Chapter 8
Moving Toward Transdisciplinary Instruction: A Longitudinal Examination of STEAM Teaching Practices

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Introduction

The emergence of STEAM (science, technology, engineering, arts, and mathematics) education, a transdisciplinary approach that focuses on problem-solving (Delaney, 2014), is occurring worldwide. However, there is little available literature regarding the efficacy of STEAM practices. As a result, educators are attempting to implement new teacher practices without a solid conception of how to design or implement effective STEAM teaching (Henriksen, 2014; Herro & Quigley, 2016a, 2016b). This relegates teachers to use existing STEM models approaching the arts or humanities as an "add-on" experience (Kim & Park, 2012; Quigley & Herro, 2016). As a result, the programs are not significantly different from current STEM education practices (Guyotte, Sochacka, Costantino, Walther, & Kellam, 2015).

In this chapter, we argue the difference between STEM and STEAM is the transdisciplinarity approach through the use of social practice theory. However, without specific examples of what this looks like in vivo, educators continue to struggle to enact meaningful STEAM practices. To address this issue, the authors developed a conceptual model of STEAM educational practices and an observation rubric intended to assess teachers' implementation of these practices during the course of a 3-year study (Quigley et al. 2017). Using this model and the longitudinal data, we focused on particular practices that contributed to students' problem-solving relevant issues but also on a practice that teachers struggled the most to conceptualize and implement, the practice of transdisciplinary teaching. This chapter attempts to define transdisciplinarity in the context of STEAM and describe the implementation successes and challenges in a variety of educational contexts.

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Theoretical Framework

Yackman (2007) is often named as the early pioneer for developing the first framework for STEAM learning. She advocated for understanding science by understanding technology. Further, she argued that arts are crucial toward interpreting science and technology. She proposed an integrative framework wherein all disciplines are integrated but in a manner that privileges science and technology over engineering and art and then suggests connecting the disciplines through mathematics. The authors are cautious in fully adopting this work in practice because of the heavy reliance on art to *inform* the disciplines instead of as an *integral component of* problem-solving. With this view, art becomes an afterthought. Another criticism is the ever-present focus on math and science (Nanni-Messegee & Murphy 2013). Also absent in Yackman's STEAM framework is a theoretical framework to understand its conceptual grounding. Without this important framing, it is impossible to situate the work in the broader contexts of educational research and theory. As such, over the course of 3 years, we have followed STEAM education research and attempted to construct a theory-based STEAM conceptual framework, which we tested and modified based on teachers' STEAM implementation practices. One particular theory has bound the instructional practices together. This theory is called social practice theory (Roth & McGinn, 1998).

Social Practice Theory

Both STEM fields and the art fields have conceived their work as social practice. For example, Dewey's (1934) *Art as Experience* called for art to be not only a component of life but also for improving life. Similarly, STEM fields have argued that the goal of advancements through these fields should be to improve life for all. However, the way in which these social practices play out in K-12 settings is less clear. Roth and McGinn (1998) describe social practice in education settings as shared, developed, and negotiated within specific communities of knowing (Bowen, Roth, & McGinn, 1999). However, the art world expands this view point and considers, "engaging with or collaborating with a public, working across a variety of disciplines, and instigating works that have relevance to both an art and a variety of non-art audience" Guyotte et al., (2014). In this way, the key components of social practice theory are collaboration outside of school setting, discipline integration, and relevance across fields. Science and art education are not the only fields that are incorporating the theory of social practices into educational practices. Both technology and engineering education have been undergoing a reform movement that examines how the profession can contribute to creating a more just society (Bailee & Catalano, 2009). Educators are examining how engineering might look if conducted as a social practice. Hence, the goals of engineering could include ecological and social justice. By altering the conceptions of engineering and by incorporating the context for the problems that are solved, social practice theory in engineering would include examining problem-solving from socially situated context. In this fashion, we connect social practice theory as a way to understand the purpose of STEAM education. From our perspective, the outcomes of problem-solving must be socially situated, and it is critical that students are able to have opportunities to examine these problems in situ and understand their importance across fields.

