From the Editor
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New Year's greetings to our readers! When we started the *Southeast Asian Journal of STEM* Education in July 2020, we could not have known that a year and a half later the world would still be trying to contain the Covid-19 virus and its mutated variants. We now usher in a new year with a new variant: the Omicron with its unbelievable 50 mutations. As STEM educators, we are aware of what viruses can do to disrupt life, not only for humans but all forms of organisms. Of course, we just happen to take it personally.

While many journals worldwide have received a lower number of submissions and have scaled back their issues per year (*SAJSE* included), we have been fortunate to receive several quality articles to meet our goal of at least five quality articles per issue. We feel that it is important to contribute to the knowledge base of STEM education and will continue to do so despite the challenges faced during the ongoing pandemic.

I would like to take the opportunity to thank the journal's Managing Editor, Thundanai Yoosamran for his excellent assistance in not only readying the articles for publication by formatting, laying out, and publishing each one, but also for keeping the journal page updated by working with the website technicians. I also owe a debt of gratitude to our in-house STEM education senior specialists Dr. Mark Wingate and Dr. Ed Reeve for giving valuable feedback about each manuscript's potential, to the Associate Editors for advice, and to Review Board members who give time to look critically at the submissions and give needed critiques.

In this issue, Volume 3, Number 1, we once again have five high quality articles, each with a unique perspective on STEM education. **Yi-Jung Lee** studied 12 STEM project-based units in an elementary school and analyzed how student teachers leveraged students' readiness, interest, and learning style to support equitable participation. **Grace Rusk Kerr** and **Michael K. Daugherty** examined the similarities and differences in the formation and implementation of both STEM education and multimodal literacy instruction, including misconceptions about and obstacles to program implementation. From a presentation at an international science education conference, **Pradeep Dass** discusses the critical roles of collaboration and teamwork in STEM education, not only in a local context but also when studying global issues. In his second co-authored article for this issue, **Michael K. Daugherty** joins with his university colleagues **Heather D. Young, Vinson Carter,** and **Leah R. Cheek** in laying out research that argues for integrated STEM lesson planning and in sharing an example from an elementary classroom project. Integrating mathematics with augmented reality technology is the basis for a literature review by **Carlo Godoy, Jr.** to support schools transitioning to smart campus curricula.

As always, we thank you for your interest in the *Southeast Asian Journal of STEM Education* and encourage you to share these fine articles with your colleagues and if a faculty member at a university, to also share them with your graduate students. We invite all STEM educators to submit a manuscript for consideration. Please send inquiries to Editor John Stiles at jsscience@yahoo.com and submit articles to Managing Editor Mr. Yoosamran Thundanai at stemjournal@seameo-stemed.org.

John Stiles

John Stiles, Ph.D., Editor in Chief

Supporting Equitable Participation Through Project-Based STEM Learning at the Elementary Level

Yi-Jung Lee
University of Arkansas, Fayetteville, Arkansas, USA
yl049@uark.edu

Abstract

This study examined 12 project-based STEM curriculum units designed for elementary school students and identified the characteristics of the curricular components in terms of content, process, and product. In addition, when the STEM units were implemented, how student teachers leveraged students' readiness, interest, and learning style (Tomlinson, 2014) to support equitable participation was analyzed and is discussed in this article. The findings showed that project-based STEM units that support equitable participation possessed several salient features. The curriculum content consisted of nonsingular concepts of subject matter knowledge and allowed multiple difficulty levels. In terms of the process, the STEM units encouraged the adoption of mixed learning styles, which could be carried out in various contexts with learning simulations and rich online resources. Regarding the product, the author explains how the STEM units required multiple representations, valued functionality, and appreciated aesthetics. Implications for how project-based STEM lessons can be enacted to support equitable participation in STEM learning and the significance of these findings are discussed.

Keywords: STEM project-based learning, equitable participation, differentiated instruction, student interest

The concept of educating students with diverse learning needs together within the regular classroom was introduced to the public at the end of the 20th century (Nordlund, 2003). Tomlinson (2014) asserted that teachers currently face the same question as teachers did decades ago: "How do I divide time, resources, and myself so that I am an effective catalyst for maximizing talent in all my students?" (p. 1). To support the equitable participation of students with different academic backgrounds, interests, and learning performance, educational authorities are seeking "teaching and learning strategies that cater for a variety of learning profiles" (Subban, 2006, p. 935).

Over the past two decades, science, technology, engineering, and mathematics (STEM) occupations have become "among the highest paying, fastest-growing, and most influential in driving economic growth and innovation" (Thomasian, 2011, p. 5). Hence, it is imperative to increase students' STEM proficiency and career aspirations from an early age (Chambers et al., 2018). Project-based learning (PBL) is a pedagogical method to engage learners in the process of inquiry and investigation based on the constructivist perspective (Han & Bhattacharya, 2001). PBL exposes students to real-world, challenging projects and values collaboration, and authentic learning experiences in a student-directed, teacher-facilitated environment (Erdogan & Bozeman, 2015; Laur, 2013). Researchers have claimed that PBL can be an optimal pedagogical method for assisting students' STEM learning and providing students with more inclusive and equitable experiences as it values student voice and choice (Erdogan & Bozeman, 2015; Mergendoller, 2018). Therefore, it is beneficial for educators to gain insight into how project-based STEM lessons support students' equitable participation at the elementary level.

In this study, the author examined 12 student teachers' project-based STEM curriculum units designed for elementary-school students (Table 1). These units can be completed in one week (5-day schedule) and were taught in grades K-5, self-contained classrooms during the unit designers' sole teaching practicum. The title of unit, standard alignments, and targeted grade level for each unit can be found in Table 1. By analyzing the curricular elements of these project-based STEM lessons, the characteristics in the student teachers' lesson plans were identified and how education stakeholders can benefit from this knowledge were discussed.

Conceptual Framework

Research has shown that individuals do not all learn in the same way (Green, 1999; Guild 2001). To effectively meet the needs of diverse learners, teachers must make specific adaptations to their lesson plans and teaching approaches. According to Heacox (2012), differentiated instruction means "changing the pace, level, or kind of instruction you provide in response to individual learners' needs, styles, or interests" (p. 5). Furthermore, Tomlinson (2014) emphasized the importance of students' prior knowledge, curiosity, and learning profiles when implementing differentiated instruction, with a focus on three curricular elements: *content* (what students need to learn), *process* (activities designed to engage students), and *products* (student presentations). These three elements were considered as main themes to guide the analysis in this study. The content differentiation was analyzed based on the STEM content standards with which the unit aligns, and the process differentiation was examined based on the approaches used to help students accomplish activities. To determine the product differentiation, the characteristics of student products were identified. Last, the considerations of students' readiness, interest, and learning style in lesson planning were also scrutinized to identify the attributes that support students' equitable participation.

Methods

Participants

Twelve student teachers who enrolled in a graduate certificate program with a concentration in STEM education were student teaching at local elementary schools and selected as participants in this study. They were in the last year of the five-year Elementary Education Master of Arts (MAT) program at a large research university in the southern United States.

Procedures

This study was conducted in the Problem-based Mathematics course in spring 2021. In this course, participants were required to design four STEM lessons and one project-based curriculum unit. At the same time, they were conducting action research for their MAT thesis, so some STEM lessons and curriculum units were carried out in their placement classrooms.

Data Collection

The collected data in this study included curriculum units from 12 student teachers. The components of the curriculum unit consist of big ideas, essential questions, scenarios, challenges, materials, daily lessons, standards, limitations, results, assessment, and deliverables. A video presentation of the curriculum unit was required as the course final project.

Data Analysis

To identify the characteristics and understand how the lessons support equitable participation, collected data were analyzed by applying thematic analysis (Clarke & Braun, 2014), in which the author "identified, analyzed, and reported patterns (themes) within data" (p. 79), and then conducted microanalyses to identify emergent subthemes based on the three curriculum elements. The author initially identified the STEM content standards with their corresponding activities. Then, the process and student products were analyzed and reported by the subthemes detected. In addition, the extent to which students' readiness and interest were factored into the lesson planning was also described. Student teachers' video presentations were used as a supplement to the written STEM curriculum units.

Results

Three main attributes were revealed in the project-based STEM units: (a) different difficulty levels, (b) mixed learning styles, and (c) multiple modes of presentation. These were followed by the consideration of student readiness and interest. In the following, examples were provided to elaborate on these characteristics in this paper and all units with the standards with which they were aligned. The attributes can be found in Table 1. Four main standards were employed to guide student teachers' STEM units: (a) Common Core State Standards (CCSS) (NGA & CCSO, 2010) along with the Arkansas mathematics framework (ADE, 2014, 2016); (b) Next Generation Science Standards (NGSS) (NGSS Lead States, 2013); (c) Standards for Technological Literacy (STL) (ITEEA, 2000); and (d) Standards for Technological and Engineering Literacy (STEL) (ITEEA, 2020).

Content Differentiation

To examine the content differentiation of the STEM units, the variety and extent of content standards were analyzed. That is, after identifying what specific STEM knowledge the unit designer wanted students to learn, the author found that the concepts of content knowledge were not introduced singularly, and two characteristics regarding content differentiation were revealed.

Targeting More than Two Content Standards

In most curriculum units, the initial learning goals were established such that students would explore more than two topics concerning STEM content knowledge. For example, the STEM unit "Design a New Animal Shelter" targeted the fourth-grade mathematics content standards "Operations and Algebraic Thinking" and "Measurement and Data" as well as other science, technology, and engineering core concepts for grades 3-5. This characteristic allowed a broad spectrum in students' STEM learning with a focus on mathematics. Another STEM unit, "Severe Storm," emphasized two science standards: "K-ESS2-1 Use and share observations of local weather conditions to describe patterns over time" and "K-ESS3-2 Ask questions to obtain information about the purpose of weather forecasting to prepare for, and respond to, severe weather," one engineering standard: "K-2-ETS1-2 Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem," and two mathematics standards that focus on Kindergarten: "Counting & Cardinality" and "Measurement & Data."

Allowing Different Difficulty Levels

The "Design a New Animal Shelter" unit also increased flexibility at the level of the designated content knowledge by providing different conditions in the unit plan. For example, the designer elaborated that she would adjust the number of animals and square footage as well as the shelter shapes for students on different academic levels. That is, advanced students were allowed to explore more complex structures and configurations while designing an animal shelter than other students in the same class. Another unit, "Let's Build a Food Truck," required students to consider the size of a food truck through applying their volume knowledge so it could be a simple rectangular box or a composite solid made of different 3-dimensional figures. Students were encouraged to demonstrate different levels of their mathematical knowledge while participating in this STEM unit.

Process Differentiation

The author examined process differentiation by analyzing the activities designed to strengthen students' construction and application of knowledge and skills in their learning environment. In the STEM units, the designers encouraged mixed learning styles in various contexts and three characteristics were identified in student teachers' curriculum units.

Occurring in Both Academic and Authentic Contexts

While learning activities could be mainly implemented in the classroom, project-based

STEM lessons extended the construction and application of knowledge within authentic contexts. For example, the Measurement unit had five-day lessons with activities to determine the lengths of selective classroom equipment, the distance from one end of the swing set to the other in the playground, and the measurements for directions in the school building using both traditional and nonstandard measuring tools (Figure 1). In this unit, students were encouraged not only to complete the assigned tasks but also to familiarize themselves with their learning environment from their classroom to the whole campus. The Create Animal Prosthetics unit concentrated on learning angle knowledge and tried to arouse students' empathy and humanity through applying the learned knowledge to create animal prosthetic devices so that they could move without severely disabling them.

Encouraging Mixed Learning Styles

Project-based STEM units encouraged mixed learning styles through visual, aural, kinesthetic, and reading/writing activities. For example, the Critter Crawlers unit exposed students to "little critter" books by Mercer Mayer and then requested them to create a similar creature and use electricity and vibration to produce life-like movements and sound. Throughout this process, students completed the unit by listening to and/or reading the story, writing their own plot, hand-making story characters with the backdrops, and then orally presenting their projects, in which their creature vibrates on its own. To achieve this goal, the student teacher prepared a series of the printed books and read-aloud videos, discussed story elements and the characters with students, provided a story structure worksheet with a semi-structure layout, and encouraged students to explore the story by using different approaches.

Using Simulations and Online Resources

It could be difficult for students to study natural phenomena in a realistic setting, and project-based STEM units thus took advantage of simulations. For example, students investigated rain clouds in the Severe Storms unit, in which they conducted a rain cloud investigation in a jar by using water, food coloring, pipettes, and shaving cream. The Create Animal Prosthetics unit included an online video to show a peacock who gets a prosthetic leg on Day 1 and provided a document of online resources as the basis for students to research more about animal prostheses on Day 2. This designer emphasized that students needed to know that engineers make changes to their designs and projects all the time, so it is okay to make changes along the way. During the work, students needed to know where and how to find the information they needed as well as continue testing and fixing their product after being informed by the weakness of the product.

Product Differentiation

Product differentiation was examined in students' demonstrations and presentations of what they had learned in the STEM units. To complete the units, students were allowed to employ multiple presentation modes, and three characteristics were highlighted in these project-based STEM units.

Requiring Multiple Modes of Representation

The assessment and evaluation of learning outcomes in project-based STEM lessons were diversified, which usually required more than one representation in students' demonstrations. For example, the Building a Food Truck unit asked students to present the food truck menu with its supply and demand items by using a table, a histogram, and verbal expression besides the physical construction of the truck. The table has shown numerical analysis of items on the inventory and the graph has presented the trends and relationship among items. Verbal explanations and arguments were needed for students to construct logical reasoning while presenting these data. Furthermore, the Q&A session was normally held to clarify information and support contentions made by the presenters in project-based STEM units when the outcome involved statistical data.

Valuing Functionality of the Product

One advantage of project-based STEM learning is that students are guided by essential questions. The goal of the lesson was to solve a relevant problem regarding the given scenario. In the Create Animal Prosthetics unit, the essential question was "Can you use angles to create a prosthesis that helps an injured animal stand on its own?" The goal for students was to research, design, and create a prototype prosthetic device for a toy animal. A successful product prioritized functionality by meeting the following criteria: (a) It must allow the animal to balance; (b) The prosthesis is removable; and (c) the angles of the prosthetic device are measurable. In the Making the Mayflower unit, students were required to create their ships that can float in the water and hold 102 pennies with the background history of the Mayflower that sailed from England to Massachusetts over 400 years ago. To make sure the built boat would function, the students started by learning the principles of floating boats, drew ideas for their boat in the design journal, made their boat based on their design ideas, tested how many pennies they can put on their boat without sinking it, and used a bar graph to record the data from each group. In this process, the student teachers made sure that students were capable to evaluate the functionality of the boat based on the constraints and provided materials. The procedure to keep track of the outcomes was rigorously completed via collecting, analyzing, and presenting information along the way.

Enhancing Aesthetics in the Design

The integration of art into STEM provided a nonjudgmental space to foster innovation in inquiry-based learning. The aesthetic consideration is extremely important for any public product. In the Building Class Community unit, the students were required to place six buildings in their community, with a focus on calculating the perimeter and area of all buildings. In students' final project, the layout and other art elements became part of their design because they wanted to build an appealing community. In the Build a Food Truck unit, students would get an opportunity to decorate their food truck not just for the convenience to deliver food, but also for attracting more people to stop by due to its fancy appearance.

