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

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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

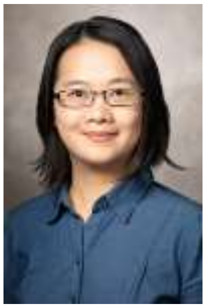
<table>
<tr><td rowspan="2">10</td><td colspan="2">Create Animal Prosthetics (4th grade)</td></tr>
<tr><td>CCSS.Math.Content.4.MD.5 & 6
NGSS 3-5-ETS1-1, 2, & 3 and 4-LS1-1</td><td>☒ Different difficulty levels
☒ Mixed learning styles
☒ Multiple modes of presentation</td></tr>
<tr><td rowspan="2">11</td>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

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.



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