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LEVERAGING PROSPECTIVE ELEMENTARY TEACHERS' STEM LEARNING EXPERIENCES: INTRODUCTION OF AN ACE MODEL

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Synopsis:

There is a need to elevate the mathematics learning experiences for prospective elementary teachers (PSETs) in acquiring mathematics knowledge through inquiries, exploring the role of mathematics in other STEM disciplines, and solidifying knowledge and skills in teaching contexts as sustainable practices. In this presentation, I will introduce an ACE course design model and will discuss its potential for creating an active learning environment to engage PSETs' mathematics and STEM learning.

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A recent research report from the National Survey of Science and Mathematics Education (NSSME) shows that mathematics and science teachers in the elementary and middle school grades do not have strong content preparation in their respective subjects and they do not feel equally prepared in each area (Banilower et al, 2018). In the mathematics education research community, the quality of preparation of future K-8 teachers has always been a central concern. To address this concern, Phillips and colleagues provided the opportunity of an early field experience to pre-service elementary teachers to enhance their content knowledge and beliefs *while* they are learning the mathematics they would teach (Philipp, et al., 2007). However, very little research has studied prospective elementary teachers' (PSET) learning experiences in mathematics *before* their admission to a teacher education program. That said most of prospective elementary teachers' learning experiences in mathematics are in the college classrooms. To explore methods for improving the design of mathematics content courses for prospective teachers, the question that motivates the study is: What types of curriculum materials are effective in leveraging prospective elementary teachers' learning experience in mathematics?

The development of mathematics content knowledge for PSETs takes place in undergraduate courses (AMTE, 2017). In many teacher education programs, PSETs are required to take one or more mathematics content courses from a mathematics department prior to admission into the program. Teacher education and research communities have been examining ways to help PSETs develop a deeper understanding of mathematical concepts, situate mathematics learning in meaningful contexts, and create learning communities that teachers and students engage in rich mathematical discourses. However, very little research has studied PSETs mathematics learning in a mathematics content course through the integration of STEM inquiries that extends their learning experiences beyond mathematics.

Engage PSETs Mathematics Learning in the Context of Integrated STEM Inquiry

There is an urgent need for an integrated approach to K-12 STEM education, leveraging its ability to the "enhance motivation for learning and improve student interest, achievement and persistence" (NRC, 2014, p.1). The integrated approach teaches STEM in a more connected manner, especially in the contexts of real-world issues, making STEM subjects more relevant to students and teachers (e.g., Bybee, 2013; NRC, 2014). Mathematical literacy is foundational to STEM education, where skills in dealing with uncertainty and data are central to making evidence-based decisions involving ethical, economic, and environmental dimensions. Mathematics thus warrants increased recognition for its role in developing students' abilities to analyze and reason with data in making informed decisions (English, 2016). The capacity to reason quantitatively within real-world contexts involves critical concepts such as number sense, ratio, measurement, problem solving, mathematical modeling, and proportional reasoning. These concepts have a common thread—applying mathematics to a STEM context—but significant differences can exist. Some emphasize using basic mathematics in sophisticated ways, while others include more advanced mathematics and critical thinking. This study emphasizes on the application of geometry and measurement concepts in STEM contexts.

Research on integrated STEM learning suggests that the instruction is often accomplished through the use of inquiry-based learning to engage students in solving complex problems that reflect real-world situations. Inquiry-based integrated STEM learning productively engages students in ways that transform their identity with respect to STEM, and this effect may be particularly strong for populations that have historical struggled in STEM classes and are underrepresented in STEM higher education programs and professional (NRC, 2014). Integrating STEM inquiries into mathematics content courses affords excellent learning opportunities for PSETs to build connections among STEM disciplines that they are going to teach and to gain appreciation of mathematics years before their teaching practices.