Student Readiness and Interest

In the 12 project-based STEM units, five of them specifically addressed the importance of student readiness and interest. Student readiness was factored in while grouping students in several units and assigning sources for the project. In terms of student interest, the student teachers recommended the detailed steps to create a final product based on the engineering design process and the incorporation of hands-on materials and manipulatives.

Although some units did not specify student readiness and interest in the main body of the lesson plans, student teachers added the section of differentiation to explain how the activities could be modified for students who are not ready for the planned unit due to content difficulty, language disadvantage, or weak interpersonal interaction. It is obvious that through providing high-quality project-based STEM instruction, teachers can support elementary students' equitable participation in learning.

Figure 1

Second graders gathering to develop strategies for a mathematical problem on Day 2 in the Measurement Mania unit. Photo by Abigail McCoy. Used by permission.

Table 1

The 12 STEM curriculum units with title, standards, and attributes exhibited

Unit	**Title (Grade level implemented)**	
	Standards Alignment (CCSS, NGSS, STL, & STEL)	Attributes the unit exhibited
1	Severe Storms (Kindergarten)	
	CCSS.Math.Content.K.MD.1 & 2 & CC.6 NGSS K-ESS2-1 & 3-2 and K-2-ETS1-2	☐ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
2	Time for Time (1st grade)	
	CCSS.Math.Content.1.MD.3 CCSS.ELA-Literacy.SL.1.2 NGSS K-2-ETS1-1 &2; 3-5-ETS1-1; 1-LS1-2 & 3-1	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
3	Making the Mayflower (1st grade)	
	CCSS.Math.Content.1.NBT.1 & MD.4 NGSS K-2-ETS1-1, 2, & 3 Arkansas Social Studies G1 H.12.1.4 Arkansas English Language Arts G1 W.1.10	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
4	Critter Crawlers (1st grade)	
	CCSS.Math.Content.1.G.1 CCSS.ELA-Literacy.RL.1.2 & 3 NGSS 1-PS4-A STL.#3.K-2	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
5	Measurement Mania (2nd grade)	
	CCSS.Math.Content.2.MD.1 & 2 CCSS.ELA-Literacy.SL.2.1.A NGSS K-2-ETS1-1	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
6	Measurement Unit (2nd grade)	
	CCSS.Math.Content.2.MD.2 NGSS K-2-ETS1-2 STL.#1.K-2	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
7	The Bad Seed Uses Measurement (2nd grade)	
	CCSS.Math.Content.2.MD.1 and 3.MD.2, 3, & 4 NGSS 3-5-ETS1-1 & 2-LS2-2	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
8	Building Class Community (3rd grade)	
	CCSS.Math.Content.3.MD.5, 6, & 7 NGSS 3-5-ETS1-1 & 2 and 3-ESS3-1	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
9	Design A New Animal Shelter (4th grade)	
	CCSS.Math.Content.4.OA.3 & 4.MD.3 STEL.#2 & 7.3-5	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation

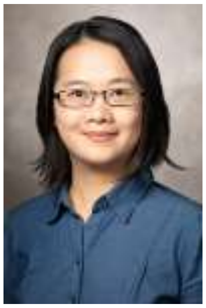
10	Create Animal Prosthetics (4th grade)	
	CCSS.Math.Content.4.MD.5 & 6 NGSS 3-5-ETS1-1, 2, & 3 and 4-LS1-1	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
11	Survivor Challenge (5th grade)	
	CCSS.Math.Content.4.MD.3 & 4 CCSS.Math.Content.5. G.1 and MD.2 & 5 NGSS 3-5-ETS1-1, 2, & 3	☐ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation
12	Build a Food Truck (5th grade)	
	CCSS.Math.Content.5.MD.2 & G.2 NGSS 3-5-ETS1-1 & 2 Arkansas Social Studies G4 E.5.4.3	☒ Different difficulty levels ☒ Mixed learning styles ☒ Multiple modes of presentation

Discussion

In the current study, the unit engaged students in the STEM learning on the content, process, and product aspects. In addition, students showed productive disposition with learning interest and readiness, which echos Shin's (2018) finding that students maintain high motivation and self-efficacy during their participation in project-based learning. Furthermore, the activities embedded in project-based STEM units were experienced via mixed learning styles in various contexts to highlight students' strengths and promote communication and participation, which also corresponds to the teaching moves that support equitable participation recommended by Wood et al. (2019). In addition, the STEM units encouraged students to employ multiple modes of presentations in their product due to the importance of justifying solutions, legitimately and comprehensively, which has been emphasized in both Common Core State Standards (NGA, 2010) and the Next Generation Science Standards (2013). All these features enhanced students' active participation in mathematical problem solving with lower anxiety, which has been associated with improved cognitive performance (Ashcraft, 2002).

Conclusion

The author concluded that when students felt comfortable with uncertainty and secure regarding the content, process, and product, educators could support equitable participation in STEM at the elementary level. Project-based STEM units that intentionally adopted nonsingular concepts of content knowledge can expand the spectrum of STEM competence for elementary students. In addition, when the content focused particularly on mathematics, the participating educators watched the young learners volunteer to bring ideas to the table and collaborate with team partners to figure out solution strategies (Figure 1) and witnessed the elder students continue being creative in designing the floor plans for different numbers of animals through using measurement even when they had failed on several drafts. The characteristics of process differentiation also exemplified that project-based STEM units can encourage authentic learning by using simulation. These findings have implications for educators and researchers, who may identify additional constraints and advantages regarding the development and adoption of project-based curriculum units in other subjects in K-12 education.



Yi-Jung Lee is an assistant professor at the University of Arkansas in the United States. Dr. Lee received her Ph.D. in Mathematics Education from the University of Georgia and has had rich math and STEM teaching experience at elementary schools in both the United States and Taiwan since 2005. She is committed to working with in-service and pre-service elementary school teachers to facilitate children's STEM learning with a focus on mathematics in formal and informal environments. Dr. Lee's research interests include mathematics and STEM teacher education, mathematical problem-solving, integrated STEM curriculum, and STEM problem- and project-based learning.

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Connections between STEM Education and Multimodal Literacy Instruction

Grace Rusk Kerr and Michael K. Daugherty*
University of Arkansas, Fayetteville, Arkansas, USA
*Corresponding author: mkd03@uark.edu

Abstract

STEM education and multimodal literacy instruction offer particular benefits to learners beyond the important 21st Century skill advantages outlined by policy advisors, educators, and CEOs. Both multimodal literacy instruction and STEM education give learners opportunities to move from being *consumers* of knowledge and meanings chosen and disseminated through the lens of the power group to being *producers* of knowledge and meanings across cultures and contexts. STEM education and multimodal literacy instruction offer pathways to meet the diverse academic and affective needs of learners, as well as for educational equity and opportunities, particularly for traditionally underserved populations. This study examines the similarities and differences in the formation and implementation of both STEM education and multimodal literacy instruction, including misconceptions about and obstacles to program implementation. Numerous studies demonstrate the effectiveness of and need for integrated STEM education at the elementary level. Preliminary research also indicates an integrated elementary curriculum might be valuable for delivering multimodal literacy instruction. Future research should focus on the effectiveness of integrated teacher preparation coursework in the areas of both STEM education and multimodal literacy instruction. Both STEM education and multimodal literacy instruction are rooted in goals for interdisciplinary practice. It is time to pursue these goals actively and consistently to ensure comprehensive foundational preparation of students in these areas and maintain their interest and engagement through secondary and post-secondary education, as well as into 21st Century careers.

Keywords: STEM education, multimodal literacy instruction, multilingual, multiliteracies, critical thinking, creative problem solving, inquiry-based learning, culturally responsive teaching, multimodal texts, integrated instruction.

The purpose of this article is to encourage the use of integrated models for elementary STEM education and for elementary multimodal literacy instruction, with the goals of promoting critical thinking and creative problem-solving, culturally responsive teaching and culturally relevant pedagogy, and sustained student engagement in the early grades. While we do review literature on STEM education and multimodal literacy as it pertains to both elementary and secondary education, our primary focus is on elementary education. To this end, we discuss the importance of STEM education and multimodal literacy instruction, the similarities and differences in the formation and implementation of both programs, and misconceptions about and challenges to the implementation of each program. In addition, we examine research on integrated STEM education at the elementary level that might serve as a model for teaching integrated multimodal literacy at the elementary level and ways the interdisciplinary goals of both programs might be explored through teacher preparation coursework. Finally, we suggest avenues for future research.

The Importance of STEM Education and Multimodal Literacy Instruction

Critical Thinking and Creative Problem-Solving

In addition to preparing future generations for changing global economies, both multimodal literacy instruction and STEM education give learners opportunities to move from being *consumers* of knowledge and meanings chosen and disseminated through the lens of the power group to being *producers* of knowledge and meanings across cultures and contexts. Moreover, these models provide opportunities to move from traditional didactic classroom spaces to hands-on, project-based learning environments that promote critical thinking and problem-solving skills.

Daugherty et al. (2017) underscore the importance of integrated STEM instruction for developing students' critical problem-solving skills. They point out that students become empowered by making connections between researching and solving STEM problems:

> Inclusion of engineering and technology at the elementary level provides children with the opportunity to be fully engaged and think critically about the problems that society is facing, especially through use of the engineering design process—which is central to the study of technology and engineering (p. 5).

Bybee (2010) also emphasizes the value of STEM education for helping students adapt and solve problems. He writes, "Students can develop 21st Century skills such as adaptability, complex communication, social skills, nonroutine problem solving, self-management/self-development, and systems thinking" (NRC, 2010, p. 31).

Williams (2015) recommends integrating multimodal literacy with inquiry-based learning, in which students work across disciplines to create digital artifacts that address issues of global importance. Whether issues are global, local, or a bit of both, Wiggins (2009), too, makes the case for authentic writing, the kind of writing that leads to that enduring understanding that in writing, audience and purpose dictate form and content. Planning backwards from the goal of a piece of writing, the "so what?" of the task, makes the task meaningful for students and teachers. Multimodal writing tasks that are part of project-based learning--such as those that follow format of the *UbD* (Understanding by Design) GRASPS (Wiggins & McTighe, 2005)--support this idea. For example, second graders may design a multimodal handbook of classroom procedures for when new students join the class, or fifth graders may create a podcast about school family events that can be posted to school social media sites. Wiggins argues, "…the point is to open the mind or heart to a real audience--cause a fuss, achieve a feeling, start some thinking. In other words, what few young writers learn is that there are consequences for succeeding or failing as a real writer" (2009, p. 30).

Culturally Responsive Teaching and Culturally Relevant Pedagogy

Gay (2010) and Ladson-Billings (1994) provide the foundational research for culturally relevant teaching and pedagogy. Gay defines culturally responsive teaching "as using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them" (p. 31). According to Ladson-Billings culturally relevant pedagogy (CRP) "empowers students intellectually, socially, emotionally, and politically using cultural referents to impart knowledge, skills, and attitudes" (pp. 16-17).

Studies in writing research, second language acquisition, foreign language learning, and reading research have examined the integration of various digital texts with literacy instruction (Tardy, 2005; Nelson, 2006; Selfe et al., 2007; Shin & Cimasko, 2008; Vasudevan et al., 2010). Selfe (2007) found the integration of multimodal communication in the classroom benefits students because:

1. it better prepares learners for their future, literate lives in a digitally mediated world;
2. it better matches learners' literacy practices in out-of-class environments; and consequently,
3. it engages and empowers learners to participate in language and literacy instruction. (p. 487)

Kim and Slapac (2015) assert that integrating multimodal texts and composition to expand the view of literacy in the classroom enables educators to access students' resources for linguistic and cognitive processing. Students are more likely to draw upon their background experiences for classroom learning when they are clearly encouraged to do so. Students recognize the separateness of in-school and out-of-school spaces, and schools do not always make or take time to affirm the different semiotics, modalities, and written/spoken communications of culturally and linguistically diverse learners. Educators must develop a space in which students believe they can share their diverse experiences and perspectives and that these experiences and perspectives are valued. "Such discursive space is essential to achieve the goal of transforming differences and conflicts into rich resources of learning and collaboration" (Gutierrez et al., 1999, p. 21). This "third space" as it is called is where one's home, family, and social network intersects with institutional constructs, such as school, work, or places of worship, for example (Moje et al., 2004). The third space aligns with multimodal literacy instruction, because it "brings competing knowledges and modes of communication into a conversation by challenging and reformulating the current academic literacy practices and discourses in youths' lives" (Kim and Slapac, 2015, p. 21).

With regard to STEM education, Leonard et al. (2018) write, "CRP creates the opportunity for students to learn in a third space where ethnic ways of knowing and core identities are valued alongside dominant canons of knowledge (Brown-Jeffy & Cooper, 2011; Gay, 2010; Lipka et al., 2005)" (p. 387). Culturally responsive STEM education research, with traditionally underserved populations, includes students identifying relationships between STEM applications and engineering students' daily lives (Wilson-Lopez et al., 2016), students producing their own scientific inquiry paths, connecting them to real-world models (Buxton, 2006), and students finding solutions to authentic math problems related to their lives and where they live (Ensign, 2003; Razfar, 2012). "Preparing underrepresented students in the United States with the STEM (science, technology, engineering, and mathematics)/ICT skills needed to fill 21st-century jobs is both a national priority (National Science Foundation [NSF], 2010) and a social justice imperative (Leonard & Martin, 2013)" (Leonard, et al., 2018).

In their study of one integrated STEM educator facilitating an elementary engineering lab, Daugherty et al. (2016) found evidence for integrated STEM education as a means of meeting the diverse academic and affective needs of students. They write:

> Melida* has found that many students who struggled in the traditional classrooms seem to soar in the engineering lab. In the lab, students have an opportunity to learn through the application of knowledge. Melida has also noticed that many students who are considered gifted in traditional classes actually depend upon teammates who struggle in traditional classroom settings. This does so much for the struggling students' self-esteem that it carries over into other areas of their lives. Students have also begun to recognize they have talents they have never explored previously (Daugherty et al., 2016, p. 34).
>
> * From a personal interview

Calls for Multimodal Literacy Instruction and for STEM Education

The New London Group and the New Literacies

In 1994 an interdisciplinary group of international scholars came together to talk about ways to address the growing educational inequity they were observing in traditionally underserved populations with which they worked, specifically regarding changing technological contexts for literacy pedagogy. Since they met in New London, Connecticut, they called themselves "The New London Group" (Cope and Kalantzis, 2009). The group formulated the concept of "multiliteracies," a view of literacy that addresses the intersection of a growing globalized community and rapidly changing technology (New London Group, 1996). Two key aspects of multiliteracies (the two "multis") are multilingual and multimodal (Cope and Kalantzis, 2009). Multilingualism encompasses not only the diversity of languages in the global community, but also "social languages" (Gee, 1990). "Cyberpunks and physicists, factory workers and boardroom executives, policemen and graffiti-writing urban gang members engage in different literacies, use different 'social languages,' and are in different discourses…And, too, the cyberpunk and the physicist might be one and the same person, behaving differently at different times and places" (Gee, 1990, p. 4). Multimodal refers to the linguistic, visual, aural, gestural, and spatial pathways or "modes" through which we understand and create meaning across different media and cultural contexts (Cope and

Kalantzis, 2009). Social semiotic theory (Kress, 2003) provides a framework for knowledge of how we use many different, but frequently intersecting sign systems to make meaning multimodally.

