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Designing Intentional STEM Connections: An Initial Case Study in an American Curriculum School

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Students benefit from the intentional integration of science, technology, engineering and mathematics (STEM) in ways that support deep conceptual learning in all disciplines. Elaborating on Bybee's (2013) nine perspectives of STEM, the article describes three specific and intentional methods in which integration, specifically in mathematics and science, can be effectively implemented and integrated. Each of the methods of integration has its purpose based on the context of the investigation, the intended learning outcomes, and the students' learning needs during the investigation. These methods of integration are discussed within the context of one lesson from a broader investigation on weather as it relates to the interaction of earth's major systems.

Keywords: *STEM, Integration, Primary Grades, Project-Based Learning.*

Introduction

Supporting science, technology, engineering, and mathematics (STEM) in the classroom has gained much momentum over the last two decades. Unfortunately, there is still no clear definition of what STEM is or means, and more importantly, what it actually looks like in the classroom (Bybee, 2013; Ring-Whalen et al., 2018). In fact, Bybee (2013) and Brown (2012) posit that a clear understanding is required because the acronym has been used in many ambiguous ways and because these ambiguities do not help educators within the reality of their practice. This means there is a need to develop methods for appropriate STEM integration, which would include such areas as curriculum, assessment or instruction so that educators can appropriately implement and integrate meaningful STEM experiences.

Review of Literature

The acronym STEM is frequently used in place of science, but how the other three content areas (e.g. engineering, technology and mathematics) are integrated varies, is inconsistent, and are often not even evident in experiences that are labelled STEM (Bybee, 2013). Mathematics, in particular, plays a fundamental and structural role in authentic science learning as seen by the description of behaviours that scientists engage in as they investigate the natural world and thus should be integrated (Michaels et al., 2008; National Research Council, 2012). Furthermore, there is an obvious overlap of the Science and Engineering Practices within the Next Generation Science Standards [NGSS] (NGSS Lead States, 2013) and the Standards of Mathematical Practice (National Governors Association, Center for Best Practices, & Council of Chief State School Officers, 2010) to promote technical ways of thinking. This overlap and alignment to technical habits of mind and interactions suggest a natural area for integration (Bennett & Ruchti, 2014).

In addition to practices, science provides multiple opportunities for students to simultaneously learn important mathematics content, especially as it relates to data analysis. However, science curricular resources rarely highlight these connections or leverage them in grade-level appropriate ways (Morris

et al., 2015). Even so, educators can be well positioned to determine how best to link and leverage cross-curricular learning for authentic STEM integration. For some situations, this may mean understanding how to integrate STEM practices and habits of mind but in others it can mean purposefully injecting other STEM disciplines so that the learning can become more meaningful and applicable. This means that teachers and teacher leaders need to be aware of the specific nature of integration and how it purposefully builds students' understandings across STEM disciplines (Kelley & Knowles, 2016). However, while technical habits of mind is a good place to start integrating STEM content, the deliberate integration of STEM content at the classroom level can be more challenging.

When integrated, and when it involves a more contextual application, STEM experiences can have greater meaning and thus allow for deeper connections and more authentic learning for students (Sandall et al., 2018). Several variables in the school context can contribute to unsuccessful STEM integration. For example, many teachers struggle shifting from teacher-directed pedagogy to the more student-directed nature of an integrated curriculum. In addition, district-level or course-level curriculum alignment is often inflexible as are the structures of school schedules and finances (Margot & Kettler, 2019). Schools and teachers often do not know what STEM looks like, especially when it comes to modifying and integrating their current curriculum (Portz, 2015). This confusion leads to very different conceptions of STEM education which can cause a "state of anxiety and insecurity and, in some cases, to reject the implementation" of STEM in the classroom (Aguilera et al., 2021, p. 597).

In order to create such learning experiences, teachers often want to understand the nature of integration of the STEM disciplines. Or rather, to understand what qualifies as quality STEM learning; the knowing when and how to integrate disciplines to support greater learning. Thus, the purpose of this study is to understand how an elaboration of Bybee's (2013) integration is actualized within a primary classroom.

