Beyond the Acronym: Preparing Preservice Teachers for Integrated STEM Education

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Abstract

Integrated STEM education seeks to build deep connections between science, technology, engineering, and math. Contextualized lessons give students greater access to these content areas and can heighten engagement. Great parallels can be drawn between liberal arts philosophies and integrated STEM education. This paper explores how one teacher team developed curriculum and enacted lessons using an integrated STEM approach. This study found that teachers viewed integrated STEM instruction as rewarding. The teachers also mentioned the need for constant communication to fully implement the model. Students perceived this model positively and enjoyed participation. Outcomes of this study have the potential to inform teacher preparation programs by making more transparent how implementation of integrated STEM models can be achieved.

Keywords: **integrated STEM, co-teaching, planning**

In traditional school settings, content knowledge takes precedence over contextualized, conceptual understanding (Davidson, Miller, & Metheny, 1995). The broader application of subject area content is often ignored as pressure mounts to cover extensive topics. Socially constructed subject boundaries create the impression that knowledge building is conducted in isolation. In reality, expertise from many subject areas is often required to solve complex societal issues. Scientists readily move between disciplines such as molecular biology, biogeochemistry, and chemical physics in both academia and industry (Wolfson, Hall, & Allen, 1998). Multi-faceted perspectives allow for a more nuanced understanding of phenomena. With societal issues such as climate change and energy consumption looming over future decades, it is vital that we expose students early on in their academic careers to these real-world problems. Students are better equipped to confront and solve complex personal, social, and global dilemmas when they can draw from differing disciplinary outlooks during formal classroom instruction (Beane, 1991; Bybee, 2010).

Integrated STEM models have the ability to build student capacity to transfer concepts and apply new knowledge to novel contexts. Creating learning opportunities that build connections between interrelated subject areas can support deep conceptual understanding resulting in increased student achievement. By clearly demonstrating integrated STEM practices of science at the K–12 level, students are provided with a more viable representation of actual science-related work. Making the transition from novice to expert scientist requires opportunities to connect knowledge from an area of study and apply it to new situations. Students who are provided with integrated STEM models of instruction are afforded entry points to transfer knowledge (Bransford, Brown & Cocking, 2000). Students are equipped to tackle complex problems early on in their science education, thus eliminating the mystique associated with advanced STEM coursework. By instilling greater feelings of self-efficacy early in a child’s academic career, students are more apt to envision a future as science practitioners and gain confidence in their skills and knowledge.

National standard reforms such as the Common Core State Standards (CCSS) and the Next Generation State Science Standards (NGSS) offer clear support for the adoption of integrated instructional methods. The CCSS developed series of standards specifically for literacy in science, social studies, and technical subjects (National Governors Association, 2010). The NGSS identifies practices of both science and engineering as well as seven thematic areas or cross-cutting concepts that act as compelling themes woven throughout subject area or grade level (NRC, 2012). Integrated STEM models are now in a period of rapid evolution to meet the latest demands outlined by educational standards and workforce needs. This integrated renaissance has created opportunities to re-evaluate habitual practices and redefine teaching and learning parameters. With the recent expansion of integrated STEM models has come new waves of acronyms such as: STEAM, STREAM, and so forth.

What is Integrated STEM?

The National Research Council (NRC, 2014) broadly defines integrated STEM as a way to build connections between and within subject areas related to science, technology, engineering, and mathematics. For the purposes of this paper, I define integrated STEM models as team teaching efforts that center on interconnecting content in order to build engagement and relevance through overlapping learning explorations that feature hands-on components.

I contend that the interdisciplinary culture of liberal arts institutions positions them to prepare teacher candidates to engage in meaningful integrated collaboration with colleagues from different disciplines. There is a general lack of consistent terminology used to describe integrated STEM education. Terms such as “multidisciplinary,” “thematic,” or “transdisciplinary” are often applied haphazardly and without clarifying parameters. Since integrated instruction spans grade levels and contexts, quantifying it becomes even more problematic. Mansilla (2005) defines “integrated understanding” as:

> The capacity to integrate knowledge and modes of thinking drawn from two or more disciplines to produce a cognitive advancement, for example, explaining phenomenon, solving a problem, creating a product, or raising a new question in ways that would have been unlikely through single disciplinary means (p. 16).

Beane (1995) elucidates the humanistic nature of integrated instruction in the following sentiment: “the central focus of integrated curriculum is the search for self and social meaning” (p. 616). Interpretation of integrated STEM education is often left to the district and its teachers.