The New London Group (1996) maintained that the changing literacies had implications for “creating access to the evolving language of work, power, and community, and fostering the critical engagement necessary for them to design their social futures and achieve success through fulfilling employment” (p. 60). Cope et al. (2009) discuss ways the new literacy pedagogy supports learners as they develop strategies for navigating the different discourses resulting from increased globalization and fast-changing communication technologies. Jewitt (2008) points out, “The terrain of communication is changing in profound ways and extends to schools and ubiquitous elements of everyday life, even if these changes are occurring to different degrees and at uneven rates” (Luke & Carrington, 2002, p. 241).

Serafini (2013) suggests a three-part pedagogical approach to multimodal literacy instruction consisting of “exposure, exploration, and engagement” (p. 92), as a means of slowly increasing students’ literacy experiences with what the author terms, “multimodal ensembles” (p. 91). Serafini draws upon Pearson and Gallagher (1983) stating:

> As teachers journey from the exposure phase, immersing students in a wide variety of texts, through the exploration phase, investigating these texts in greater detail, and eventually the engagement phase where students experiment with producing and disseminating these texts, teachers relinquish their responsibilities for interpreting and creating various multimodal ensembles as students accept more responsibility across these roles (Pearson & Gallagher, 1983) (Serafini, 2013, p. 92).

STEM Education

The acronym STEM for the fields of Science, Technology, Engineering, and Mathematics was first used by the National Science Foundation (NSF) in the 1990s (Sanders, 2009). STEM education concerns learning and instruction in all four of these fields. STEM education programs can be found at all grade levels, as part of the school day and/or in after-school formats (Gonzalez & Kuenzi, 2012). Gonzalez and Kuenzi point out that policy concerns regarding education in these fields date back to George Washington’s first State of the Union Address and that today “the economic and social benefits of scientific thinking and STEM education are widely believed to have broad application for workers in both STEM and non-STEM occupations” (p. 1). In 2007 President George W. Bush signed the America COMPETES Act, otherwise known as the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, which “authorized STEM education programs at the National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), Department of Energy (DOE), and Department of Education (ED)” (Gonzalez & Kuenzi, 2012, p. 2). Subsequent administrations have also pushed for funding for STEM education initiatives including President Barack Obama’s Let Everyone Dream campaign for youth from traditionally under-represented groups (Fact Sheet, 2015). “As such, many contemporary policymakers consider widespread STEM literacy, as well as specific STEM expertise, to be critical human capital competencies for a 21st century economy" (Gonzalez & Kuenzi, 2012, p. 1).

Challenges to Implementation

When implemented effectively and consistently, STEM education and multimodal literacy instruction offer pathways to educational equity and opportunities, particularly for traditionally underserved populations; nevertheless, each program is beset with challenges to consistent and meaningful implementation. These challenges include common misconceptions surrounding STEM and multimodal literacy instruction and students' lack of interest and engagement with these programs.

The Challenges of Common Misconceptions about STEM Education and Multimodal Literacy Education

STEM vs. STEM Education

Sanders (2009) discusses the importance of making the distinction between STEM and STEM education. "Most, even those in education, say 'STEM' when they should be saying 'STEM education,' overlooking that STEM without education is a reference to the fields in which scientists, engineers, and mathematicians toil. Science, mathematics, and technology *teachers* are STEM *educators* working in STEM *education*. It's an important distinction" (p. 20). The "technology" in STEM is often mistakenly understood to allude solely to computers, and most people—even, or particularly, educators—see STEM education as referring to science or math (Sanders, 2009; Bybee, 2010; Daugherty, 2010), and often as a means "to address perceived problems by heaping on increased expectations and requirements for mathematics and science education" (Daugherty, 2010, p. 19). As Bybee (2010) states, "Once again, the education community has embraced a slogan without really taking the time to clarify what the term might mean when applied beyond a general label" (p. 30).

Education Technology vs. Technology Education

A misunderstanding held by numerous teacher educators, preservice teachers, and in-service teachers is that the terms *technology education* and *education technology* can be used interchangeably. Daugherty (2010) writes:

> First, many assume that the technology in STEM is referring to the implementation of computers and/or instructional technology devices and software. While computers are certainly a part of the equation in technology education, this definition is far too narrow an understanding and represents only one technological tool among many (p. 20).

The definition of education technology has been reassessed and reconfigured over the last several decades (Kurt, 2016). The most recent update to the definition was in 2007 by the

Association for Educational Communications and Technology (AECT): "Educational technology is the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources."

Just as it is for any field of instruction, teacher knowledge of educational technology can be a very important component in making STEM content and multimodal literacy instruction accessible to students; however, using technology as a pedagogical strategy is not the same as the actual teaching of technology or *technology education*. The goal of technology education is to develop students' technological literacy (Daugherty, 2010).

Multimodal Texts: Categories and Examples

Misconceptions about exactly what multimodal texts are can lead to poor literacy instruction. A text is considered multimodal when its meaning is conveyed across two or more modes, which include not only spoken and written language, but also visual, audio, gestural, tactile, and spatial (State of Victoria, 2018). As is the case with the term *technology* in STEM education frequently being used synonymously with *computers* and related *devices*, an assumption often made in multimodal literacy instruction is that multimodal texts are synonymous with digital texts. While there are numerous examples of digital multimodal texts such as film, social media platforms, blogs, animation, and so on, many multimodal texts are not digital in nature. Picture books, graphic novels, and posters are all examples of multimodal texts that may or may not be digital. In addition, live performances such as theater, dance, concerts, and storytelling are also multimodal texts that convey meaning:

> Each mode uses unique semiotic resources to create meaning (Kress, 2010). In a visual text, for example, representation of people, objects, and places can be conveyed using choices of visual semiotic resources such as shape, size, line, and symbols, while written language would convey this meaning through sentences using noun groups and adjectives (Callow, 2013), which are written or typed on paper or a screen (State of Victoria, 2018, para. 5).

Multimodal literacy is about making meaning from texts and conveying meaning through composition. Literacy teachers who feel these areas are sufficiently covered by students reading online articles and writing papers using Google docs are mistaken. As Truman Capote is reported to have said about the work of Jack Kerouac and other Beat poets, "That's not writing. That's typing."

The Challenges of Student Engagement

Research shows that fewer and fewer students are choosing to take STEM classes in high school, and those who do are not necessarily continuing to pursue these fields in college and careers (Daugherty et al., 2017; Sawchuk, 2018). Despite policy initiatives and designated funding for STEM education, studies show graduates from high schools offering substantial numbers of STEM classes are no more likely to major in STEM fields in college than are graduates from secondary schools with fewer STEM course offerings (Sawchuk, 2018). Daugherty et al. (2017) write that “alarming numbers of students seem to be opting out of STEM programs of study at the secondary and postsecondary levels, many making the decision to avoid STEM courses and programs of study as early as fourth or fifth grade” (p. 12).

Interestingly, assumptions about students being naturally drawn to multimodal literacy classroom practices are also often wrong (Braziller & Kleinfeld, 2015; Stowe, 2012; University of Michigan, n.d.). Teachers may think that because students engage daily with multimodal texts through social media, text messaging, news apps, video apps, and so on, they will actively engage in and even prefer multimodal text analysis and composition. In fact, students are generally used to accessing these texts in an uncritical way and will need clear instruction and modeling in order to analyze and make meaning from multimodal texts, just as they must be taught to close read or analyze alphabetic texts (University of Michigan, n.d.). Regarding multimodal composition, particularly with secondary and post-secondary students, Braziller and Kleinfeild (2015) write:

> They have grown up watching YouTube, listening to sound bites, doing all of their communication on a phone. But this doesn’t mean that they have done a lot of composing. Sometimes they initially resist the idea of creating multimodal compositions, preferring the familiar, the text, the essay. They believe that’s easier because they are already familiar with it. The reality is that you will have to sell your students on the value of a composition class whether you take a multimodal approach or a traditional approach (para. 6).

Obstacles to consistent, engaging implementation of STEM education and multimodal literacy instruction (common misconceptions surrounding STEM and multimodal literacy instruction, and students’ lack of interest and engagement with these programs) may be more effectively addressed through integrated instruction beginning in elementary grades. STEM education programs have been commonly implemented at secondary and post-secondary levels. The same is generally true for multimodal literacy instruction. Emphasis on high-stakes testing encourages silo approaches to content-area instruction in upper grades. This results in missed opportunities for interdisciplinary, integrated practices that promote learning motivation and transfer of knowledge (Wiggins and McTighe, 2005).

Integrated Instruction at the Elementary Level

Satchwell and Loepp (2002) explain that “an integrated curriculum is one with an explicit assimilation of concepts from more than one discipline. As much as possible, integrated curricula apply equal attention to two or more disciplines (Huntley, 1999)” (para. 3). Kress (2010) describes multimodal literacy as “a framework that requires a collective interpretation of two or more scripts, visuals, videos, graphics, animations, sounds, music, gestures, and facial expressions for producing meaning” (p. 54). Research suggests that beginning integrated STEM education programs and multimodal literacy instruction gives teachers a chance to support young learners’ inherent curiosity about the world around them.

Murphy (2011) writes, “Children at birth are natural scientists, engineers, and problem-solvers. They consider the world around them and try to make sense of it the best way they know how: touching, tasting, building, dismantling, creating, discovering, and exploring. For kids, this isn’t education. It’s fun!” (Murphy, 2011, para. 5 as cited in Daugherty et al., 2017). Likewise, Cope et al. (2018) maintain young children possess innate multimodal dispositions:

> Let’s consider that when a child is born, they look, they touch, they feel. They are multimodal; that’s how they make meaning. And what do we do to them? We put them in school and as they go through the grades, we strip all that out. We say read, write, read, write, test, read, don’t touch, don’t move, don’t scribble. The essay or the tick-a-box test for correct usage become the way of expressing knowledge (para. 8).

There are widespread calls for STEM education. There are policy initiatives and funding for STEM education. In response, many school districts have chosen to begin STEM coursework in secondary grades. Schools that teach STEM fields in elementary grades generally focus on math and science, particularly math, since this content area is subject to elementary standardized testing. Engineering is usually de-emphasized in the curriculum and technology taught in a peripheral manner. Nadelson et al. (2013) point out that elementary education builds the foundation for and interest in the STEM fields, yet elementary teachers’ lack of training and sense of efficacy may impact student engagement and learning in science, technology, engineering, and math. This, in turn, can have implications for whether students go on to pursue further studies and careers in these fields. Carr et al. (2012) note that 41 states have engineering-related curriculum standards, many of which are designated for elementary grades, and of course, Next Generation Science Standards (NGSS) recommend developing students’ engineering skills at the elementary level (Next Generation Science Standards (NGSS) Lead States, 2013). Sanders (2009) states:

> Integrative STEM education is not intended as a new stand-alone subject area in the schools accompanied by new “integrative STEM education” licensure regulations, as some might suspect. Given the amount of content knowledge necessary to be an effective science, mathematics, or technology educator, it’s very difficult to imagine a new teaching/licensure program that would prepare individual pre- and/or in-service teachers with sufficient science, mathematics, and technology content expertise—and the pedagogical content knowledge—to teach all three bodies of knowledge effectively (p. 21).

Daugherty et al. (2017) assert that effective teacher preparation in elementary STEM education must not only emphasize standards in science, technology, engineering, and math, but also develop teacher enthusiasm for helping students make interdisciplinary connections.

Calls for multimodal literacy instruction are not nearly as widespread as those for STEM education, and they have largely been ignored. Schools continue to emphasize print literacy because that aligns with high-stakes testing. In teacher education programs, as well as in elementary classrooms, teaching with and about multimodal texts is often viewed as a strategy for scaffolding students until they are ready for "real" texts. Again, the often-peripheral use of technology by teacher educators and classroom teachers reflects views that multimodal composition is addressed by having students compose print texts with a keyboard, occasionally inserting pictures found on the internet, and creating presentations for class projects, usually PowerPoints or Prezis. In addition, more and more state departments of education are requiring the Foundations of Literacy test as part of teacher licensure. This will no doubt result in even less emphasis on multimodal literacy in elementary literacy methods coursework. This is short-sighted, of course, for without the ability to access, navigate, and comprehend multimodal texts, students will not have the skills for critical media literacy, real-world communication, and workplace applications.

"One of the biggest challenges when adding anything to the elementary curriculum is finding a proper context in which to enact it. Many teachers do not have much experience with multimodal literacy concepts (which is a challenge in its own right) and are accordingly unsure of where these concepts may be introduced in the curriculum" (Serafini, 2015, p. 419). Williams (2015) asserts that avoidance of technology instruction by teachers may be reinforced (albeit unwittingly) by teacher preparation programs. Preservice teachers often enter teacher education programs with firmly held views of literacy as a "print-bound process" (para. 3), and technology education courses are usually offered as separate courses from literacy methods classes. She writes, "Though these courses are designed to show construction of knowledge in the area of technology integration, they are often presented in isolation, unable to demonstrate the importance of incorporation of practice across the curriculum and throughout content areas" (para. 3). As Cope et al. (2018) state:

> This has huge pedagogical implications, not just about what we might do, but what we probably have to do. Learners come to school with a different set of sensibilities. The phrase that Mary and I used to describe that is a shift in the "balance of agency" (Cope & Kalantzis, 2009, p. 172). But here's the contradiction: What do we see in schools? Let's take the flipped classroom. It's using new multimodal technologies for yet another transmission from one to many. So, in some sense it's not a change at all, because a real change would be to have the kids research the topic and make the video themselves or write the text themselves (p. 9).

In a study on how prepared educators are to teach multimodal composition, Chandler (2016) writes this regarding his findings: "If the participants claim to have any relevant background at all, they tend to be self-taught or perhaps having attended a brief in-service program. Mid-career teachers seem to be the least engaged in any structured learning" (p. 14).

Future Research

"Advocates of more integrated approaches to K–12 STEM education argue that teaching STEM in a more connected manner, especially in the context of real-world issues, can make the STEM subjects more relevant to students and teachers" (Honey et al., 2014). While there is still much work to be done to address the urgent issues in STEM education, STEM educators, particularly those in teacher preparation programs are developing ways to address these issues.

Recommendations for integrated STEM in the elementary grades, outreach programs in which STEM teacher educators work with classroom teachers to deliver integrated STEM content, scholarships, and other funding to encourage students to pursue STEM fields are some of the purposeful solutions to problems in STEM education. Many elementary teacher preparation programs require STEM methods coursework, but for many programs, STEM coursework is still elective in nature. Effective STEM methods coursework provides teacher candidates with a foundation for teaching engineering design. "But curricula that emphasize the performative dimension of engineering are particularly suited for students traditionally experiencing difficulties in STEM subjects—including those marked learning disabled—because it supports literacy in a manner that transcends modes" (Roth, 2017, p. 261). Coursework in STEM education may greatly augment the preparation of future K-6 teachers. Leaders in teacher education may wish to also consider delivering elementary methods coursework in the STEM fields in an integrative manner as a tool for replicating practices in the primary school. This would enable preservice teachers to participate in and see the integrative model in action at the post-secondary level. Of course, this would also require a great deal of cooperation on the part of faculty members who teach methods courses in elementary math, science, technology, and engineering, but this interdisciplinary collaboration would be particularly useful for future fifth- and sixth-grade teachers who are often departmentalized in elementary schools and are almost always departmentalized in middle schools.