Understanding the Current Field of STEAM Education

To understand the worth of implementing a transdisciplinary approach in the context of STEAM, it is helpful to differentiate transdisciplinarity from multidisciplinary and interdisciplinary, as these ideas are often conflated which creates a misunderstanding when educators attempt to implement these practices (Kaufman, Moss, & Osborn 2003). Mallon and Burnton (2005) argue multidisciplinary teaching and learning K-12 happen when experts across disciplines work "independently on different aspects of a project (p. 2)." Additionally, others understand multidisciplinarity as occurring when experts work parallel to one another while still remaining within their own disciplines (Slatin, Galizzi, Melillo, Mawn, & Phase in Healthcare Team, 2004). Interdisciplinary-structured teaching and learning builds upon multidisciplinarity, by claiming it intends to "unify two or more disciplines or to create a new 'interdisciplinary' (hybrid) discipline at the interface of the mother disciplines" (Schummer, 2004, p. 11). Finally, Nicolescu, one of the key promoters of transdisciplinary education, claims transdisciplinarity is said to occur when "knowledge corresponds to an in vivo knowledge…and includes a system of values, the humanistic values" (Nicolescu and Ertas 2013, p. 18). Many scholars agree transdisciplinary education is a holistic approach to education (Collin, 2009; Lattuca, 2003; Slatin et al., 2004); however, Arthur, Hall, and Lawrence (1989) claim it is grounded in *one* discipline while acknowledging the different viewpoints, assumptions, and findings of others. We agree with Arthur and colleagues that it often produces new perspectives but disagree that the grounding is only in one discipline. From our conceptualization, transdisciplinary teaching involves multiple disciplines where there are naturally occurring overlapped spaces between the disciplines to produce new perspectives (Gibbs, 2015). This type of problem-solving helps learners see the connections between their content and others (Pohl, 2005). When addressing teaching, Wang et al. (2011) contend that transdisciplinarity requires teachers to be able to integrate context while combining a multidisciplinary approach to blending disciplines.

What makes transdisciplinarity important for problem-solving is that it focuses on the content of one discipline and uses contexts from a different discipline to make the content more relevant. For example, a teacher might create a unit around the appropriate enclosure sizes for zoo animals. The math content would be ratios and calculating area and/or volume; however, understanding animal behavior makes the topic more relevant and would provide a better platform for solving the problem.

We view transdisciplinary inquiry as incorporating both context and content integration. As teachers design STEAM practices, the goal is to teach transdisciplinarity; however, we realize this goal may not always be attainable. That said, using any level of discipline integration provides an opportunity for multiple contents and methods to solve problems.

Today's youth will be confronted with challenges and questions that require global-view thinking to solve. The types of questions they will solve are deep-seeded, transdisciplinary issues which force comprehensive approaches to solving (Galliot, Greens, Seddon, Wilson, & Woodham, 2011). This requires a high level of creativity and is one of the reasons that creativity is one of the critical skills of the twenty-first century (Liao, 2016; Trilling & Fadel, 2009). This focus on creativity has led the push for STEAM education, and advocates of STEAM education believe that STEAM offers educators the chance to challenge their students to be creative and effective problem-solvers in today's competitive culture. Most researchers agree a truly transdisciplinary space for STEAM education should allow for each discipline within STEAM to occur in concert with one another, making it nearly impossible for students to categorize their learning into discrete disciplines (Liao, 2016). This type of authentic integration of disciplines is what the authors look for in well-designed STEAM scenarios; transdisciplinarity of STEAM education is said to have the "potentiality to address contemporary social issues, perhaps even on a global scale" (Ahn, 2015; Guyotte et al., 2014; Liao, 2016).

The novelty of introducing art into the STEM curricula has been well-received by numerous researchers and predicted to "move the needle" in transdisciplinary education (Bequette & Bequette, 2012; Liao, 2016; Maeda, 2013; Watson, 2015). Creative problem-solving approaches through artmaking and problem- or project-based learning open a new avenue for students to draw connections among their knowledge, skills, and abilities and how to use these connections in advancing their own education (Liao, 2016). By allowing students to explore and develop their own knowledge in this manner, educators hope this will provide ample opportunity for organic and self-directed innovation in teaching and learning, contrary to the typical thought of economic innovation (Land, 2013), which normally involves producing a product and ultimately a profit.