The ACE Model for Undergraduate PSET Mathematics Instruction

Curriculum developers and teacher educators have put forth efforts to improve the design of mathematics content courses for PSETs by promoting classroom discourse practices, or adding instructional materials, such as classroom video clips to examine students' mathematical thinking and reasoning. Others have recommended active learning strategies, including using dynamic software, student centered group discussion, and hands-on activities, so that the knowledge is acquired by participating in mathematics discourse or by working in a pre-constructed situation. However, our experiences from teaching mathematics content courses and conversations with other mathematics instructors indicate that even when PSETs attended a thoughtfully planned course designed to engage them in rich mathematical thinking, many reacted to the course in a perfunctory manner. For example, Hart et al. (2013) examined PSETs' perceptions of the mathematics content courses and found that what PSETs learned in their mathematics content courses rarely supported them to develop a positive attitude toward mathematics learning, disconnected to their future teaching, and failed to develop their mathematics knowledge for teaching in a robust way. This paper aims to discuss the affordance of ACE course design model for advancing PSETs' mathematics learning and teaching experiences by: (1) *Applying* learned knowledge and skills to the practice of teaching, (2) *Connecting* crosscutting concepts through STEM inquiries and practices; and (3) *Experiencing* community-based experiential learning to enhance their attitudes and beliefs toward mathematics teaching and learning. Each element of the ACE model has shown promise for improving PSETs learning outcomes. However, these promising tools are rarely integrated and deployed in core disciplinary mathematics classes. In the following, a brief description of the ACE model is provided.

Applying learned knowledge and skills to the practice of teaching

The phrase "apply learned knowledge and skills to the practice of teaching" often refers to the notion of pedagogical content knowledge (PCK) (Shulman, 1986), or the knowledge of content and students (KCS) (Hill & Ball, 2008). For example, in a mathematics content course, PSETs are often asked to "making sense of students' mathematical ideas, processes, and practices" (AMTE, 2017, p.74), a common practice of elementary teachers. However, these could be challenging tasks for some PSETs because they may lack understanding of how children learn mathematics. *Applying Learned Knowledge and Skills to the Practice of Teaching* extends PSETs learning experiences beyond their own mathematics classrooms. In particular, it provides learning opportunities for PSETs to interact with elementary school students outside of classrooms, applying their knowledge and skills in teaching contexts. This approach supports Bybee's (2013) argument, "discipline-based knowledge is essential. However, so are opportunities to learn how to apply knowledge and skills to situations one confronts…"(p.X).

Connecting crosscutting concepts through integrated STEM inquiries and practices

Mathematics teacher educators strive to improve the quality of the teacher preparation programs. In mathematics content courses, methods of incorporating active learning strategies and facilitating student-centered classroom norm are used to engage PSETs' learning. For example, using hand-on activities to make abstract concepts more concrete and visible, or connecting mathematics concepts with visual arts (e.g., fractals, symmetry, golden ratios, etc.) to gain appreciation for mathematics. However, as described earlier, PSETs will be responsible for teaching multiple subject areas including science, mathematics, literacy and social studies in elementary schools. *Connecting crosscutting concepts through integrated STEM inquiries and practices* provides PSETs with learning opportunities for exploring pedagogies and practices of integrated STEM inquiries, and demonstrates that "mathematics can influence and contribute to the understanding of the ideas and concepts of other STEM disciplines" (p. 241). This element of the ACE model also offers opportunities for PSETs to strengthening their understanding of elementary STEM education.

Experiencing Community-based Experiential Learning (CBEL)

Sociocultural and constructivist theorists both highlight the crucial role that activity plays in mathematics learning and development. Cobb (1994) argued, "mathematical learning should be viewed as both a process of active individual construction and a process of enculturation into the mathematical practice of wider society" (p. 13). That is, constructivists analyze thought in terms of conceptual processes located in the individual, whereas sociocultural theorists take the individual-in-social action as their units of analysis (e.g., Minick, 1989; Sfard, 1998). For example, when teacher educators try to *create* experiences for PSETs to enhance their conceptual understanding, they view mathematical learning as active construction. Cobb called to explore ways of coordinating constructivist and sociocultural perspectives because "each of the two perspectives, tell half of a good story, and each can be used to complement the other" (p.17). Mathematics teacher educators have endeavored to improve PSETs mathematical learning in active construction, but there is scholarship to be done when it comes to exploring the possibility of coordinating constructivist and sociocultural perspectives. The term, "*Community-Based Experiential Learning" comes from Kolb's (2015) framework. Integrating CBEL* in mathematics content courses provides PSETs access to socially and culturally diverse interactions with elementary school students. Interactions with diverse elementary school children will influence the processes of PSETs' mathematics reasoning and its increasingly sophisticated mathematical ways of learning the content (e.g., Philipp et al. 2007; Kolb, 2015).