"Multimodal literacies instruction . . . enables children to have creative autonomy, to think and act in unique ways, and allows all children to have academic access through dynamic paths" (Sanders, 2010, p. 131). Teacher educators in literacy instruction may have a worthy model from the field of STEM education, where leaders have called for integrated instruction at the elementary level. Like many teacher education programs in STEM, literacy teacher educators might consider developing programs to provide training for and work with classroom teachers to build their confidence in teaching elementary multimodal literacy instruction--instruction that neither excludes nor privileges traditional print texts. Just as elementary teacher educators in STEM fields are encouraged to consider delivering teaching methods coursework in an integrative manner, elementary literacy teacher educators might benefit from an intra-disciplinary methods coursework delivery system. To ensure fully integrated, comprehensive, multimodal literacy education for preservice teachers, teacher educators in literacy could also plan instruction through interdisciplinary approaches with faculty in elementary content-area methods courses.

Both STEM education and multimodal literacy instruction are rooted in goals for interdisciplinary practice. This may well be the perfect opportunity to pursue these goals actively and consistently to ensure comprehensive, foundational preparation of students in these areas, and to maintain their interest and engagement through secondary and post-secondary education, as well as into 21st Century careers.

See next page for author bios

Grace Rusk Kerr is a teaching assistant professor of childhood education at the University of Arkansas in the U.S. Dr. Kerr's research interests include literacy and education policy. Her work has appeared in *The American Review of Public Administration* and *Public Administration Quarterly*.

Michael K. Daugherty is a Distinguished Professor of STEM Education in the College of Education and Health Professions at the University of Arkansas in the United States. He earned a BS, MS, and EdD from Oklahoma State University. Dr. Daugherty speaks nationally and internationally on STEM education, project-based learning, technological literacy, standards, and curriculum development. He is the author of 26 books and book chapters, over 70 journal articles, and numerous curriculum sets. Michael has conducted more than 100 presentations and keynote addresses at state, national, and international conferences. He has been the recipient of numerous awards including the Technology Teacher Educator of the Year Award by the American Council on Technology and Engineering Teacher Education, the Award of Distinction by the International Technology & Engineering Educators Association, and most recently, the Mary Margaret Scobey Award by the Elementary STEM Council.

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STEM and STEM Education: Collaboratively Addressing Global Challenges of the 21st Century

Pradeep M. Dass
Northern Arizona University, Flagstaff, Arizona, USA
E-mail: pradeep.dass@nau.edu

Abstract

The acronym STEM, and its related phrase STEM Education, both imply some form of relationship between multiple disciplines and the education in those disciplines. One prominent aspect of that relationship is "collaboration" between people working in these disciplines as they address questions that require a nexus of knowledge and expertise from multiple disciplines. This nexus and collaboration are particularly important to address the global challenges we face at the present time. Using some examples from the USA, this article discusses the important role of collaboration in STEM education and is adapted from the keynote address the author delivered on the same theme at the 2021 international conference of the East Asian Association for Science Education (EASE).

Key Words: STEM, STEM education, collaboration, global challenges.

Collaboration, Sustainable Development, and STEM Education in the Asian Context

Being an international consortium of science and STEM education professionals from countries in the east Asian region, the East Asian Association for Science Education (EASE) is a collaborative organization by definition. Many of the educational, environmental, and economical issues faced by the countries represented in EASE are common between these countries. Hence, it is natural for EASE as an organization to consider a collaborative approach for addressing these issues, which involve two, sometimes opposing, elements: Development and Sustainability. Often, development seems to come at a cost of sacrificing sustainability (of the environment, economy, etc.) or maintaining sustainability implies an inability to pursue development. Considering the potential of science/STEM education in addressing this apparent contradiction between development and sustainability, the EASE 2021 international conference focused on building a collaborative vision for "new" science/STEM education, using the context of the Sustainable Development Goals (SDGs) developed by the United Nations Department of Economic and Social Affairs and adopted in 2015 (Gaffney, 2014).

Of the 17 SDGs, goal #4 focuses on "quality education and lifelong learning opportunities for all." Given the science/STEM education focus of EASE as an organization and of the *Southeast Asian Journal of STEM Education*, it is important to consider the implications of SDG #4 for science/STEM education and how collaborations can help address the issues and challenges we face.

STEM and STEM Education imply combining the knowledge of science, technology, engineering, and mathematics to address real world issues, especially the global issues of the 21st century. It turns out that the most pressing current issues we face at a global level, such as global climate change, COVID-19 pandemic, etc., require a nexus of knowledge from various STEM disciplines and strong education in STEM, for us to be able to effectively address and deal with these issues. Thus, a collaborative approach is imperative. To develop these abilities in our students, a focus on high quality STEM education needs to be a significant component of the "quality education" called for in SDG #4 for all students and, in order to provide this quality education, we need highly qualified teachers (SDG #4—Target 4.C).

Collaboration in STEM

The advent of the acronym STEM, and subsequently STEM Education during the final decades of the 20th century, implied a recognition of the growing trend of scholarly activities in these fields shifting from isolated works of one or more individuals in specific disciplines to collaborative interdisciplinary teams working to solve problems and address questions that transcended the traditional boundaries of different disciplines. There has been a shift, in a manner of speaking, from "lone science" to "collaborative STEM". Interdisciplinary research teams began to be formed, drawing scholars from a variety of STEM fields whose collaborative contributions would accomplish what no single field or discipline could accomplish within its own knowledge boundaries. At the same time, a great surge in interdisciplinary, hybrid fields of study—such as Bioinformatics, Chemecology, Environmental Toxicology, etc.—had been emerging (Hurd, 1997). Collaboration between disciplines and people working within those disciplines has become increasingly important and indeed necessary to deal with the issues our global society currently faces. Examples of some currently prominent and very serious issues that demand urgent and continuing attention are global climate change and the COVID-19 pandemic. They also represent problems that cannot be solved by knowledge from any one discipline of STEM.

The recognition of the need for and value of collaborative activity in STEM to solve contemporary problems is evident in the fact that the entire *Nature* issue of 17 June 2021 (Volume 594, #7863) focused on the topic of collaboration and teamwork. The articles in this issue of the journal describe collaborative activity that addressed a number of different issues, some global such as the COVID-19 pandemic, and some local such as the recent drinking water crisis in Flint, Michigan, USA. The stories in this issue of *Nature* illustrate that collaborations are happening:

- across national borders, cultures, and disciplines;
- between science and society; and
- between science and industry.

The editorial in the mentioned issue of *Nature*, titled "Research Collaborations Bring Big Rewards: The World Needs More" ends with the following statement (*Nature* Editor, 2021, pp. 301 – 302):

> The metaphor 'standing on the shoulders of giants' has been much overused by scientists past and present. Today, such 'giants' are not only the investigators named on papers and project grants, but also every other participant in the research process. **The future lies in standing on the shoulders of crowds.** (Emphasis mine)

The following two "cases" further illustrate the extent to which collaboration is helping address issues or answer questions that are too big to be tackled within the silos of traditional disciplinary boundaries.

The Human Genome Project

A project to identify and map the location of every single gene in the human genome, launched in 1990 and declared completed in 2003, may appear to be a "biology project" at first glance. However, a more careful look reveals that this project was highly collaborative, interdisciplinary, and international in nature. The following details indicate the collaborative, interdisciplinary, and international nature of the human genome project.

- *Disciplinary overlap and collaboration:* The project logo includes names of the disciplines from which knowledge and expertise was drawn to complete this project: biology, physics, chemistry, engineering, informatics, and ethics.
- *Institutional collaboration:* The work was done at 20 universities and research centers.
- *Trans-continental and trans-national collaboration:* Seven countries across three continents were involved in the work—USA, UK, Japan, France, Germany, Canada, and China.

Considered the world's largest scientific research project, it was a highly interdisciplinary and collaborative endeavor to address an extremely significant, yet most fundamental question regarding humanity.

The COVID Moonshot Project

An international collaboration to develop an anti-viral drug (von Delft, et al., 2021) had the following characteristics of a highly collaborative STEM endeavor:

- The work involved 150 participants.
- The participants represented a wide range of expertise from different fields including bioinformatics, phylogenetics, epidemiology, chemistry, computer modeling, and even military.
- The participants represented academia and several industries such as pharmaceutical and biotechnology.
- The participants represented several countries from different continents.

- A wide range of technologies were used.

This is a project addressing a current, extremely pressing global issue of the ongoing COVID-19 pandemic. Such issues cannot be addressed without the kind of collaboration seen in the COVID Moonshot project.

In an essay reflecting on her work just prior to retiring, Dr. Anne Schuchat, then Principal Deputy Director of the Centers for Disease Control and Prevention (CDC) in the US, made the following comment that reflects her recognition of the role and value of the collaborative work now so common in STEM (Schuchat, 2021):

> The teams carrying out data analysis and field investigations and launching communication drives or laboratory studies have experienced the joy of knowing their collective efforts can achieve something none of them could do on their own (p. 23).

Collaboration in STEM Education

The recognition of these collaborative trends seen more often than not in STEM is reflected in the *Framework for K-12 science education* released by the National Research Council (NRC) in the US (National Research Council, 2012). This framework identifies three dimensions of science critical for school science education. The first of the three dimensions is *Scientific and Engineering Practices*. This *Practices* dimension identifies 8 activities that characterize the work of scientists and engineers. More importantly, the identification and naming of these practices collectively as "scientific and engineering" practices clearly emphasize the close collaborative relationship between science and engineering (the S and E of STEM). They also explicitly convey the message that school science education should include and emphasize this relationship between science and engineering.

Also in 2012, an edited volume, titled *Integrating Science, Technology, Engineering, and Mathematics* (Rennie et al, 2012), was published as part of the *Teaching and Learning in Science* series by Routledge. The editors of this volume claim that it derives from 15 years of research conducted by them in two countries (Australia and Canada). This publication thus indicates that the efforts to integrate STEM disciplines in school curricula were underway well before the release of the *Framework* in the US. The editors of *Integrating Science, Technology, Engineering, and Mathematics* provide the following as the purpose of their research and the focus of this publication (Rennie et al., 2012, p. vii):

> Our focus is particularly on the school subjects of science, technology, engineering, and mathematics, the so-called STEM subjects, because we believe that these are the subjects needed for clever and creative solutions to the issues facing our rapidly changing, global world. In the real world, problems cannot be solved by experts in just one discipline, such as mathematics or chemistry; they require interdisciplinary teams to work toward solutions. …In school, we believe that integrating at least some parts of the curriculum offers teachers and students opportunities to address real-world problems. Further, it enables the school to connect with its community, and thus reflect the fact that we live in a connected, global world.

Two years after the release of the *Framework*, the NRC released another report titled *STEM Integration in K-12 Education* (National Research Council, 2014). The NRC Committee on Integrated STEM Education spent two years "to develop a research agenda for determining the approaches and conditions most likely to lead to positive outcomes of integrated STEM education at the K-12 level in the United States," culminating in the release of this report (National Research Council, 2014, p. vii).

A literature search of publications during 2000 – 2021, using keywords "Collaboration in STEM" and "STEM Education," revealed 227 peer-reviewed articles reporting on collaborative instructional activities in both K-12 and college level classes. The advent of the *International Journal of STEM Education* during the last decade of the 20th century is a testament to the rise of scholarly activity in the integrated field of STEM education, as being distinct from science education, mathematics education, technology education, or engineering education. Therefore, it is evident that similar to the rise in collaboration between professionals in the STEM disciplines since the latter part of the 20th century, integration of STEM disciplines in school curricula, collaboration between teachers of these disciplines, and scholarship in the field of STEM education has also been on the rise. The following is an example of a project specifically designed to integrate science and mathematics instruction in grades 6 – 8, around real-life local issues, followed by the description of an instructional model effective at promoting collaboration between students in the classroom.

Science and Mathematics Integration for Literacy Enhancement (Project SMILE): Collaboration Among Teachers

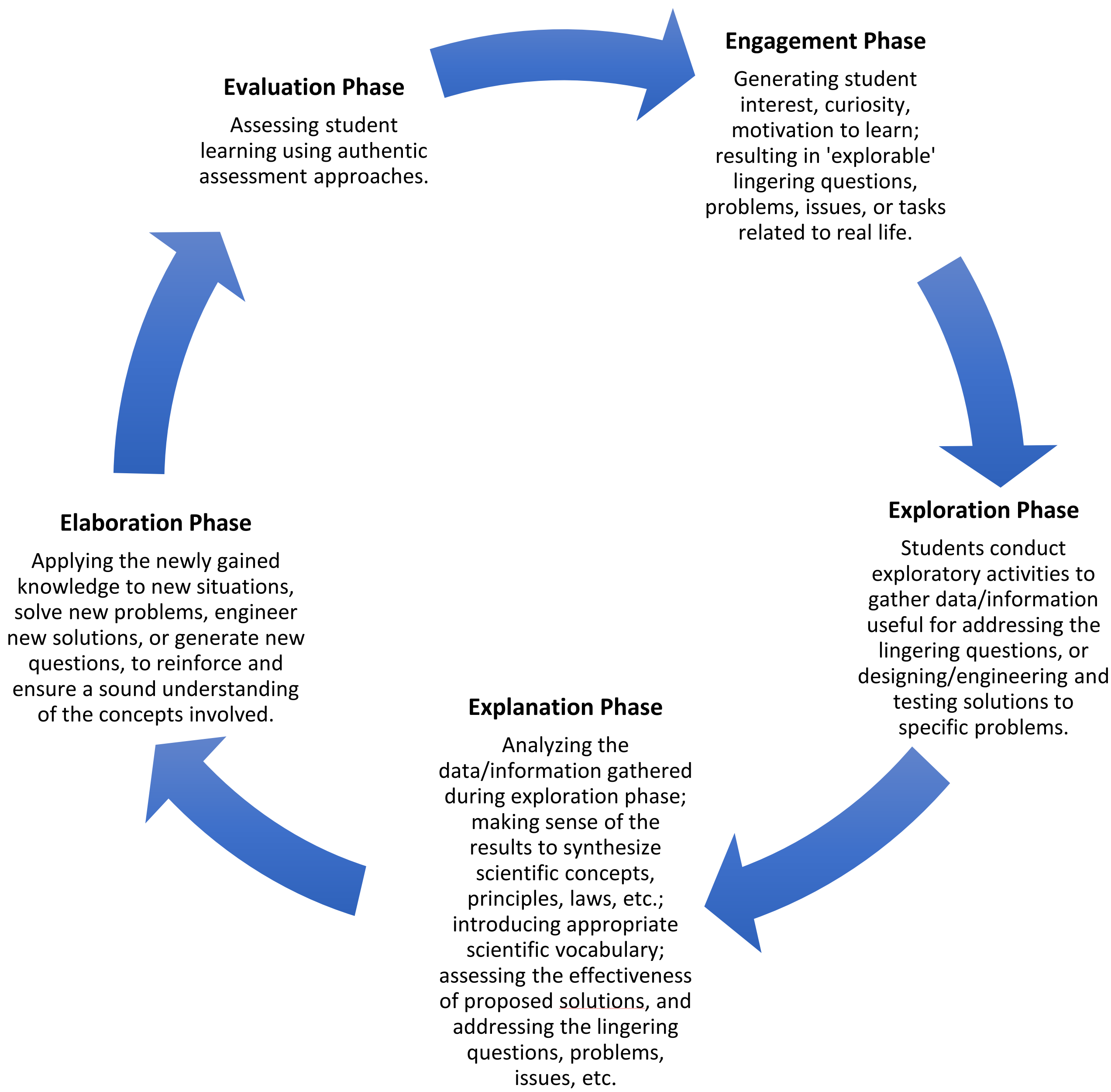
Funded by the National Science Foundation (Award #0918505), this project brought together grades 6 – 8 mathematics and science teachers in the state of North Carolina, USA. The teachers were engaged as teams over a period of three years to learn strategies for integrating science and mathematics instruction at their grade levels, focused around real-life, locally relevant issues and problems, and using *InspireData* as the specific technology tool to collect, organize, visualize, and query data relevant to student investigations. Thus, the S, T, and M of the STEM disciplines were involved in the integration process. Teachers of science and mathematics developed thematic instructional units for their grade level together as a team, and further collaborations with technology resource personnel in their schools enabled efficient and effective use of the *InspireData* software. The units were all designed around specific local issues or problems of relevance to the students' lives. All this resulted in students experiencing how real-life issues, problems, or questions can be addressed by combining knowledge from science and mathematics and employing appropriate technology tools. More details and results of this project can be found in Dass and Spagnolo (2016) and Dass and Moore (2015).

