation Development. (2016). *International migration outlook 2016*. OECD Publishing.

Olenick, R. P. (2008). *The mechanical universe: Introduction to mechanics and heat*. Cambridge University Press.

Olsen, C., & Diane, M. (2004). *Cross-sectional study design and data analysis*. College Entrance Examination Board.

Palmer, D. (1993). How consistently do students use their alternative conceptions? *Research in Science Education*, *23*(7), 228–235.

Pozo, J., & López-Íñiguez, G. (2014). Like teacher, like student? Conceptions of children from traditional and constructive teachers regarding the teaching and learning of string instruments. *Cognition and Instruction*, *32*(3), 219-252.

Rapp D.N. (2005). Mental models: Theoretical issues for visualizations in science education. In J. K. Gilbert (Ed.), *Visualization in science education*: *Models and modeling in science education* (pp. 43-60). Springer, Dordrecht.

Ross A., & Willson V. L. (2017). Paired samples t-test. In A. Ross & V.L. Wilson (Eds.), *Basic and advanced statistical tests* (pp. 17-19). SensePublishers, Rotterdam.

Seker, H., & Welsh, L. (2006). 'The use of history of mechanics in teaching motion and force units'. *Science & Education*, *15*(1), 55–89.

Sjoberg, S., & Imsen, G. (1998). Gender and science education. In P. J. Fensham (Ed.), *Development and dilemmas in science education*, (pp. 218-248). Falmer.

Skopeliti, I., & Vosniadou, S. (2014). Conceptual change from the framework theory side of the fence. *Science & Education*, *23*(7), 1427–1445.

Slater, E., Morris, J., & McKinnon, D. (2018). Astronomy alternative conceptions in pre-adolescent students in Western Australia. *International Journal of Science Education*, *40*(17), 2158-2180.

Soh, T., Arsad, M., & Osman, K. (2010). The relationship of 21st century skills on students' attitude and perception towards physics. *International Conference on Learner Diversity* , *2010*(*7)*, 546-554.

Sørensen, H. (2007). " Gender inclusive science education?" In D. Corrigan, J. Dillon, & R. Gunstone (Eds.), *Re-Emergence of values in science education* (pp. 249-269). Brill.

Sperandeo-Mineo, R., Fazio, C., & Tarantino, G. (2006). Pedagogical content knowledge Development and pre-Service physics teacher education: A case study. *Research in Science Education*, *36*(3), 235–268.

Stylos, G., Evangelaki, G., & Kotsis, K. T. (2008). Misconceptions on classical mechanics by freshman university students: A case study in a physics department in Greece. *Themes in Science and Technology Education, 1*(2)*,* 157-177.

Sun, L., Bradley, K., & Akers, K. (2012). A multilevel modelling approach to investigating factors impacting science achievement for secondary school students: PISA Hong Kong sample. *International Journal of Science Education*, *34*(14), 2107-2125. https://doi.org/10.1080/09500693.2012.708063

Taber, K. S. (2002). *Chemical misconceptions: prevention, diagnosis and cure.* RSC.

Taber, K. S. (2008). Conceptual resources for learning science: issues of transience and grain- size in cognition and cognitive structure. *International Journal of Science Education*, 30(8), 1027-1053. https://doi.org/10.1080/09500690701485082

Taber, K. S. (2009). *Progressing Science Education*. Springer.

Taber, K. S. (2014). Meeting Educational objectives in the affective and cognitive domains: Personal and social constructivist perspectives on enjoyment, motivation and learning chemistry. In M. Kahveci, & M. Orgill (Eds.), *Affective dimensions in chemistry education.* (pp. 3-27). Springer.

Treagust, D., & Chu, H. (2014). Secondary students' stable and unstable optics conceptions. *Journal of Science Education and Technology*, *23*(2), 238–251.

Treagust, D., & Duit, R. (2008). Compatibility between cultural studies and conceptual change in science education: there is more to acknowledge than to fight straw men! *Cultural Studies of Science Education*, *3*(2), 387–395.

Tsai, Y.-M., Lauermann, F., & Eccles, J. S. (2017). Math-related career aspirations and choices within Eccles et al.'s expectancy–value theory of achievement-related behaviors. *Developmental Psychology, 53*(8), 1540–1559.

Tytler, R. (2007). The nature of students' informal science conceptions. *International Journal of Science Education*, *20*(8), 901-927. https://doi.org/10.1080/0950069980200802

Villarino, G. N. (2018). An investigation of students' conceptual understanding of the concepts of force and energy. *International Journal of Innovation in Science and Mathematics Education*, *26*(6), 22-61.

Vosniadou, S., (2019). The development of students' understanding of science. *Frontiers in Education*, *4*. https://doi.org/10.3389/feduc.2019.00032

Wagner, W. (2019). *Using IBM® SPSS® statistics for research methods and social science statistics*. SAGE.

Wallace, C., & Brooks, L. (2014). Learning to teach elementary science in an experiential, informal context: Culture, learning, and identity. *Science Education*, *99*(1), 174-198.

Wood-Robinson, C., & Clough, E. (2010). Children's understanding of inheritance. *Journal of Biological Education*, *19*(4), 304-310. https://doi.org/10.1080/00219266.1985.9654757

Yockey, R. (2007). *SPSS demystified: A step-by-step guide to successful data analysis*. Prentice Hall Press.