Theoretical Framework

Bybee (2013) outlines nine commonly accepted perspectives for defining STEM, but only six of these nine are applicable at the classroom-level. Of these six, the research team examined only those STEM perspectives that best supported a more complex integration at the classroom level; specifically, STEM means coordination across disciplines and STEM means complementary overlapping across disciplines numbers four and six above. Then, the team elaborated on these two definitions and created three specific methods for STEM integration which are referred to as: 1) *Simultaneous Infusion*, 2) *Temporary Shift in Discipline*, and 3) *Lateral Concept Connections*. In this project, *Simultaneous Infusion* uses mathematical and scientific habits of mind and practices, such as the importance of using data and communicating ideas and understandings in STEM, and are considered simultaneously during the science lesson. When using *Temporary Shift in Discipline*, is a shift from one discipline (e.g. science) to conceptually explore a skill in another discipline (e.g. mathematics), and then a shift back to the original discipline (science) to bring new understandings to the primary science focus. And lastly, with *Lateral Concept Connections* the focus of the learning moves from a primary science concept to a new science concept. The purpose of this shift is to give students new content to reinforce a mathematical concept.

In order to provide clarity and consistency, the research team established a working definition of STEM. For this project, STEM learning is understood to be opportunities, within technical content areas, to understand, create, and discuss ideas and concepts that supports students' critical thinking, analysis skills, and connections to larger concepts across and within STEM disciplines (Li et al., 2019). This focus also follows the National Council of Supervisors of Mathematics and the National Council of Teachers of Mathematics joint position paper on STEM learning (2018). Namely, that students have a strong mathematics foundation and that any STEM program or curriculum should enrich the mathematics program and also address mathematics with integrity.

Methods

The purpose of this qualitative exploratory case study (Løkke & Sørensen, 2014) was to understand how an elaboration of Bybee's (2013) integration is actualized within a primary classroom. Examining specific cases is important as it allows for the testing of theory by using multiple data collection methods in varied, yet similar, contexts to provide a more accurate and rich description of the unique, dynamic, and complex nature of classroom learning environments. With a purposeful focus for integration in mind, the research team and classroom teachers examined how the strategic integration of scientific and mathematical experiences, using the three aforementioned elaborations, allowed for a more dynamic and purposeful ebb and flow of STEM learning. That is, by using these three elaborations, the research team wanted to better understand how this elaborated framework supports the teaching and learning of integrated STEM in an upper primary classroom; this includes both challenges and affordances with respect to planning and implementation.

Participants

The primary participant in this case study was one second-year grade five teacher in their classroom, which included 23 students, from a school located in the Intermountain-west of the United States. This school serves a population with substantial social needs and financial insecurities and thus many students also often receive additional behavioural and/or social-emotional support and services. There are approximately 500 students across all grades and most teachers have between 20 and 28 students in each class and are responsible for teaching all subjects except for physical education and music, both of which are offered on a limited rotational basis. It is common to have students several years behind in reading and/or mathematics and annual test scores show that, while slightly higher than average scores across the state, only about 45% of students score at proficiency levels in mathematics.

Instructional Setting

The interdisciplinary activities described herein were developed as part of a larger, upper primary science project examining ways the geosphere, biosphere, hydrosphere and the atmosphere interact. These lessons were co-created with classroom teachers along with science education and mathematics education researchers around the intended elaborations. In the activities described below, which is a subset of the larger project on integrating STEM learning through project-based learning, the lesson objectives were to analyse and interpret weather data in order to develop understandings between weather and climate in different regions of the world.

Data Collection & Analysis

Data collected included classroom observations of students' interactions and comments, field notes from lesson planning meetings, and notes from post-lesson discussions with the teacher. Emphasis was placed on the interpretations and meaning that the researcher and the teachers had towards integrating STEM. Data were independently read and analysed to identify common themes (Paton, 2002) and were then re-categorized as needed to appropriately capture the emergent patterns.

Limitations

A primary limitation in this study revolves around the fact that it includes only one classroom, within one school. Another limitation centres on the fact that data comes from the first and only iteration of the elaborated integrations with teachers. As such, this greatly reduces the richness of the data and thus the interpretations that can be made despite promising findings for future research are limited.