The Learning Cycle: 5E Model for Promoting Collaboration Among Students

For projects and efforts, such as Project SMILE described above, to be successful in the classroom, appropriate instructional models and strategies ought to be used by teachers for effectively engaging students in interactions and collaborations among themselves. Otherwise, students will not experience or learn what collaboration and integration really means and looks like in real life. The 5E model of the Learning Cycle maps extremely well with the *Scientific and Engineering Practices* dimension presented in the NRC *Framework*, thus proving to be an effective instructional tool in achieving the vision of the *Framework*. Complete details of the 5E model and the mapping of its phases with individual *Practices* can be found in Dass (2015). Figure 1 below provides a visual representation of the 5 phases of this instructional model.

Figure 1

The 5E Model of the Learning Cycle



While each phase of the 5E model provides opportunities for students to interact and collaborate, the EXPLORATION phase of this instructional model provides most opportunities for students to collaborate as they conduct their group investigations. An example in Southeast Asia was a collaborative project in Thailand in which high school students developed a plan to reduce air pollution caused by burning leaf litter and built composting bins, which turned the organic material into soil and created an income for the school (Intha & Phusavat, 2021).

Conclusion

As we strive to provide "quality education" to all our students, envisioned in SDG #4, we must remember that a very important component of this quality education is the opportunities we ought to give to our students to learn STEM in the context of real-world issues, whether they be local or global. This needs to be done using instructional approaches, which engage students in collaborative activities that reflect and simulate, to the extent possible in the classroom, what is done by STEM professionals in real life, as illustrated in the examples mentioned in this article. Such educational experiences in school will equip our students to handle real-world problems and make them effective as global citizens capable of dealing with global challenges they face. Of course, in order to provide this kind of quality education to our students, we need highly qualified and competent teachers, as envisioned in Target 4.C of SDG #4. Two examples of efforts to produce such teachers within the US are worth mentioning here.

100K in10 Network

This is a nationwide collaboration involving a variety of institutions, organizations, businesses, and professional associations, working together as partners to produce, provide professional development for, and retain highly qualified STEM teachers (https://100kin10.org). The network was initiated in 2011 in response to the then US President Obama's call to produce 100,000 STEM Teachers over the next 10 years. The year 2021 marks the end of that 10-year period and the network has exceeded its goal of producing 100,000 teachers by about 9,000 teachers. The network currently includes over 300 partner organizations, including the author's home institution and department, and they are pursuing many avenues of work to enhance STEM teachers and STEM teaching across the US.

The UTeach Network

Developed at the University of Texas at Austin, Texas, the UTeach model of integrated, undergraduate secondary science and mathematics teacher preparation started in 1997. The implementation of the model saw significant growth in the number of students enrolling in this teacher education program at Austin. Based on that success, the model began to be replicated at other universities across the US. At the present time there are 46 universities (including the university where the author works) in 23 states and Washington, DC, where the UTeach model is being used to prepare secondary science and mathematics teachers. Since the beginning of the

UTeach program, all of the 46 UTeach programs across the nation have collectively produced 6,870 new highly qualified teachers (https://institute.uteach.utexas.edu/).

These examples are shared with the intent that they might spark some new ideas regarding how to increase the number of highly qualified and competent STEM teachers to meet Target 4.C of SDG #4 and to make the vision of SDG #4 a reality in the classrooms across the countries represented in the membership of EASE and the readership of the *Southeast Asian Journal of STEM Education.*

Pradeep M. Dass serves as the chair of the Department of STEM Education at Northern Arizona University, Flagstaff, AZ, USA, where he is also the Walkup Distinguished Professor of Science Education. Dr. Dass is a veteran high school biology teacher and science teacher educator, with a Ph.D. in Science Education from the University of Iowa, Iowa City, IA, USA. His current scholarly interests lie in ways that STEM education can be made culturally relevant for students and can equip students to effectively address contemporary issues, whether they be local or global in scope.

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Developing Integrated STEM Challenges to Foster 21st Century Skills

Michael K. Daugherty, Heather D. Young, Vinson Carter, and Leah R. Cheek*
University of Arkansas, Fayetteville, Arkansas, USA
*Corresponding author: lrcheek@uark.edu

Abstract

One of the challenges facing today's elementary teachers is creating integrated experiences that are both engaging and relevant for young students. Developing individuals who can think critically and are competent in 21st century skills such as communication, collaboration, and problem solving is one of the primary goals in education. More often, teachers are turning to STEM engineering design challenges as a vehicle for this integration. In this article, the authors make the case for integrating STEM into additional content areas such as social studies, art, and language arts by implementing the *Raising the Flag* STEM Engineering Design Challenge. The authors also provide an example of this challenge in one third-grade classroom and specify information for elementary teachers seeking to integrate content areas and 21st century skills in a creative way through an engineering design project titled *Raising the Flag.*

Keywords: integration, 21st Century Skills, elementary education, STEM education, Project Based Learning, integrated STEM, elementary STEM, curriculum design

Developing STEM Challenges to Foster 21st Century Skills

According to the P21 Partnership for 21st Century Learning (2014), "Global competence is critical for innovation in the 21st century" and the integration of learning experiences that expand upon global and cultural knowledge will best prepare students for the modern world (p.1). With the prediction of future deficiencies in the labor force in science, technology, engineering, and mathematics (U.S. Bureau of Labor Statistics, 2021), politicians, researchers and educators continue to concentrate on increasing STEM experiences and proficiencies for school-aged students. Archer et al. (2020) articulate:

> Increasing and diversifying participation in STEM is a pressing concern for policymakers, practitioners, and researchers across the globe. Moreover, despite longstanding investments of time and resources in attracting more young people, patterns in STEM participation in post-compulsory schooling remain stubbornly resistant to change (p.4).

To address such global awareness, elementary STEM education must cultivate and deliver learning experiences that help young learners develop cultural and societal understandings while exploring the ways cultures have influenced the development of modern societies. Upadhyay et al. (2021) identify the value of students and teachers recognizing personal experiences of the students to analyze the causes and effects of inequities and injustices, providing a potential path for personal transformation and social change. Edelen et al. (2019) urge teachers to include culture, self-expression, creativity, and community for students to gain insight not only to their own lives but to the lives of others. Further clarifying the importance of 21st century skills in the classroom, Edelen, et al. (2019) affirm, “it is becoming increasingly important for students to have experiences that require them to transfer content knowledge and practices from multiple disciplines so that they can be positioned as problem-solvers to improve and solve complex problems of the world” (p. 11). Subsequently, project-based STEM in the elementary classroom represents a unique opportunity to expand upon important 21st century social and cultural content knowledge.

Supporting this line of inquiry, Li et al. (2019) recommend project-based learning be used as a tool for delivering 21st century skills in the classroom. Elementary teachers should design learning experiences that foster a student’s ability to think critically, solve problems, collaborate, and communicate effectively. Swift et al. (2018) assert, “a weak emphasis on innovation and design in education, especially at the primary level, has contributed to challenges in meeting STEM-related job demands” (p. 7). Cook and Bush (2018) further clarify by stating, “we often hear that students need to be prepared for jobs that do not yet exist and therefore need creative problem-solving skills to navigate the complex and multidimensional aspects” (p. 93). However, as Daugherty and Carter (2018) note, the structure of many school systems may inhibit collaboration and the integration of STEM throughout the curriculum. They recommend implementing an interdisciplinary STEM problem-centered learning approach as one of the best ways to ensure 21st century skills such as collaboration are explicitly taught and learned. Lambert (2015) suggested that while 21st century skills and problem-solving abilities are important, many students are not reaching higher levels of thinking in many areas of the STEM disciplines. Supporting this notion, English (2018) suggests that teachers may lack knowledge and confidence in implementing design-based experiences. Additionally, teachers may also believe STEM problem-centered learning and design may be beyond young children’s capabilities.

Capobianco et al. (2014) assert integrating technological and engineering literacy practices and design in the classroom as early as grade one demonstrates potential in nurturing and maintaining student interest and involvement in STEM. Robinson (2017) points to an inconsistency when contrasting the summoning for a STEM labor force with the current technological literacy and engineering practices reality in the elementary classroom by maintaining, “…although engineering has the power to integrate STEM disciplines for young children, engineering does not appear as a subject area in the accountability examinations; therefore, some schools have been slow to find space in the elementary curriculum to accommodate it” (p. 20).

To change the status quo, elementary teachers must not only develop problem-centered learning experiences for students but must also incorporate desirable 21st century social and cultural competencies into the classroom. Lambert (2015) highlights that preparing students to thrive requires teachers to be knowledgeable about 21st century skills, understand how different technologies and pedagogies encourage these skills, and know how to evaluate student learning when 21st century skills are incorporated into the learning process. Similarly, Putri et al. (2019) emphasize that since the societal purposes of education are changing, so must curriculum, teaching strategies, and methods of assessment evolve. "By putting a name on the kinds of 21st century skills employed (e.g., communicating, collaborating, critical thinking, nonlinear thinking, etc.) and describing the benefits of having these skills, teachers can more readily justify a commitment to make use of these tools in their classrooms" (Lambert, 2015, p. 2441).

Alismail and McGuire (2015) suggest that many students are being taught 21st century skills in effective school systems by teachers that recognize the importance of the competencies. Teachers who understand project-based learning can play a substantial role in helping students develop 21st century skills by applying innovative strategies and methods that increase student competencies. Diversely, other teachers may need more specific training and support to integrate 21st century skills instead of relying on a traditional model of instruction. Alismail and McGuire define a traditional approach to teaching in which "a teacher taught the content by repetition, making students say or write the same thing over and over again, which made class less interesting" (p. 150). Dole et al. (2016) assert it may take more time to do hands-on projects and solve real-life problems than the traditional model, but teachers need to be comfortable making decisions of depth instead of breadth. "New pedagogies will require changes in the relationships between teachers and students, in teaching and learning strategies, and in how learning is assessed, as the skills needed in the 21st century may not be amenable to paper-and-pencil tests" (Dole et al., p. 45).

"Without better curriculum, better teaching, and better tests, the emphasis on '21st century skills' will be a superficial one that will sacrifice long-term gains for the appearance of short-term progress" (Rotherham & Willingham [2009], p. 20). Supporting this assertion, Chen and Yang (2019) conducted research to examine the effectiveness of inquiry, design, and collaborative project approaches by comparing the effects of project-based learning and those of traditional instruction on student learning. Based on their research, they conclude inquiry-based designs, such as project-based learning, have a positive effect on students' academic achievement compared with traditional instruction, making it an effective and proven alternative to traditional direct instruction. Additionally, their research points out that active and collaborative learning-based engineering design challenges have a more significant impact on student performance than other variables, including student background and prior achievement—clearly, students are most successful when they are taught how to learn as well as what to learn.

Building an Integrated STEM Engineering Design Challenge

The structure of modern elementary classrooms since the implementation of the Common Core State Standards and the Next Generation Science Standards requires deeper levels of content integration. With increasing pressure to focus on standardized testing and learning, finding the means and time to facilitate critical thinking throughout the curriculum is challenging. To do this, more elementary teachers have begun to engage in project-based learning strategies in their classrooms and are utilizing engineering design methodology to deliver important conceptual STEM content; however, there is little evidence that that 21st century competencies like culture, societal impacts, values, beliefs are heavily represented in such lessons. The engineering design challenge described in this article was developed to illustrate one method by which an engaging, collaborative, and integrated STEM engineering design challenge can deliver both important STEM content and 21st century skills. The *Raising the Flag* STEM Engineering Design Challenge (detailed in Appendices A-C) is designed to address multiple national standards in science, English language arts, technology and engineering education, mathematics, art, and social studies as well as 21st century skills. The engineering design challenge presents students with opportunities to explore how societal beliefs are represented in flags, the history of flags, what values flags represent, the flag as a symbol, pictorial symbols, the importance and nationalism of flags, and the standard shapes and sizes of common flags. While completing this engineering design challenge, students engage in engineering design methods and collaborative techniques to design and create a family flag, classroom flag, and school flag.

This design challenge was implemented with one third grade class of twenty-four students and their classroom teacher. Faculty from a local university assisted the classroom teacher as he guided his students through the design challenge. The classroom teacher was responsible for the mini lessons spanning various content areas, which were used to introduce academic information and 21st century skills prior to the design challenge (see Appendices A-C for details). These mini lessons included weather conditions, various uses of flags including symbolism and meaning, measurement and symmetry, and similarities and differences in states' and nations' flags. Following the mini lessons, the classroom teacher and university education faculty introduced the design challenge through a series of problem-solving scenarios, the first being that students were told they would be competing in a neighborhood "capture the flag" competition.

One essential part of any STEM design challenge is documenting the problem solving and critical thinking strategies students engage with as they complete their challenge. During this challenge, the third-grade students were encouraged to do this recording in an engineering journal (See Appendix B). The journal asked students to record answers to questions such as "What is the problem?", "How can the problem be solved?", and "Draw three different solutions to the problem." Some of the problems the students identified that required critical thinking included the difficulty of measuring and precisely cutting the dowel rod for the flagpole, as well as communicating effectively with their team member and applying previous knowledge from the classroom mini lessons when creating their classroom flag. The journal further asked students to test their design after they produced it and record the results of these tests. Students were encouraged to work in teams of two throughout this challenge and evaluate the effort and work of their group members.