Benefits of Integrated STEM

With societal issues such as climate change and non-renewable energy consumption looming over future decades, it is vital that we expose students early on in their academic careers to real-world problems. Multi-faceted perspectives allow for a more nuanced understanding of phenomena. Students are better equipped to confront and solve complex personal, social, and global dilemmas when they can draw from differing disciplinary outlooks during formal classroom instruction (Beane, 1991; Bybee, 2010).

When properly supported, integrated STEM instruction has the potential to improve the teaching of science concepts. Levy (2013) investigated student understanding of water flow rates based on height of pipe, diameter of the pipe, and resistance. Fifteen children of kindergarten age were selected to participate in this study through hands-on construction of a water system. The researcher sought to determine whether the design task improved understanding of the topic, ability to find interrelatedness between the three variables, and capability to transfer knowledge to real-world scenarios. Students assigned to the treatment group had significant gains in understanding general rules associated with water flow rates. Furthermore, “different from the control group, the builders all showed a budding ability to coordinate two rules in predicting and explaining water system behaviors in the post-test” (p. 556).

Integrated STEM teaching has the potential to inform the self, support individual growth, and provide one small way to dismantle structural oppressions that play out in our schools. Integrated STEM education expands the notions of curricula beyond the borders of the traditional subject silo. Integrated STEM offers a broadened view of science teaching and learning that values a wider array of "lifeworld," or the experiences that make up a person's being experiences (Cooney, 2012). Rather than presenting a narrow bundle of content, students are exposed to content that is embedded as part of a problem that requires a solution. As a result, the role of teacher shifts from ultimate knower to facilitator. As part of integrated STEM instruction, teachers "model problem solving and encourage reflection, communication skills, autonomy, and self-monitoring. They teach students to see problems as opportunities and model the notion that interaction among colleagues is important for creative problem solving" (Madden, Baxter, Beauchamp, Bouchard, Habermas, Huff, Ladd, Pearon, & Plague, 2013, p. 542).

Subject area teaching "requires knowledge of teaching strategies, methodological issues, the curriculum and how to bring the topic alive for students" (Hobbs, 2012, p. 282). Within integrated STEM models, teachers collaborate to build a collective sense of competence and confidence. Like students, each teacher possesses a unique lifeworld that shapes the content and pedagogical approaches that he or she implements. They can enhance their practice by sharing classroom experiences as well as personal histories that also inform them as individuals. Through these professional interactions, students are also exposed to authentic collaborative interactions. A community of learning can emerge as a result, which offers opportunities to connect content more broadly. Since scientific discoveries often involve the interaction and collaboration of many investigators, actual scientific work is further illuminated through integrated STEM educational models (Grinnell, 2011). Thus, integrated STEM education serves as one way to present a more unified view of science and life-worlds.

Study Context

The integrated STEM team central to this study gained a reputation for exemplary STEM education. Hundreds of educators visited the district to learn more about how this particular model of STEM integration functioned. This integrated STEM team frequently partnered with a variety of organizations, including the National Aeronautics and Space Administration (NASA), and invited community members to be part of the learning experience. Engineers, architects, and scientists interacted with the students and often evaluated final projects. This integrated STEM model existed for a period of over five years. The teaching team created the model using mainly locally sourced resources and with minimal oversight from the district. This district is a suburban public school located in the Northeast United States with an overall enrollment of more than 3,000 students.

This study focused on a single eighth grade team that consisted of one science, one math, one social studies, one special education, and two ELA teachers, as well as one teaching assistant. All of the teachers' significant years of teaching experience ranged from 7–22 years. During the year this study was conducted, the district assigned 101 students to this integrated STEM team, referred to as the "orange team."

Methodological Approach

I selected phenomenology as a theoretical frame and methodology because of its focus on the experience of participation in one such model. Creswell and Clarke (2007) explained that an inquiry is appropriate for phenomenological study if "it is important to understand several individuals' common or shared experiences of a phenomenon. It would be important to understand these common experiences in order to develop practices or policies, or to develop a deeper understanding about the features of the phenomenon" (p. 60).

I observed and recorded a number of lessons and also conducted semi-structured interviews with teachers and students after the implementation of these lessons. I completed fieldwork in the spring of 2016. I recorded over of 1,300 minutes of instruction as well observations of planning and lunchtime, and one professional development session that featured the participants. To generate themes, I segmented my data into moment units that showcased a particular experience. I also gathered a sense of the model from observing and interviewing participants and debriefing after lessons. This data was coalesced to gather a sense of both the individual experience and overall function of the model. My understanding of this integrated STEM model guided my interactions with participants and framed the way in which I read my data. The information obtained from interviews and observations then, in turn, contributed to my overall understanding of the model.