CBEL does not just benefit PSETs mathematical learning, but also increases their civic engagement, and offers educational opportunities in acquiring 21st –century workforce skills as future teachers. Research in CBEL and teacher education argues that as a teaching and learning pedagogy, CBEL increases critical teaching dispositions such as professional commitment and acceptance of diversity. According to Bringle and Hatcher (2000), CBEL is a course-based educational experience in which students participate in an organized community-based activity that meets community needs and reflects on the experiences in such a way as to gain further understanding of course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility. That is, CBEL not only provides PSETs the opportunity to interact with children that may enhance their mathematics learning, but more importantly it may effect their beliefs about mathematics, their attitudes towards mathematics learning and teaching (NRC, 2014). As discussed, the ACE model not only has its practical values, but also is supported by several learning theories.

ACE Geometry and Measurement Course Design & Development

As in many college-based mathematics content courses, the Geometry and Measurement course designed for PSETs usually includes the study of two-and three-dimensional geometric objects and related measurements, as well as concepts in Euclidean transformations, symmetry and similarity. PSETs are often not engaged in learning geometry and measurement concepts because their thinking operates at low levels of geometric thinking (Wang, 2016), and the concepts are often taught in isolation with rote memorization that offers little connection to real world applications. In ACE geometry and measurement course, PSETs will have opportunities to explore mathematics through inquiry-based learning using integrated STEM inquiry modules, and apply learned knowledge to the practices of teaching with elementary students through community-based experiential learning.

Hands-on, Inquiry-based Learning has been advanced as a particular approach to the design of engaging inquiry activities that offer students the opportunity to investigate authentic topics and engage in learning processes that transcend traditional methods of instruction (BIE, 2016). Hands-on elements (e.g., designing artifacts or conducting experiments) are embedded within inquiry-based learning, allowing PSETs to work side-by-side in teams or small groups, and offering new opportunities for relevant, productive classroom norms and discourse practices. For instructors teaching the course, they incorporate the "Five Practices" for orchestrating productive discussion in mathematics and science (Smith & Stein, 2011; Cartier et al, 2013) to guide the instructional planning and classroom discussions to inform classroom discourse practices, and to keep students "hands-on and minds-on". The inquiry-based learning context will allow PSETs to experiment with both concepts in mathematics and applications in other STEM disciplines.

Integrated STEM Inquiry Activities provide an engaging context in which PSETs can practice and apply learned knowledge and concepts. Prior research has shown the advantage of engaging students in integrated STEM inquiry that require the application of multiple STEM concepts and skills as opposed to focusing on instruction in discrete subject areas. By adding integrated STEM inquiry activities as co-curricula materials to reveal geometry and measurement concept through other STEM disciplines, it provides PSETs the *early* exposure to integrated STEM inquiry (an on-going professional development activity for in-service teachers in STEM education), and the opportunity to enhance their understanding and appreciation of mathematics in STEM disciplines. Using an integrated STEM inquiry approach will thus help engage PSETs learning in mathematics and in STEM education.

Community-based Experiential Learning (CBEL) offers learning experiences for PSETs to apply their knowledge and skills to the practices of teaching. After PSETs explore the integrated STEM inquiry activity in class, they will work in teams of 4 people to plan and facilitate the module in afterschool programs as a course activity. This course component serves as an experiential learning activity that provides PSETs the opportunity to interact with elementary school students, to apply their learned knowledge and skills, and to enhance their knowledge and appreciation of mathematics, and to increase their self-efficacy in elementary STEM education.

Inquiry Design of "3D Crystal Structure of Solids"

The **3D Crystal Structure of Solids** is designed as a co-curricular activity to be used in the ACE geometry and measurement course. The activity is relevant to and motivated by our students' surroundings in aspects of daily life and research activities on campus (e.g., rock salt and solar cells etc.). **Figure 1** illustrates crosscutting concepts in this ***3D Crystal Structure of Solids activity*** and the mathematics concepts that are introduced in the ACE geometry and measurement course. Table 1 highlights the implementation of the activity and related the instructional practices.