Project Implementation & Findings

At the start of the lesson, students watched a video report from the National Oceanic and Atmospheric Administration on the winter outlook for the region. This was to help students contextualize how weather data can be used in their geographical area. This video report included various types of graphical data, numerical data, and a verbal discussion of the current snowpack, projected snowpack, and what this data means in terms of spring flooding forecasts. Students spent some time discussing what they heard, and what they believed were the implications of the data in their daily lives. Students were also asked to consider what knowledge and information they needed to interpret the data, based on what the meteorologist was telling them. Lastly, students were asked to consider the ways in which scientists and mathematicians think and behave in a similar fashion as they watched the video.

Next, students explored data from their own weather station. This raw data showed the daily mean temperature (F°), high and low temperatures (F°), heat and cool degree days (days when buildings needed to be heated or cooled), time, rain and average wind speed (mph) with data reported to one decimal place. Students were asked to describe what the weather was like for a week, using the raw data from one week. In small groups, students were allowed to choose any variable they wished to consider (i.e. High Temperatures, Heat Degree Days, or Average Wind Speed) and then they discussed what they noticed, wondered about, and questions they had about the data with their group to decide the "story" this data was telling. Next, they were asked to develop a statement about what their variable was "generally like for the week" and then to find a way to support the accuracy of their statement; this led to the first elaborated method of integration.

Simultaneous Infusion

Simultaneous Infusion is when the learning goals and outcomes of both content areas are well aligned and sometimes identical. This is often the case when supporting students' STEM habits of mind and is why this kind of integration was used initially to help set the context for learning. For the first lesson, the intent was for students to see the connections between the behaviours scientists and mathematicians engage in as they investigate and attempt to make sense of real-world phenomena. Thus, the local National Oceanic and Atmospheric Administration report for snowfall and the discussion on the ways in which scientists and mathematicians think and behave in a similar fashion.

Again, getting students to recognize how scientists and mathematicians use data and statistical thinking (Lane-Getaz, 2006) in similar ways is important in helping them make connections to the importance of mathematics within science.

One student indicated “All those numbers come from somewhere and they have to know what they mean before they can give a report,” highlighting the importance of keeping the context in mind when analysing and interpreting data. Another student commented, “Mathematicians make graphs and other ways to share what they know. It looks like scientists do this, too,” which further highlights similarities in how mathematicians and scientists communicate their understandings. This prompted a discussion about the relationship between science and mathematical practices.

During the whole class discussion that followed, students often described the data in more general and relative terms. Such as for High Temperature, students said that the week was warm. This created a great opportunity to discuss objectivity with the statements as the word warm alone actually cannot be used to describe the data as it is both relative and imprecise. After further discussion about how to make precise and objective statements, one student eventually recognized that they should “first try to be exact with the numbers and then figure out what those numbers mean.” This statement was agreed upon by the class and allowed the teacher to focus their attention on how mathematics can strengthen STEM learning and how both scientists and mathematicians need precision in their work. This led to the second elaboration of STEM integration.

Temporary Shift in Discipline

The Temporary Shift in Discipline pauses the learning from one discipline (e.g. science) to focus on learning a specific skill or concept in another discipline (e.g. mathematics), which will be necessary for further exploring the concepts in the initial discipline. This shift in focus allows for “just in time” learning to occur rather than teaching larger and discrete lessons on content that may seem unrelated or irrelevant to students if taught in isolation.

This part of the lesson shifted to a reasoning talk (Bennett, 2018), a process by which students reason about mathematical relationships and structures, in order to focus on key mathematical concepts that were important in exploring the science concepts. Namely, how compensation strategies can aid them in multiplying and dividing decimals. That is, by shifting to a mathematical concept, in this case the relationship between whole number operations and operations on decimals, students were able to quickly shift back to exploring the science using the mathematics in purposeful and relevant ways.

Because the intent was to help students recognize strategies for making sense of the data within a science exploration, we did not move into a formal mathematics lesson about operating on decimals but highlighted how understandings of place value used to transform the decimals into whole numbers in order to work with the data in an easier manner. Temporary Shifts in Discipline is about accessing or learning concepts from another discipline, in this case mathematics, at the right moment to make the learning in the intended discipline more meaningful, in this case the science. At this point, the final elaboration for STEM integration was used to help the students examine the weather data.