Results

The Orange Team Integrated STEM Model

This particular model of integrated STEM combined a myriad of pedagogical approaches. Hands-on projects that included all team teachers were a regular occurrence. In Figure 1 below, students constructed an insulating box using a limited number of materials. Students then tested their boxes by adding ice and leaving them in direct sun for several hours. To assess their effectiveness students calculated the percentage of ice melt. Students were expected to work in small groups to accomplish nearly all of their academic tasks. The teachers gathered all the students together on a weekly basis to build a sense of community and modeled positive interactions. Each student was provided with a laptop computer for use during class time.

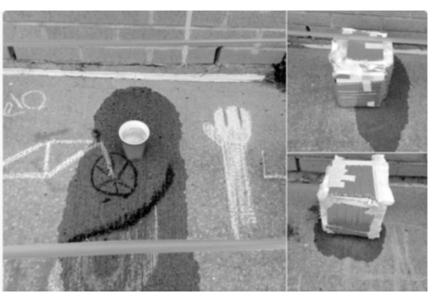

Figure 1: Insulated boxes during test phase of the Keep It Cool project

Overall, students felt that the integrated STEM model presented content with sufficient levels of cognitive challenge. One student believed that the content covered seemed easier because of the amount of teacher supports in place. Another student also identified caring attitudes of teachers as contributing to his success. The students considered topics like nanotechnology to be of high interest. Students frequently referred to this model as "hands-on" and enjoyed participation in projects that created some form of final product, such as an insulated icebox or rubber band powered car. As one student stated in an interview: "We'll be learning about something that will connect to life, you know, outside of school."

Teacher Collaboration

Co-teaching practices. To better understand how the team created co-teaching experiences, I recorded and analyzed over 1,300 minutes of footage. I found that whole group instruction with all students and teachers present comprised 30% of the lessons. Single subject area instruction took place in a total of 35% of the lessons recorded as part of this study. Notably, there were only 14 minutes of observed instruction completed with only the science instruction. The remaining time was divided among an array of teacher groupings.

Table 1: Co-teaching Combinations and Time Dedicated for Instruction

Co-teaching Combinations	Number of Times the Combination Appeared	Number of Intructional Minutes
Science, TA	91	483
Science, TA, Math	10	83
ELA, Special Education	6	20
Social Studies, TA	8	28
Social Studies, TA, Science	13	63
Science	4	14
Science, ELA	31	144
Science, ELA, Math	20	45
Science, Math	1	83
Science, Math, Social Studies, TA, ELA, Special Education	69	420

Based on observations, this integrated STEM approach balanced content area instruction with integration of other disciplines. The team incorporated significant opportunities to engage with one another. Whole group instruction was a normal practice carried out on a consistent basis. After years of collaboration, science teacher, Jeremy, mentioned how he struggled to separate content because it has been “intermingled for so long” (Interview, 4/5/16). The team relied on each other’s content-area knowledge and understanding of pedagogical practice.

Constant planning. Teaching assistant, Deb, recalled “Our plans, our team works, twenty-four seven” (Interview, 6/15/16). The team communicated not only in person but also through email and text messages outside of school. The teacher team dedicated one block of planning time each morning to the development of this model. They also used a common lunchtime to negotiate instructional decisions. The participants identified lunchtime discussion as the most fruitful time for developing future vision. Only twenty minutes in length, the team used the morning plan period to finalize plans for that day. Sam, the special education teacher, explained, “It’s very much on-going. Like, this morning, for example, we thought we had a plan. And then it sort of got morphed but everybody was there. So, you know, it’s just the constant communication” (Interview, 4/8/16).