The challenge was appropriately paced over the course of a week and the students were successful with the content and design work. They remained engaged throughout the mini lessons presented by their teacher and were excited to work with the visiting university faculty to complete the flag design challenge. The design challenge, while fun for these students, could have been more challenging if they had also been asked to devise a way to raise and lower their flags using a pulley system. Students in third grade have been introduced to simple machines and this could have added another dimension to the work. Another challenge would have been to allow these students to research the appropriate size ratio prior to creating their flags, rather than presenting them with the correct paper size. As written, this challenge is most appropriate for first and second grade students. However, with a bit of adaptation, it can be appropriately challenging for third grade students as well. Additionally, the time frame of the challenge may be adjusted according to the age group and specific classroom constraints. Figure 1 shows pictures documenting one third grade class' progress during this design challenge.

Figure 1

One Third Grade Class' Raising the Flag Design Challenge

		
Student measuring and cutting dowel rod for the flagpole	Student group collaborating to design flag	Close-up of group's flag

The remainder of this article is organized into the various content areas that can be integrated into this STEM engineering design challenge and the benefits of engaging students in these types of integrated learning challenges.

Connecting STEM and Science Content

A good STEM lesson includes the uncovering and real-world application of scientific knowledge. Specific science content could be introduced prior to the *Raising the Flag* Design Challenge that would strengthen the scientific understandings of the students regarding weather and environmental conditions affecting the flying of flags. It is important for students to understand that flags must be made of materials that will withstand environmental conditions, and some materials can withstand environmental conditions better than others.

Technology and engineering background information is integrated into this science content lesson when discussing the technological advances made through the development of new products; flags constructed of human-made materials typically last longer than those made of natural materials (cotton vs. polyester vs. nylon). Special materials are used for flags that must be used in special places (e.g., moon landing flag or sports team flags on car windows). Weather conditions also play a role in this design challenge. Students may choose to observe and record weather data for a period of time by observing existing flags blowing. They could further use these data to estimate wind speed and determine wind direction.

Connecting STEM and Mathematics Content

A good STEM lesson also includes the uncovering and real-world application of mathematic knowledge and problem solving. To ensure success with the design challenge, some math concepts may need specific focus prior to the construction and testing of the student-designed flag. These concepts could include the different purposes of shapes; teachers may desire to focus on the composition of two-dimensional or three-dimensional shapes. A lesson focused on scale would also be important. Different sized flags are used for different purposes. Students will further need to understand the importance between defining attributes versus non-defining attributes in flags.

Students will recognize the connection between math and social studies content when counting the number of stars or different symbols on flags. They can connect this number to the historical significance of the flag and discuss symbolism. Measurements used in flags are also typically symbolic. Students could further explore the partitioning of circles and rectangles into two and four equal shares, describe the shares using the words halves, fourths, and quarters, and use the phrases “half of,” “fourth of,” or “quarter of” to describe their work.

Connecting STEM and Social Studies Content

Social Studies is heavily integrated into this STEM design challenge. The historical use of flags is an important focus prior to the creation of the students’ flags. Flags are used to represent the beliefs of people in a region or area. Ships, airplanes, and space vehicles use flags to identify the home country. Further understanding of symbols is also required. Symbols are used to represent things or values that are important to people, cultures, and nations/states/regions. One of the students’ requirements when designing their own flag is the appropriate use of symbols. Students must be able to represent their group accurately and creatively on their flag. They can be encouraged to seek out the meaning of various symbols on other flags prior to the construction of their own flag.

Connecting STEM and Art Content

Art is integrated into this STEM design challenge using symbolism and color. Historically, colors and characters are used to symbolize different emotions and feelings. Shapes elicit various responses as well. These concepts can be explored using famous artwork and/or illustrations in children's picture books. For example, curved and circular shapes may give the illusion of comfort and stability while angular shapes may make people feel excitement or agitation. Colors work in a similar manner with emotion and symbolism (red for boldness, blue for loyalty, purple for royalty, etc.). Additionally, the mathematical concept of symmetry is another way to integrate art with math and social studies since symmetry is important to the historical significance of flag creation.

Connecting STEM and Language Arts Content

English Language Arts can be integrated into the STEM design challenge when using informational text to delve deeper into various content areas for information about the historical and current significance of flags. Flags have commonly been used to send signals or messages. One example of this is in the use of nautical flags; ships use a different flag for every letter of the alphabet. A list of informational trade books that could further enhance this *Raising the Flag* Engineering Design Challenge can be found in Figure 2. Students can use these texts to build schema about flags and connect scientific ideas or concepts. These texts can also guide students as they seek to answer questions about the details of a concept.

Figure 2

Informational Text Titles on Flags, their Symbolism, and History

Title	Author(s)
Flags of the World	Sylvie Bednar
The Flag Book	Lonely Planet Kids
Flags of the Fifty States: Their Colorful Histories and Significance	Randy Howe
Flags of Countries Around the World	Melissa Ackerman
Flying Colors	Robert G. Fresson
Why Are There Stripes on the American Flag?	Martha E.H. Rustad and Kyle Poling
Did You Carry the Flag Today, Charley?	Rebecca Caudill
Flag Lore of All Nations	Whitney Smith
Raise the Flag: Terrific Flag Facts, Stories, and Trivia	Clive Gifford
I Wonder Why Countries Fly Flags	Philip Steele
Stars and Stripes: The Story of the American Flag	Sarah L. Thomson and Bob Dacey
All Countries, Capitals and Flags of the World: A Guide to Flags from Around the World	Smart Kids
The World Encyclopedia of Flags: The definitive guide to international flags, banners, standards and ensigns with over 400 illustrations	Alfred Znamierowski

Conclusion

STEM is increasingly important to our society and efforts need to be undertaken to engage students in the study and application of these disciplines at an early age. STEM education, by definition, is the integration of Science, Technology, Engineering, and Mathematics in schools. Additional integration can naturally be accomplished through a bit of creative thinking. Highlighting each content area already present in STEM and incorporating subjects such as Language Arts through the use of informational texts, Art using shapes and colors, and Social Studies from a historical perspective further strengthens the elementary curriculum and allows students to make deeper connections with the content. This engineering design challenge titled *Raising the Flag* is one example of how this type of integration is possible in the elementary classroom.

By providing elementary-aged students with engaging, positive, and successful experiences with the STEM disciplines, we can accomplish what Beers (2011) suggested as one outcome of integrating 21st century skills into the classroom: creating children who yearn for more information, who think critically to solve problems, who regularly cross disciplinary boundaries, and who work collaboratively and often continue that learning well beyond the classroom. The challenge described in this article did just that in one third grade classroom. Delivering integrated STEM education in the elementary classroom is another step toward creating a population that engages with and seeks out opportunities to solve human problems in the 21st Century.

See author bios on the following page.

Michael K. Daugherty is a Distinguished Professor of STEM Education in the College of Education and Health Professions at the University of Arkansas in the United States. He earned a BS, MS, and EdD from Oklahoma State University. Dr. Daugherty speaks nationally and internationally on STEM education, project-based learning, technological literacy, standards, and curriculum development. He is the author of 26 books and book chapters, over 70 journal articles, and numerous curriculum sets. Michael has conducted more than 100 presentations and keynote addresses at state, national, and international conferences. He has been the recipient of numerous awards including the Technology Teacher Educator of the Year Award by the American Council on Technology and Engineering Teacher Education, the Award of Distinction by the International Technology & Engineering Educators Association, and most recently, the Mary Margaret Scobey Award by the Elementary STEM Council.

Heather D. Young is an Associate Professor in the Department of Curriculum and Instruction at the University of Arkansas. She is a former public-school teacher and literacy specialist with over 20 years of experience teaching, coaching, and mentoring teachers. Dr. Young serves as the Director of the University of Arkansas Clinic for Literacy and teaches both graduate and undergraduate literacy coursework. Her research interests include literacy education and assessment, the process of teacher change, and the impact of authentic and intensive experiences on teacher preparation

Vinson Carter is an Associate Professor of STEM Education at the University of Arkansas, where he teaches courses in Technology & Engineering Education and Elementary Integrated STEM Education. Dr. Carter speaks nationally and internationally on STEM education and curriculum development.

Leah R. Cheek has served as a public-school teacher, laboratory preschool director and adjunct professor**.** She is currently a Doctoral Academy Fellow Ph.D. candidate in Curriculum and Instruction at the University of Arkansas.

See Appendices A-C following the References

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Appendix A. Raising the Flag Engineering Design Challenge Plan

RAISING THE FLAG

GRADE LEVEL: 1st – 3rd
CONTENT AREAS: Science, Technology and Engineering, Mathematics, Art, English Language Arts, Social Studies

BIG IDEAS:
- Flags represent cultures, places, and beliefs
- Symbols can be used to represent things that are important
- The engineering design process can be used to create and display different flags

CONTENT STANDARDS:
Science:
- Next Generation Science Standards
    - ESS3-3: Earth's Systems: Represent data in tables and graphical displays to describe typical weather conditions expected during a particular season.
    - PS1.A: Structure of matter: Matter exists as different substances that have observable different properties. Different properties are suited to different purposes. Objects can be built up from smaller parts
    - PS2.A: Forces and motion: The effect of unbalanced forces on an object results in a change of motion. Patterns of motion can be used to predict future motion. Some forces act through contact, some forces act even when the objects are not in contact.
    - ETS-1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
    - ETS-1-2: Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.

Technology and Engineering:
- Standards for Technological and Engineering Literacy (2020)
    - Standard 1: Nature and Characteristics of Technology and Engineering
        - Benchmark H: Design solutions by safely using tools, materials, and skills.
    - Standard 2: Core Concepts of Technology and Engineering
        - Benchmark I: Describe the properties of different materials.
    - Standard 3: Integration of Knowledge, Technologies, and Practices
        - Benchmark D: Explain how various relationships can exist between technology and engineering and other content areas.
    - Standard 7: Design in Technology and Engineering Education
        - Benchmark I: Apply the technology and engineering design process.
        - Benchmark J: Evaluate designs based on criteria, constraints, and standards.

Mathematics:

- Common Core Mathematics Standards
    - 1.MD.1: Order three objects by length; compare the lengths of two objects indirectly by using a third object
    - 1.MD.2: Express the length of an object as a whole number of length units, but laying multiple copies of shorter objects (the length of the unit) end to end
    - 1.G.2: Compose two-dimensional shapes or three-dimensional shapes to create a composite shape and compose new shapes from the composite shape
    - 2.MC.A.1: Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.
    - 3.MD.B.4: Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch.

***Art*:**

- National Core Arts Standards
    - Visual Arts: Creating 1.2.2a: Make art or design with various materials and tools to explore personal interests, questions, and curiosity.
    - Visual Arts: Creating 1.2.3a: Apply knowledge of available resources, tools, and technologies to investigate personal ideas through the art-making process.
    - Visual Arts: Connecting 10.1.2a: Create works of art about events in home, school, or community life.

English Language Arts:

- Common Core ELA Standards
    - RI.2.1: Ask and answer such questions as who, what, where, when, why, and how to demonstrate understanding of key details in a text
    - RI.2.3: Describe the connection between scientific ideas or concepts, or steps in technical procedures in a text

Social Studies:

- C3 Framework for Social Studies Standards
    - D2.Geo.3.K-2: Use maps, globes, and other simple geographic models to identify cultural and environmental characteristics of places.

CONTENT INFORMATION:

Science

- Flags are made of materials that will withstand environmental conditions.
    - Some materials can withstand environmental conditions, and some cannot.
- A pulley is used to hoist a flag up the flagpole. A pulley is a simple machine designed to make tasks easier.
- Weather data can be taken by observing flags blowing to 1) estimate wind speed (The Beaufort Wind Scale) and 2) determine wind direction.

Technology/Engineering

- As new products have been developed, flags have been made of human-made materials that last longer than natural materials (cotton vs. polyester vs. nylon).
- Special materials are used for flags that must be used in special places (Moon landing flag, sports team flags on car windows).
- Flags can be used to notify people (surveyor boundary markers), warn people (roadway flaggers), or warn of approaching danger (flag on dune buggy).
- Symbols are used to communicate (more from symbols book).

Mathematics

- Different shapes have different purposes.
- Symmetry: Can also integrate this idea with Social Studies as illustrated through this resource about the history of the Arkansas flag: http://www.netstate.com/states/symb/flags/ar_flag.htm.
- Scale: Different sized flags are used for different purposes.
- Count the number of stars on various flags and describe why that number is important.
- Distinguish between defining attributes versus non-defining attributes; build and draw shapes to possess defining attributes.
- Compose two-dimensional shapes or three-dimensional shapes to create a composite shape and compose new shapes from the composite shape.
- Partition circles and rectangles into two and four equal shares, describe the shares using the words halves, fourths, and quarters, and use the phrases half of, fourth of, quarter of. Describe the whole as two of, or four of the shares.

Social Studies

- Flags represent the beliefs of people in a region or area.
- First flags were used by the military so send signals on the battlefield.
- Ships, airplanes, and space vehicles use flags to identify the home country.
- Symbols are used to represent things that are important to people, cultures, a nation/state/region. For example:
  - The United States flag includes a 5-sided star for each State.
    - Started with only 13 stars, now has 50.
    - Blue on the flag represents freedom; red represents hardiness, courage, and valor; white stands for purity and innocence.
  - The Olympic flag represents the five original participating continents of the games, while the six colors are those that appear on all the national flags of the world at the time it was designed in 1912.

MINI LESSONS/ACTIVITIES:

Listed below are 6 suggested mini lessons/activities that would be beneficial to complete prior to the flag challenge. These activities will help introduce the content information to students. As *the teacher, it is important to remember that your role is to be the facilitator. You should guide the students in discovering the answer(s), instead of directly telling the students the solution.*

1. Discuss weather conditions with students - wind speed, wind direction, materials used to make flags, etc.
2. Ask the students to name different kinds of flags that they have encountered. Discuss the uses of various flags (notify people, warn people, communicate, mark boundaries, etc.).
3. Measure different flags around the classroom and school and discuss the different sizes and measurements of flags.
4. Show the students a flag with symmetry and a flag without symmetry and discuss.
5. Show the students a flag with many different shapes, have the students draw all the shapes that they see in the flag, and discuss their differences.
6. Read a book on the history of the flag representing a specific country, state, or province. Discuss the use and meaning of the symbols on the flag(s) and the use of color and the meaning behind different colors.

ESSENTIAL QUESTION:

How are symbols, shapes, codes, and patterns used on flags to represent culture, places, beliefs, and history?

"Raise the Flag" PROBLEM-SOLVING SCENARIOS:

- Your neighborhood is competing in a "capture the flag" competition! Each family needs a flag to place in their front yard to represent the family. You need to design and create a flag that represents YOUR family.
- Our classroom needs a flag to represent the class at a school assembly. Work in a small team to design and create a flag that represents OUR classroom.
- Our school is participating in a town parade. Our class needs to design and create a flag that represents OUR school. The flag that best represents the school will be used at the town parade.

DESIGN CHALLENGE:

Students will work individually to design a flag the represents their family. Following this activity, the students will be placed into groups and asked to design a flag that represents the classroom, and ultimately the school. After completing each flag, the students and/or teams must present the flag and describe how the flag represents their family, classroom, or the school.

DIFFERENTIATION AND ADAPTATION:

(For third grade students specifically) Students should research appropriate flag measurements and then apply that knowledge when creating their group flag. To add another challenge, groups may design a pulley system to use when raising and lowering their flag on their flagpole.