Lateral Concept Connections

Lateral Concept Connections is a purposeful movement between two seemingly unrelated core ideas of the same discipline (e.g. the earth science study of weather and the biological science study of birds). While this may seem like a *Temporary Shifts in Discipline*, it does not shift disciplines in a major way and the secondary discipline is also not a major focus. Rather, *Lateral Concept Connections* help students understand a concept within a discipline because of tangential relationships, skills, or concepts within the larger discipline that require a secondary discipline. In the weather study, numbers were presented as a mean, and students had not yet worked on measures of central tendency, there were gaps in their understanding of how to interpret the data.

For example, to help students consider how to describe the general nature of the weather for the week with their chosen variable, students were asked to consider an alternate data set on a given number of birds observed in the morning over a four-day period. This prompt was:

“Mr. Lopez counted the number of birds he saw on his bird feeder each morning. During the 4 days he counted 8 birds the first morning, 7 birds the second morning, 9 birds the third morning and 8 birds on the last morning. About how many birds came each day? Create a model to show your thinking.”

Students discussed what “about how many” meant and described it in two distinct ways. Some students used a sharing approach and talked about how “evening out” of all the birds for all of the days would tell the average while others pointed out that “we are kind of looking for the tipping point. The place where the number of birds on one side is the same as the other.” For the first way of thinking about the mean (sharing), students wanted to find how to “share the birds” for the whole week. Through a purposefully orchestrated discussion, students agreed that “putting all of the birds together is like adding them all up,” which then lead another student to say that “sharing them all is kind of like dividing.” All of which ultimately allowed the students to understand the process needed to describe their weather data. Students agreed that, in order to “share the weather data correctly,” they needed to add up the values for their variable and then divide it by seven, as there were seven days in the week, in order to “share the data” evenly.

At this point, students moved back into the science portion of the lesson to further analyse, interpret, and report on their weather variable for the week. Note that in this case, the lesson content deviated significantly from the primary science activities in order to support a deeper understanding of the concept of mean and measures of central tendency. Again, these concepts were fundamental to their success in describing the weather for the week.

Discussion of Results & Implications

This project found that by deliberately integrating mathematics and science content through the use of Simultaneous Infusion, Temporary Shift in Discipline, and Lateral Concept Connections students were better able to develop deep conceptual knowledge in both disciplines. Attention to these elaborations, and how they appropriately scaffold learning, explicitly attend to understandings in both content areas at strategic times, and create opportunities to apply these understanding to authentic real-world problems are the heart of natural and purposeful STEM integration.

However, the initial planning was substantial and the primary teacher often relied on the other research team members to understand the nuances in the integration. This suggests that the initial planning process was not necessarily easy for the teacher, which leads to other complications with respect to implementation. Namely, if the planning is too challenging for teachers, then the elaborations may not actually help with mathematics integration in STEM learning as intended. On the other hand, and is the case with many new pedagogical approaches when initially adopted, it may be that more experience and time thinking within this framework is needed. This indicates the elaborated integration process needs to be further studied to understand the specific challenges teachers may face when implementing this elaborated integrated approach and the extent to which these challenges are a result of the conceptualization, design, or newness of the framework when implementing in classrooms.

With respect to the student learning, the data indicates that students were able to move fluidly between the different transitions to make the deliberate connections intended during the planning phase. This was even the case for shifts between disciplines (i.e. Temporary Shift in Discipline). Such results are encouraging as it suggests, from a learning perspective, the elaborated integrations support STEM learning outcomes and do so in an organic, natural manner. What is not clear at this point is the extent to which this occurs. That is, given the limitations of this case study, it is unclear if these elaborated integration experiences would be evident in other areas of mathematics and science. This is especially true given the easily accessible nature of statistics and working with data in science. It may be that other mathematical content does not lend itself to the elaborated integrations in a meaningful way.

In a time dominated by talk of STEM, and where students' ability to do STEM is critical for their success in a tech-driven globally competitive society (National Research Council, 2012), a deliberately integrated approach can provide opportunities for "more relevant, less fragmented and more stimulating experiences for learners" (Furner & Kumar, 2007, p. 186). It is time for STEM to be more than just any isolated discipline or an arbitrary accumulation or tangentially related experiences. It is time for STEM to be a transformational process to explore learning in a manner that may not otherwise be realized; a dynamic process that intentionally builds connections for students across and within disciplines through a more organic process.

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