The interactions that took place during lunch helped to illuminate how decisions were made that directly impacted instruction. The degree to which each teacher contributed to the conversation varied. Deb, the team teaching assistant, usually worked on a task that was organizational in nature. For instance, she counted money, or called about grade-level shirts; those kinds of tasks kept her attention most days. She also used her phone quite a bit and it rang several times during the lunch period. Sam deferred to the other team members before offering his contribution. He credited Calvin, the social studies teacher, with building in accountability aspects of the planning process: “Calvin Mitchell has been, sort of, our guiding light, he’s been like, everyday twelve after til eight thirty-five, we are talking about team stuff, and we do” (Interview, 4/8/16). Sam may have felt less a part of the collective considering his position on the team had only been full-time for two years. Jeremy and Terri, an ELA teacher, tended to make the most logistical decisions like the allocation of time for activities or scheduling events. Calvin's commentary during planning time centered on approaches to reimagine traditional formats. Noel, the other ELA teacher, seemed agreeable to most decisions. Annie, the math teacher, did not have a common lunch period and therefore was unable to contribute during this time.

Each planning session generated a distinctively different feel. Not every moment of team planning was productive and positive. Outside constraints such as state testing requirements, grading, and other administrative tasks took away time typically spent to organize future lessons. There were many occasions where outside factors limited, interrupted, or refocused conversations.

When faced with the challenges associated with integrated curriculum development, many teachers revert to pre-existing structures due to familiarity and ease. The science teacher, Jeremy, expressed this tendency in the following passage:

> Here's what I find, personally, when push comes to shove and I start to get nervous about something. I refer back to something I have done in the past. That's something that I think we've all done. We start getting uncomfortable, we retreat back to, "Well I've been doing this for twenty years, so" (Interview, 5/6/16).

The teachers found this integrated STEM model reinvigorating. They expanded their repertoire of skills and practice.

> Annie (math teacher): I was pretty stuck in my ways (smiles)…I think it's a struggle for all of us to go to somebody else's room and to see what they're doing and see that somebody might be changing a little what you're doing and the way that you do it…it's a good struggle 'cuz it's creating growth in all of us (Interview, 5/19/16).

Many of the participants expressed that it took some time to feel comfortable with the integrated STEM experience. Despite differences in ideologies associated with practice, the team leveraged individual strengths. The group remained committed to refining curriculum and adjusted lessons every year in order to best meet the needs of their current student group.

Discussion

Lencioni (2006) described five team dysfunctions that can staunch collaborative efforts. The team dysfunction that can be most detrimental is the lack of trusting relationships. Lack of trust can undermine group efforts by creating an environment where individuals are risk adverse. Individuals in the group are fearful to display behaviors that may be perceived as weaknesses. With vulnerabilities stifled the team cannot productively move forward. There is an overall inability to anticipate potential pitfalls and generate appropriate responses. The second team dysfunction that can create barriers to productive team outcomes is the inability to participate in healthy conflict. While often viewed with a negative connotation, conflict can actually assist teams find multi-faceted solutions. The absence of a strong commitment to the team is another team dysfunction that can also result in limited productivity. Lack of accountability and inattention to outcomes are also considered team dysfunctions. The orange team was able to circumvent these dysfunctions through the development of trusting bonds over several years of interaction and an intense commitment to integrated STEM education. Teachers emphasized the need to communicate with each other throughout the school day as well as during time at home. Choreographing integrated STEM lessons with all team members required multiple forms of communication ranging from in-person conversations to text messaging interactions.

Woolley, Chabris, Pentland, Hasmi, and Malone's (2010) large scale, quantitative study of team effectiveness resonates with the outcomes of this study. The researchers developed a statistical model to understand how individual contributions impact the overall team outcome. Woolley et al. found that if groups were successful at a single task then the group tended to perform well on all other future tasks. Woolley et al. argued that a "collective intelligence" emerged that could not be quantified as simply the sum of all individual intelligences. Highest levels of "collective intelligence" were found in teams where all members had equal opportunity to speak. Teams where one or two voices dominated conversations resulted in declines in collective intelligence. Social sensitivity, or the ability to empathize with others based on their gestures and tone of voice, was also considered an important element of "collective intelligence". Those teams with elevated social sensitivity performed at a statistically significant higher level on collaborative tasks.

The act of teaching is an intensely social endeavor that requires a balance of both content area knowledge and human interaction. Teachers must interpret the signals from both peers and students in order to successfully engage in the learning process. The findings from this study confirm the results from Woolley et al.'s work on collective intelligence factors. The orange team group planned together on a daily basis and created a space for all teachers to communicate their content area needs. During integrated STEM units, co-teaching patterns suggest an equal balance between delivery of content by the individual and delivery of content in a contextualized manner that involved all parties. Each teacher was critical in both the development and enactment of integrated STEM units. The orange team purposefully balanced single content and integrated content co-teaching episodes as part of this model. In this way students were able to engage with concepts in different ways. Generally, students were introduced to a concept by a single content area teacher and then applied their understanding during integrated learning tasks.