PARAMETERS OR CONSTRAINTS:

- The flag must:

- Be designed using the materials supplied by the teacher
- Be appropriately proportioned (12” x 18” for grades 1 and 2 OR ratio of 1.5)
- Include symbols, shapes, and colors that represent their family, the class or the school
- Include holes that will allow the flag to be mounted to a "flagpole"

TOOLS AND MATERIALS:

TOOLS	MATERIALS
Scissors Hole Punch Pens/pencils/Markers Paint Colored pencils Crayons Glue	Paper Cloth Cardstock Dowel rods (for flagpoles) Small carabineers String Thumbtacks **Other materials may also be appropriate.*

DELIVERABLES:

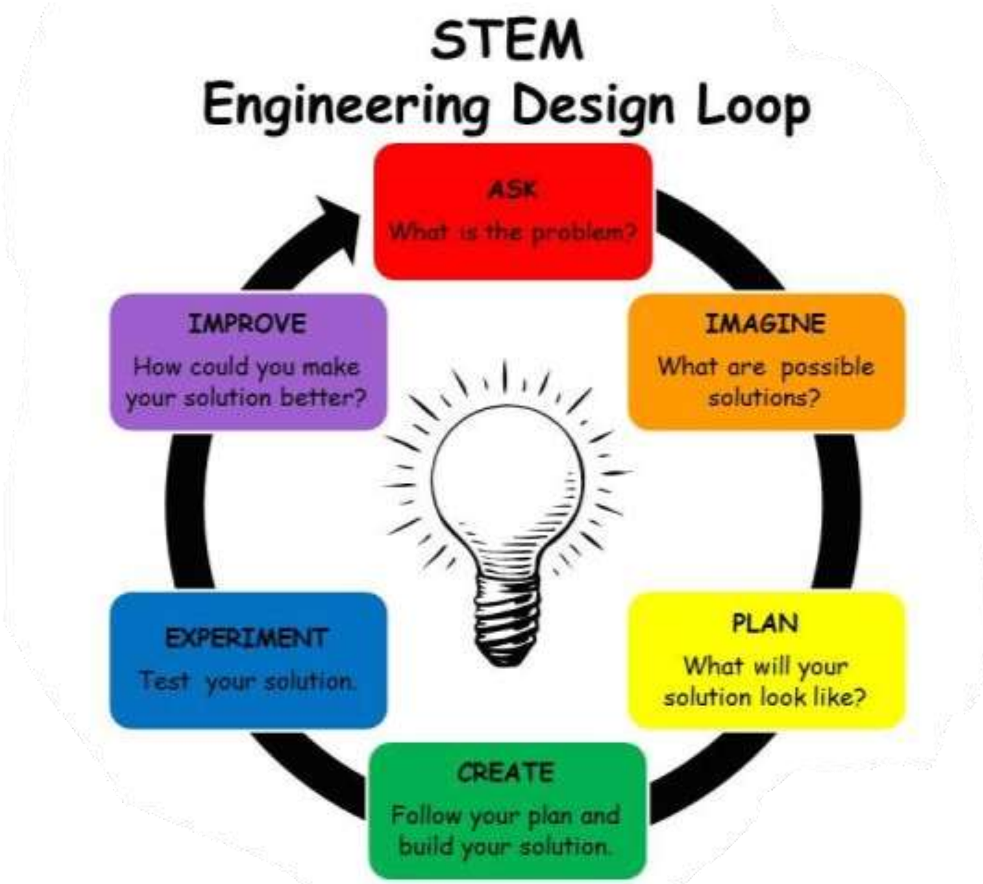
- Student engineering design journal and completed flags

EVALUATION:

- Student engineering design journal (evaluation of process and reflection)
- Teacher rubric
- Optional: partner or team evaluations

Appendix B. Raising the Flag Student Instructions and Journal Template

Raising the Flag!
How are symbols, shapes, codes, and patterns used on flags to represent culture, places, beliefs, and history?



Family Flag:

Your neighborhood is competing in a capture the flag competition! Each family needs a flag to put in their front yard that represents them. You need to design and create a flag that represents YOUR family.

- The flag must:
  - Be designed using the materials supplied by your teacher.
  - Measure exactly 12" by 18" or a ratio or 1.5.
  - Include symbols, shapes, and colors that represent your family.
  - Include holes that will allow the flag to be mounted to a "flagpole."

Design your family flag!

Ask: What is the problem?	____________________ ____________________ ____________________ ____________________
Imagine: How can the problem be solved?	____________________ ____________________ ____________________ ____________________

Plan: Draw three different solutions to the problem.		
Idea #1	Idea #2	Idea #3
Create: Draw a final copy of your flag & attach it to a flagpole!		

Test: Does your flag represent your family?	____________________ ____________________ ____________________ ____________________
Share: What symbols are you going to share with your classmates and what do they represent?	____________________ ____________________ ____________________ ____________________
Improve: What changes would you make to your flag?	____________________ ____________________ ____________________ ____________________

School Flag:

Our school is participating in a town parade. Each class needs to design and create a flag that represents OUR school. The flag that best represents the school will be used at the town parade.

- The flag must:
  - Be designed using the materials supplied by your teacher.
  - Measure exactly 12" by 18" or using a ratio of 1:1.5
  - Include symbols, shapes, and colors that represent your school.
  - Include holes that will allow the flag to be mounted to a "flagpole."
  - The school flag must represent every student in the school.

Design our school flag!

Ask: What is the problem?	__________ __________ __________ __________
Imagine: How can the problem be solved?	__________ __________ __________ __________

Plan: Draw three different solutions to the problem.		
Idea #1	Idea #2	Idea #3
Create: Draw a final copy of your flag & attach it to a flagpole!		

Test: Does your flag represent your school?	__________ __________ __________ __________

Share: What symbols are you going to share with your classmates and what do they represent?	____________________ ____________________ ____________________ ____________________
Improve: What changes would you make to your flag?	____________________ ____________________ ____________________ ____________________

Appendix C. Raising the Flag Rubrics

Partner/Team Evaluation:

Your Name: ____________________________
Partner's Name: ____________________________
Date: ____/____/__________

Self and Team Evaluation

	Me			Partner or Team		
Worked as a team.	☺	😐	☹	☺	😐	☹
Good listeners.	☺	😐	☹	☺	😐	☹
Accepting of new ides.	☺	😐	☹	☺	😐	☹
Used materials and tools correctly.	☺	😐	☹	☺	😐	☹
Followed project guidelines.	☺	😐	☹	☺	😐	☹
Comments:						

RAISING THE FLAG CHALLENGE

Project Rubric

(**To be used by the teacher)*

Student Name: ___________________________

- ❖ The student participated and followed directions.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

- ❖ The student used symbols effectively and/or accurately on their family flag.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

- ❖ The student used symbols effectively and/or accurately on their school flag.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

- ❖ The student's design loop journal was completed and ideas were developed.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

- ❖ The student successfully completed the family flag and school flag.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

- ❖ Student demonstrates understanding of the overall concepts.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

- ❖ Student worked collaboratively with partner or team.
  - o Minimally Demonstrated 1 2 3 4 5 Strongly Demonstrated
  - o Evidence or Comments:

Total Score: ____/35 points

Comments:

A Review of Augmented Reality Apps for an AR-Based STEM Education Framework

Carlo H. Godoy, Jr.
Philippine Navy
godoy.carlo@navy.mil.ph

Abstract

Within the past two decades, Augmented Reality (AR) applications have received increased attention. Augmented Reality is now widely used in the education sector at level K-12. AR is expected to be generally adopted in two-to-three years in higher education and four-to-five years in K-12. Applying AR technology in the education sector especially in STEM subjects, can result in having a smart campus. In adopting a SMART Campus strategy, education practitioners must address many intrinsic issues in science, technology, engineering, and mathematics (STEM) research. For example, in physics, there are expensive or insufficient laboratory systems, system faults, and difficulty simulating other experimental circumstances; in technology, many schools do not have enough computers; in engineering, there are only a few instructors who are knowledgeable in computer-aided design (CAD); and in mathematics, few teachers incorporate technology into their lessons often because they believe it is still better to teach through the traditional methods. Hence, In this paper we discuss how AR is being used now in different learning areas in STEM to open new doors to researchers and teachers as they transition their schools into SMART campuses with the use of AR apps. Aligned with this, a suggested framework for school administrators and policymakers is proposed based on a review of the positive benefits of different AR apps.

Keywords: Augmented Reality, education, e-learning, mobile game application, game-based learning, gamification, science education, technology education, engineering education, mathematics education, STEM education

Author Note: A Review of Augmented Reality Apps for an AR-Based STEM Education Framework is an extension study stemming from a previous review that the author conducted. The extension study was done to craft a framework for STEM Education that the author hopes will help schools in the Philippines.

Augmented Reality (AR) apps have received increased attention over the previous two decades. AR generates fresh world experiences with its data layering over 3D space, suggesting that AR should be embraced over the next 2–3 years to give fresh possibilities for teaching, learning, study, or creative investigation according to the 2011 Horizon Report (Chen et al., 2017). This article discusses the different augmented reality applications that are being used in STEM education and will then create a suggested framework based on the review results. Azuma, as cited by Akçayir and Akçayir (2016), states that virtual objects in an Augmented Reality applications appear in coexistence in the same space as the objects that are located in the real world, hence it is very well-suited for enhancing STEM learning environments. AR is now a common technology used in instructional environments in the education sector (Fernandez, 2017).

According to Rouse, as cited in Jung and tom Dieck (2018), AR is the integration of information in digital format, which includes live video in the real time environment of a certain user. In augmentation of live videos, integrating a video picture to a digital environment involves identification of an object replicated from features of the physical world. It is then captured as any format that will be considered as a video picture. It will mean increasing the responsiveness of the generated video picture to the state needed to control the object from the physical world itself (Kochi et al., 2017). In an augmented reality system, the integrated digital information can only be seen using devices like phone cameras. Hence, it cannot be seen in the real world without using a camera. These digital information forms can be represented in different forms like a stack of virtual cubes or manipulating a non-real object in a variety of ways (Hilliges et al., 2018). AR can also be used to indicate or layer additional information onto a real environment. This supplemental information is considered optional and may not affect the actual user of the system itself. The methods being used by an AR system to provide these supplemental information are the following: (a) Tracking the user's point of view, (b) Capturing a camera field of perspective, and (c) Obtaining additional data in the field of perspective captured for at least one object (Pasquero & Bos, 2017). One example of supplemental information is found in vehicles. In this manner, it obtains additional data in the field of a perspective captured for at least one object. Hence, if the user's interest has been captured, the system should present an augmented reality replica of a vehicle and cover the user's environment based on the point of interest (Habashima et al., 2017).

Augmented Reality for STEM Education

AR is widely used now in the K-12 level of the education sector (Akçayır & Akçayır 2016). Ferrer-Torregrosa et al. (2015) stated that AR is also being used now by different universities. The application of the technology in the education sector can lead to a "smart campus." Smart campuses are designed to benefit professors and students, handle the resources available and improve the experience of the users with proactive services (Ozcan et al., 2017).

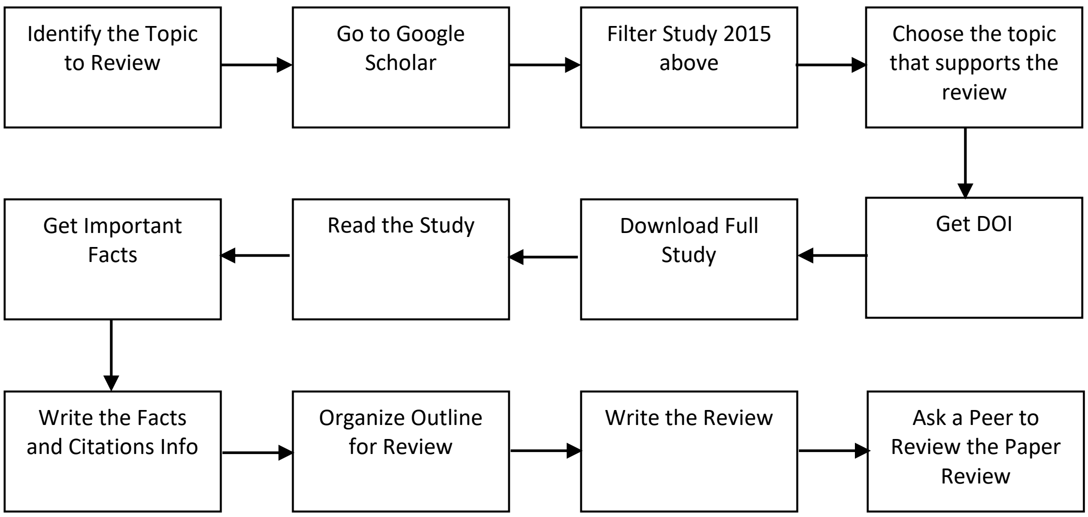
As highlighted in the Horizon report, AR is acknowledged as one of the most significant innovations in Higher Education and K-12 education technology (Johnson et al., 2015). AR is gradually becoming integrated as an emerging technology in the region of inclusive education that adapts learning to provide equal footing through accessible exploration and experiences by all (Marín-Díaz, 2017). Johnson et al. stated that AR is anticipated to be widely adopted in higher education in two-to-three years and in K-12 in four-to-five years (cited by Saltan, 2017). Consequently, it is essential to explore how teachers and scientists incorporate AR into teaching-learning procedures if this is the present state of the art for the use of AR in education. AR became visible in the early 2000s and its effectiveness for learning was soon established by educational research (Dede et al., 2017).

Review Methodology

To share more about the ways in which AR is being used in STEM education, the author conducted a focused review of AR in STEM education research. A representation of the strategy employed in completing the review is shown in Figure 1. The search procedure started by selecting the topic to be reviewed. In this case the topic is AR for STEM Education. The topic selected explored the different sectors in STEM that are using Augmented Reality as a tool for teaching and learning. After identifying the topic, the next step was to search Google Scholar. About 1,530,000 results were noted with 97,600 filtered to explore further. In this part the study was filtered depending on the importance of each study. The importance was filtered using exclusion-inclusion criteria, which are shown in Table 1. Another filter that needed to be added is the year when the publication was published. It assumed that a five year interval will still make a certain publication valid. Once the filtering was been set, the author selected the relevant documents that would build the foundation of the review. This study will only focus on how the different disciplines are being used in the education sector and is not deemed as a comprehensive review. After knowing the foundation and the outline where the documents would be discussed, the DOI (Digital Object Identifier) of each publication was used to be able to access the full copy. Once the full study had been acquired, all documents were reviewed. During the review process, it was necessary to filter which documents were needed to support the selected topic. Once the important facts had been gathered and the studies had been filtered, the review was written.

Figure 1

Review Methodology



Reviewing Augmented Reality for STEM (Science, Technology, Engineering, Mathematics) Education

After applying the exclusion and inclusion criteria (Table 1), the author selected different literatures that helped in the discussion of the review.