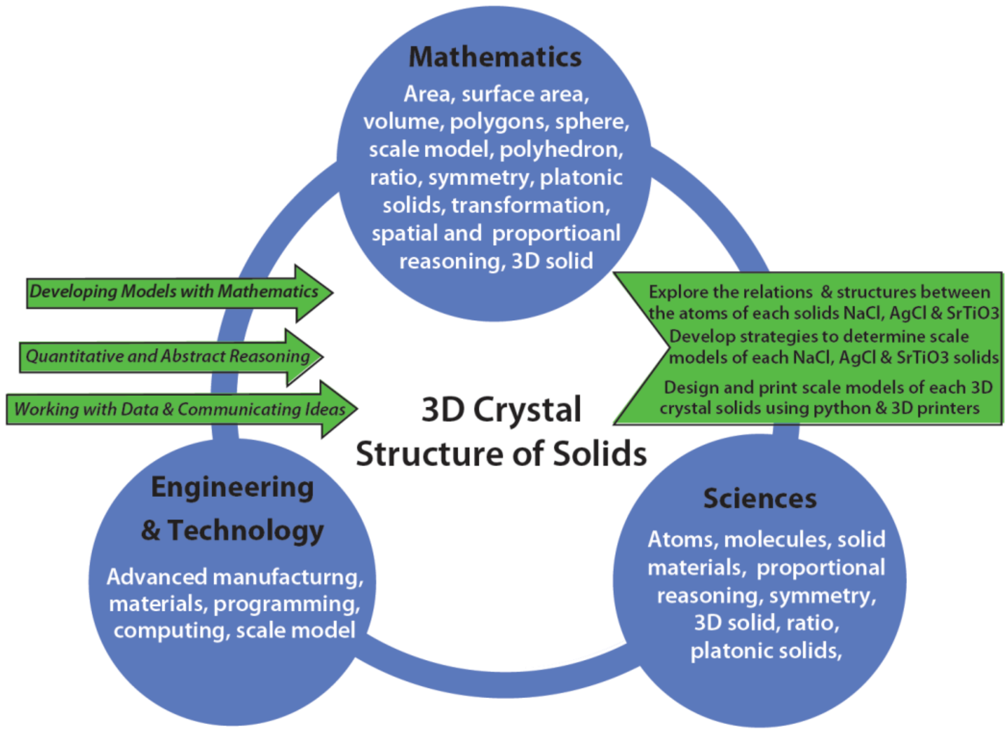
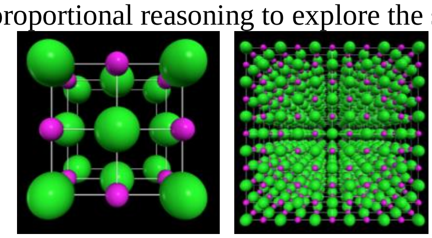
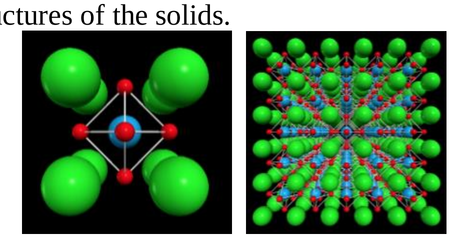


Figure 1. Crosscutting concepts in the module of 3D Crystal Structure of Solids

Figure 1 summarizes one of the IME STEM inquiry models, including concepts in mathematics, science, technology and engineering that are highlighted in the module of "3D Crystal Structure of Solids", and some key mathematical practices that will guide the enactment of the inquiry module. For example, this module is designed to engage and advance student mathematics learning by connecting important mathematics concepts (e.g., ratio, similarity, platonic solids, spheres, symmetry, etc.) with crosscutting concepts (e.g., material and scale model) in engineering and disciplinary core ideas (e.g., crystal solid structures) in science. **Table 1** provides a snapshot of the 3D Crystal Structure of Solids inquiry module's learning goals, learning activities, assessment strategies, and final products, etc.