Integrated curriculum is most effective when applied to concepts with natural intersections (Fensham, 2009). Pedagogies associated with different disciplines can vary significantly. Integrated STEM teaching requires an openness to further one's understanding of unfamiliar disciplines in order to implement curriculum with accuracy. The implementation of integrated STEM models requires the acknowledgement that disciplines exist within a greater social context. Cultural, ethical, economic, and environmental considerations should be woven in as part of STEM related curricula, thus affording greater accessibility to students with diverse backgrounds.

Lessons for Teacher Preparation

Co-teaching must be considered when transitioning from traditional schooling to an integrated STEM model of instruction. The co-teaching approach carried out by this team has important implications on teacher training programs. The orange team members viewed each other as assets that allowed them to professionally grow. Co-teaching opportunities that pair novice and expert teachers may have great benefits for both parties. Expert teachers may feel enriched by new ideas and outsider perspectives on teaching practice. Novice teachers can boost their capacity to work with other disciplines while also enhancing their abilities to develop content-area specific pedagogies.

Roth (1998) conducted a three-month intensive study of science teachers participating in a co-teaching model of instruction as part of a school-wide improvement plan. The goal of the co-teaching experience was to pair novice teachers with experts in order to bolster skills such as questioning and providing feedback. Roth (1998) found that three types of teacher learning emerged as a result: (1) in practice learning, (2) ability to engage in conversations about practice, and (3) ability to synthesize theory and practice. “Once explicit, these aspects contributed to a change in their professional discourse in which they made sense of classroom events” (p. 387). Co-teaching reshapes traditional supervisory models by providing space for co-construction of narratives based on classroom experiences. Expert teachers can support novice teachers in ways that allow for organic growth. Opportunities for reflection on experiences are a necessary element for any teacher development program. Traditional structures and organizations often stifle this form of communication. Integrated STEM educational contexts rely on open exchange of ideas and pedagogies.

In many ways the goals of integrated STEM education closely parallel the vision and mission of liberal arts institutions. Integrated STEM education seeks to build student interest and capacity through the exposure of real-world scenarios that can prepare them as both learners and citizens. Liberal arts teacher preparation programs offer an ideal context for preservice teachers to collaborate with multi-disciplinary partners. “Disciplinary transcendence does not necessarily mean cutting oneself off from the ground where one stands, but rather widening one’s horizons (Giri, 2002; Wall & Shankar, 2008, p. 552). This integrated STEM model interpreted the purpose of instruction more broadly. Social engagement was incorporated by design. Students were expected to communicate their understandings and justify their positions on social issues.

Challenges of Implementation

The subject silo model has long dominated the way in which teaching and learning occurs within school systems. Teacher certification systems are currently organized in a fashion that also values single subject area expertise. Teachers without extensive background in research, real-world contexts, or other disciplines may feel insecure or hesitant to implement models that stretch their own ability and comfort level (Fensham, 2009). Participation in extensive, embedded practical experience during teacher preparation can counteract reliance on traditional patterns of instruction. Furthermore, preservice teachers require opportunities to engage in multi-disciplinary group exchanges that promote social understanding and build collective trust.

Conclusion

Researchers or practitioners cannot easily label integrated STEM education due to the complexity of factors related to its implementation. The orange team central to this investigation synthesized a variety of instructional approaches based on collective professional knowledge of teaching and learning. Teachers pushed back on the idea of a “one size fits all” model of instruction.

The team created a curricular Frankenstein from project-based and collaborative learning approaches, engineering design challenges, responsive and flipped classroom techniques. Co-teaching was part of daily instruction but remained flexible based on the learning activity at hand. In order to manage all these working pieces teachers were constantly engaging in professional conversations. The ability of teachers to function productively as a group was central to their sustained classroom success.

In order for the integrated STEM movement to transition from novelty intervention to academic mainstay, further overlap is needed between preservice teachers and practicing professionals. Building capacity to integrate is a long-term endeavor that requires embedded professional development supports. The implementation of integrated STEM models requires serious commitment on the part of the teacher preparation provider to support novice teachers in the labor associated with contextualized lesson planning and instruction. There is also a need for physical materials as well as expanded community and departmental partnerships. Through early career exposure to integrated STEM approaches, collaborative practices may be perceived as less intimidating and more normative. Teacher preparation programs must reimagine siloed curricula to meet the needs of learners in compelling ways.

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