Table 1

Exclusion and Inclusion Criteria

Exclusion Criteria	Inclusion Criteria
Comparison of GBL to normal and blended learning	Effectiveness of games for educational purpose as a supplementary tool
Games that are not for SPED, Language Skills and Technical Vocational Education	The study should either be for SPED, Language Skills or Technical Vocational Education
Duplicate Studies	The game should be visually impacting in terms of the subject area

There was no definite number of articles included but the author has chosen more than 10 literature reviews and included the most suitable for the review. Below are the results per discipline.

Science

Education Professionals must tackle several problems intrinsic in the training of science fields such as physics costs or inadequate laboratory equipment, mistakes of equipment, or difficulty in simulating certain experimental circumstances (Cai et al., 2017). These normally lead to student's learning achievement in physics to be lower, hence students may have low motivation in learning this subject. Augmented Reality can be a successful approach to tackling these problems. A study about magnetic field instruction has been conducted in relation to the problems. Results of the analysis demonstrated that the movement-sensing software based on AR can enhance the learning attitude and learning result of the learners. This research offers a case for applying AR technology to secondary education in physics (Cai et al., 2017). In learning about health science, medical anatomy, and neurosurgical procedures it is also very helpful to use Augmented Reality as a learning tool. In an environment where a required structure needs to be examined from all angles, anatomical learning is best performed using a tool that will show these angles (Moro et al., 2017). Augmented Reality is one of the best tool to show angles as the developer can easily manipulate how the augmented object will rotate and be displayed.

Compared to traditional pedagogical schemes, Virtual Reality (VR) and AR have the ability to produce improved teaching environments. 3D learning environments can increase the motivation/engagement of learners, improve the representation of spatial information, improve learning contextualization and create superior technical skills (Pelargos et al., 2017). Over the previous several centuries, neurosurgical has experienced a technological revolution, from trephination to image-guided navigation. Advances in Virtual Reality and Augmented Reality are some of the latest ways of integrating into neurosurgical exercise and resident education (Pelargos et al., 2017). Another application named Guided Exploration Training MAR software has been tested. Majid et al. (2021) conducted a research to test this AR application using a post and pretest method and the result has shown a positive feedback. In this study, visualizing each atom's 3D model helps the students to gain more insight into the chemical properties of group one metals. The increase in scores demonstrates that in the end complicated materials can be used and learned using the Guided Exploration Training MAR software.

Studies have shown that AR technology can significantly improve learning results in education. For example, AR enables learners to participate in real-world explorations such as marine life explorations that not everyone has been able to experience (Akçayir et al., 2016). Marine schooling includes problems that are rich and multifaceted. Raising awareness of marine settings and problems requires fresh teaching materials to be developed. In line with that, a digital game-based learning was tailored for primary school learners to design an innovative marine learning program incorporating augmented reality (AR) technology (Lu & Liu, 2015). The results of using this technology are the following: (a) Learners were extremely confident and satisfactorily viewed the learning operations ; (b) Learners obtained target goals for understanding ; and (c) The innovative teaching program specifically helps small academic achievements and enhance learning efficiency. Another great application of Augmented Reality in science is an AR-based simulation scheme for a cooperative investigation-based teaching activity in a science course and which discovered that AR-based simulation could involve learners more deeply in the investigatory project activity than traditional simulations could (Hwang et al., 2016).

Technology

Augmented reality has attracted great government attention among these techniques because it offers a fresh teaching view by enabling learners to visualize complicated spatial relationships and abstract ideas (Phon et al., 2015). Research has shown that, owing to a number of factors, many Malaysian non-technical learners have low motivation in studying ICT courses, such as absence of effective teaching practices and efficient teaching apps. In the outlook of such issue, the research teams conducted a quasi-experimental analysis to examine the adverse effect of a new application for mobile augmented reality learning (MARLA) on the motivation of learners to learn a topic of an ICT course at a university (Hanafi et al., 2017). Another study under the ICT education sector has a goal of exploring whether the integration of AR methods would facilitate application for changing the style as well as analyzing a distinct outcome in educating the learners, which uses a blended learning approach based on online methods and AR (Wang, 2017). It was found that technology instructional scientists should take cautious consideration of the educational goal architecture, the data size shown on the cellphone monitor, and the teaching machinery and school facilities setting when incorporating AR apps into a course in order to obtain an appropriate learning situation.

The effect of Augmented Reality and QR Code Integration on achievements and views of undergraduate students taking computer training was examined by Bal and Bicen (2016). A test study group included 50 volunteer students taking a compulsory computer course studying in Near East University's Department of Guidance and Psychological Therapy. The study used experimental research design. Students were divided into two classes at the beginning of the term, namely experimental and control groups, consisting of 25 students in each group. During the first lecture, a pre-test was given to the two groups and a lecture was given using conventional methods, in which computer features were described and computer feature functions were explained to the 1st group. Three-dimensional images of hardware features in the computer course hardware chapter were demonstrated to the 2nd group by means of augmented reality and QR technology a laboratory environment with screen, projection, and voice systems. During the lecture, students examined computer hardware with QR code cards and increased reality technology from their own mobile devices, and all lectures were given until the end of the semester in this way.

At the end of the semester, a post-test was given to the experimental and control groups and the experimental group also was provided a questionnaire related to the virtual reality and computer hardware course application with QR code integration. Results from the study showed that the experimental group's level of achievement was higher. Results showed in this context that computer hardware course implementation with augmented reality and QR code integration has a positive impact on students and their academic accomplishments with positive views towards this course. Based on the findings, the approach used in this study is expected to lead to the introduction of technology into education and thus technology and education should be mutually beneficial.

Engineering

Augmented reality is very effective in engineering and can have many applications, which includes boosting the learner's motivation in this field. AR may help an engineer or designer to design a product in the right environment, enabling them to be mindful of space limitations or other barriers. It may also encourage an engineer to incorporate esthetics into their design, making sure that when it is done and assembled their product would look pleasing to the eye. Or maybe an engineer may need to build an improvement to an existing component or system, but they do not have the original element drawings or models. Considering the size, shape and existing features, AR allows an engineer to design directly on the existing item (Heimgartner, 2016).

A study conducted by Martin-Gutierrez et al., (2014) has provided a clear proof of the positive used of AR in Engineering Education. Analysis provides findings that demonstrate how engineering students produce better academic outcomes and are more inspired by integrating the latest generation of technical resources into the learning process. Twenty-five first year students studying for a degree in Mechanical Engineering used AR technology to assist them in the graphic engineering subject matter. A control group of twenty-two classmates used conventional class notes during the study. Both these students took an analysis and two surveys to provide input on the teaching content: one to find out the efficacy and quality of the material itself, along with the student satisfaction level; Another for measuring student motivation by using the available technologies during the course of the research. The findings revealed a substantial statistical disparity in their academic outcomes and appeared to be higher in the experimental community; this community also displayed a higher motivation level than the control group.

Mathematics

An integrated STEM (Science, Technology, Engineering and Mathematics) lesson requires to participate and nurture students‘ interest in real-world circumstances, which has been proven to boost learner's motivation in this subject and while real-world STEM situations are naturally incorporated, the embedded STEM contents are rarely taught by school educator (Hsu et al., 2017). One of the hardest subjects of that track is Mathematics. One example of a Mathematics subject is Solid Geometry. To give a better experience in learning solid geometry, a study has been conducted to combine Augmented Reality (AR) technology into teaching operations designing a learning scheme that helps junior high school learners learn sound geometry (Liu et al., 2019; TeKolste & Liu, 2018). Based on the result of the study, AR really gives a big leap in learning solid geometry.

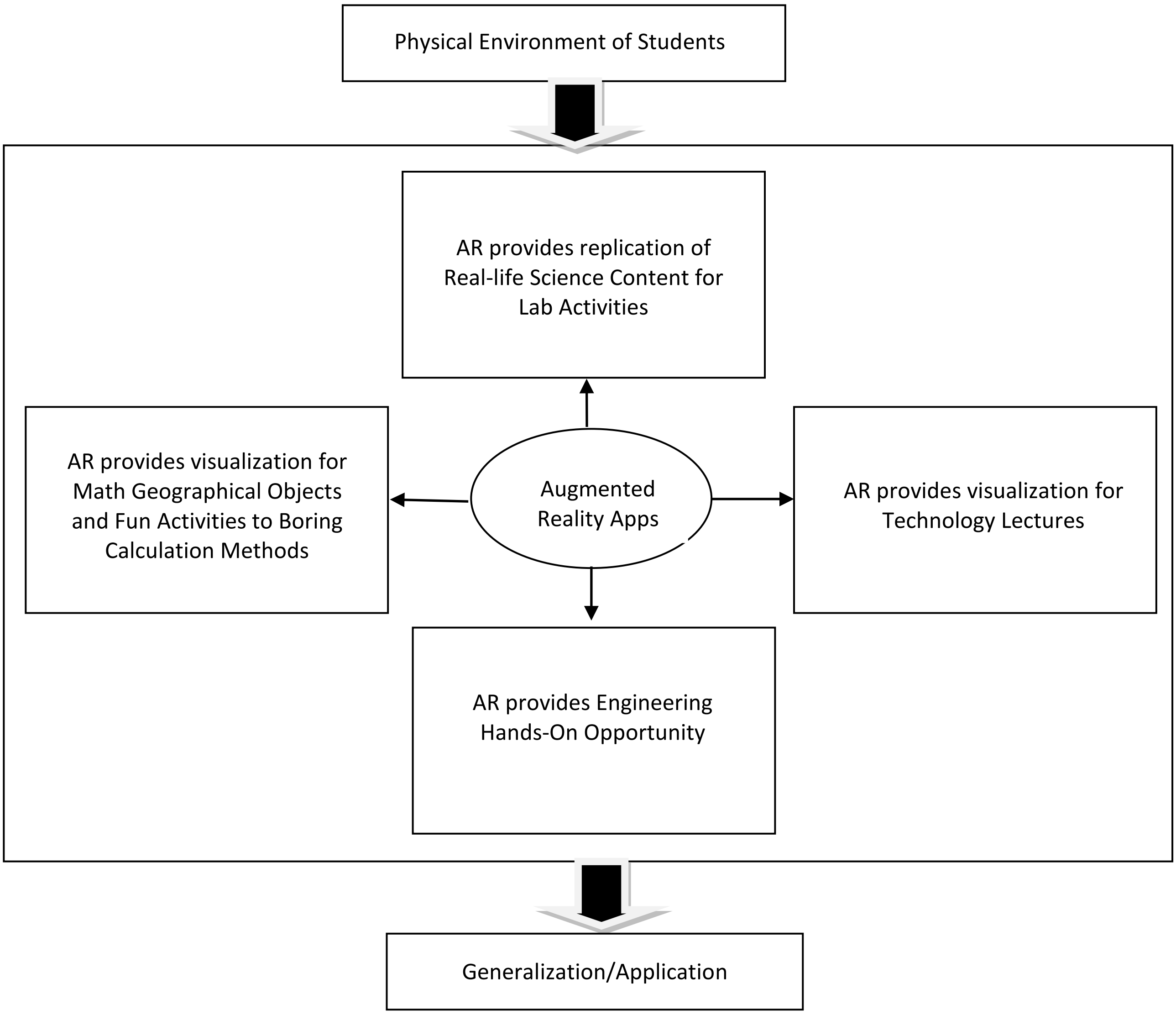
Castillo (2015) on the other hand has introduced a new software framework for the creation of AR applications based on publicly available components. It offers a comprehensive view of the subsystems and the tasks involved in developing a mobile AR application. The standard task of plotting a quadratic equation was chosen as a case study to gain feasibility insights into how AR could help the teaching-learning process, and to analyze the student's reaction to the technology and the application. The pilot study was carried out in a Mexican Undergraduate School with 59 students. To collect information on the experience of the students using the AR application, a questionnaire was developed, and the review of the results obtained is presented. The findings obtained by applying the questionnaire on the use of AR technology indicate that using AR can help enhance the teaching-learning process in Mexican classrooms and inspire the students and can be an innovative tool to revolutionize the learning paradigm.

Another study deals with the use of AR in teaching and learning math that uses this technology to its complete benefit in providing concrete experience in interacting with revolutionary solids. At the end of the study, it was found out that Augmented Reality is beneficial in the understanding of computing solids of revolution volumes (Salinas & González-Mendívil, 2017). AR techniques are strongly linked to calculation capacity and computational calculations, and therefore their evolution is related to personal computer development. It is therefore essential to begin by referring to some of the works that have been created through the implementation of these techniques at global and national level, primarily in the field of education and teaching (Coimbra et al., 2015). It can be inferred that from the birth of AR it was already related to Mathematics. AR makes mathematical ideas simpler to comprehend because it provides better visualization and interaction. We can therefore conclude that three-dimensional techniques, such as AR, improve mathematics teaching and learning. At the same time as the imperative to better comprehend the use of mobile devices for learning mathematics in many nations, there is a powerful political will to enhance teaching and learning process in mathematics education to support innovation that drives economic growth and create the capacity of tomorrow's workers for future work markets (Bano et al., 2018).

AR-Based Framework For Stem Education Derived From The Review As A Basis For School Administration And Policy Makers

Figure 2

AR-Based STEM Framework



A STEM (Science, Technology, Engineering and Mathematics) education framework can now be derived from the review. STEM lesson requires to participate and nurture students' interest in real-world problems and lectures, so the framework shows that Augmented Reality integrates the physical environment with the content and activities. The different applications discussed on the review has shown that Augmented Reality has been a successful aid in learning the different subject areas under the STEM strand. According to Kelley et al. (2016), enhanced integration of STEM subjects might not be more successful if the implementation strategy is not strategic. A well-integrated curriculum, however, gives students the ability to learn through more meaningful and engaging ways, promotes the use of higher critical thinking skills, enhances problem-solving abilities and increases retention. In that case, the above framework serves a guide for school administrators, policy makers and STEM Department Heads on how AR-Based Activities can be implemented as a supplementary learning tool as part of their blended learning approach. Given this framework, a physics teacher might very well be able to increase the student's learning ability.

CONCLUSION

As shown in the results of the review, AR has been proven to help organizations and teachers in teaching different STEM disciplines and can be applied here in the Philippines as well as in other areas of the region. Studies have shown that the use of AR can be more efficient in teaching support than other technology-enhanced settings. If content is represented as 3D to learners, it is possible to manipulate objects and handle the information interactively. Rapid technological evolution changed the face of education, especially when technology was coupled with adequate pedagogical foundations. This combination has developed fresh possibilities to enhance the quality of teaching and learning experiences (Nincarean et al., 2013).

Based on the findings, Augmented Reality and the framework presented can help boost the education sector of the Philippines. The combination of these two processes will definitely lead to a new system which will have a major impact on the STEM sector of Education (Phon et al., 2015). In implementing this new system, the AR-Based Stem framework is helpful for school administrators, policy makers and STEM Department Heads

Carlo H. Godoy, Jr. is a former Escalations Manager at Novartis Pharmaceutical and Support Analyst for SQL at Human Edge Software Philippines. Currently he is a Computer Programmer/Sail Plan Manager at the office N6 of the Philippine Navy. He is also a Research Scholar at the Technological University of the Philippines in the Masters in Information Technology program specializing in studies related to educational technology using emerging technologies like augmented reality. Mr. Godoy has been in the education sector for eight years. He currently serves as a thesis adviser in the Technological University of the Philippines, Manuel L. Quezon University, and in STI College Munoz Edsa.

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