Table 1. Dimension for the module of 3D Crystal Structure of Solids

Module Title	3D Crystal Structure of Solids
Module Description	PSETs will work in teams of 4 to investigate solids with face centered cubic (fcc) crystal structures such as NaCl, AgCl and Perovskite structures such as $SrTiO_3$, $CaTiO_3$ and so on. They will apply concepts in geometry & measurement to design and build scale models of crystal structures using different parameters in a pre-developed, Python graphical user interface (GUI). They will then print the 3D scale models and use proportional reasoning to explore the structures of the solids.  NaCl with 1 (left) and multiple (right) unit cells  SrTiO3 with 1 (left) and with multiple (right) unit cells

Final Product	Design and visualize solid structures of $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$, using a pre-developed, open-source Python GUI and print the 3D scale models of the solids using 3D printers.
Crosscutting STEM Concepts	Volume, platonic solids, ratio, scale model, similarity, symmetry, programming, computing, advanced manufacturing, proportional reasoning, material, crystal solids
Learning Goals	**Learn** geometry & measurement concepts from the Textbook materials **Apply** the concepts to design and build 3D crystal structure of solid using IME STEM inquiry study guide & worksheet **Connect** crosscutting concepts in STEM through inquiry module and practices
Guiding/Driving Question	How can we design 3D crystal structure solids of $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$?
Sample Sub-questions	What shapes do $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$ have and how do you describe them? How do we build a scale model of each $NaCl$, $AgCl$ & $SrTiO_3$, and $CaTiO_3$? What mathematics concepts are needed to design and visualize scale models of $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$ using the Python GUI? By varying the ratios of size between the atoms in the Python GUI, what are the roles of ratio in constructing different structures of $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$ that help us to understand solid structures and to determine their configuration parameters? What symmetries can you describe using printed scale models of $NaCl$, $AgCl$ & $SrTiO_3$, and $CaTiO_3$?
Sample Learning Activities	**Research** on solid structures of $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$ and their configuration parameters (sciences & mathematics) **Build** scale models of each $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$ by using different parameters using pre-developed Python GUI (mathematics, technology & engineering). **Visualize** created 3D models of $NaCl$, $AgCl$ & $SrTiO_3$, $CaTiO_3$ using spatial reasoning through the Python GUI (mathematics & science) **Print** the output mesh file (STL format) using 3D printers (technology & engineering)
Assessment Strategies	**Five Practices:** facilitate classroom discourse practices **Process assessment**: classroom assessment using questioning techniques to assess student learning through in-class discussions. **Outcome assessment**: Pre-& post- surveys, Cognitive-Based Assessment, reflections
Tools & resources	Textbooks, online course template for instructors, IME STEM inquiry website, Student IME STEM study guide & worksheets, computers installed with pre-developed Python GUI and Netfabb software (for 3D printing), 3D printers, plastics (ink) for 3D printing
Aligned Course Content	**Geometry**: Lines, angles, circles, spheres, polygons, polyhedron, solids, platonic solids, symmetry, similarity, reflection, rotation, translation; **Measurement**: length, area, surface area, volume, capacity, dimensions
Aligned Practice Standards	Reason abstractly and quantitatively, model with mathematics, use appropriate tools strategically, look for and make use of structure (CCSSM, 2010) Developing and using models, analyzing and integrating data, using mathematics and computational thinking, constructing explanation (NGSS, 2013)

Discussion

The ACE course design model leverages different learning experiences for PSETs to learn and practice mathematics in and outside their traditional college classrooms, and made it possible to incorporate to Cobb's (1994) view, "Mathematical learning should be viewed as both a process of active individual construction and a process of enculturation into the mathematical practice of wider society" (p. 13), with what experiential learning could offer to better prepare our future teachers. In this approach, the ACE model provides PSETs the opportunity to have socially and culturally diverse interactions with elementary school children through organized STEM inquiry activities. In terms of the design and development of curriculum materials, it is a work of an interdisciplinary team, and collaboration among a university and local community partners. The development of ACE course design model took a first step in exploring methods of improving the design of mathematics content courses to engage PSETs mathematics learning. It also took a first step to reconsider the possibilities of multiple approaches of instructional and curriculum changes in mathematics content courses for future teachers in our teacher preparation program.

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