This chapter aims to look at ways educators can rethink problem-solving approaches in the classroom. Based on the authors' research and experiences, the type of problem-solving skills that best fosters real-world problems is transdisciplinary or authentic problems, which require multidiscipline thinking to solve. In fact, most scholars agree that best preparing our students for future careers must involve thinking across discipline boundaries (Berry et al., 2004; Stepien & Gallagher, 1993). Further, this type of teaching and learning can foster understanding of STEAM concepts in their real-world applications; as we know, real-world problems are typically interdisciplinary by their very nature (Asghar, Ellington, Rice, Johnson, & Prime, 2012). One approach to effective STEAM education is relevant problem-based curricula. In a problem-based learning environment, salient STEAM concepts are naturally nested in concepts of real-world problems. Generally, the problem-based approach to teaching STEAM tries to mirror the practices used by real experts to solve real-life problems within their respective fields (Crawford, 2000; Colliver, 2000). This also underscores the importance of inviting community experts into the classroom as it offers students insight into their personal experience and challenges they may face on the job.

Not only do these experts offer their first-hand experience and knowledge surrounding the context, they also offer students a tangible example for how their learning will reach beyond the walls of their classroom (Vernon, 1995). Problem-based learning (PBL) offers students connections and relevance for their learning and has proven to increase student motivation for learning (Galand, Bourgeois, & Frenay, 2005; Norman & Schmidt, 1992; Vernon & Blake, 1993; Wood, 2003) and develops a sense of importance for "responsible, professional attitudes with teamwork values" (Barrows, 1996). Some recognize the need and importance for incorporating experts into the classroom but face obstacles of local experts having difficulty finding the time to physically visit the classroom. Recently, educators have been utilizing technology to overcome and create ways their local experts can connect virtually with their students using video chat and other technology (Poulson, 2014).

STEAM education also has its critics. One of the major areas of criticism is with the amount of collaboration that this pedagogy requires. Due to STEAM education being so new, teaching resources, professional development opportunities, and even trainings are difficult for faculty to come by. Some claim there is interest in the idea of STEAM, but when it comes down to implementation, educators are easily deterred due to the vague conceptualization (Bequette & Bequette, 2012). Some also question the possibility of being able to truly pay tribute to all subjects equally without "watering down" the main purpose of STEM education (Jolly, 2014). Finally, there is also the fear that educators will incorporate "art" into a STEM curriculum, just for the sake of incorporating art into the lesson (Gettings, 2016). We understand these critiques and agree that without intentionality, the addition of the arts seems more like an afterthought inside of an integral part of the problem-solving process (Quigley, Harrington, & Herro, 2017).

The authors purport that it is the transdisciplinary approaches in the context of STEAM education that offer students the holistic and problem-based learning opportunities they need to be successful in their respective future careers. In this way, these educational practices are thought to provide an authentic method of subject integration versus simply adding in all subjects together into one lesson for the sake of doing so.

Conceptualizing Transdisciplinary STEAM Education

The goal of this chapter is to provide examples of in vivo STEAM education so teachers and teacher educators interested in STEAM-based education have research-based examples of how this transdisciplinarity practice looks in classrooms. These examples were created by examining them through our STEAM education model. Quigley et al. (2017) developed this model after several years of STEAM work with middle school teachers (Herro & Quigley, 2017; Quigley & Herro, 2016; Quigley et al., 2016).

From our prior studies (years 1 and 2), which included 43 teachers from 14 middle schools, we found effective STEAM teaching should position teachers to create transdisciplinarity problem-solving scenarios foregrounding problems for students to solve, using creative and collaborative skills that encompass various disciplines. This is significantly different from the beginning with the content and having students solve narrow problems (Herro & Quigley, 2016a). To illustrate the difference between the two approaches, we provide the examples below:

Transdisciplinary STEAM scenario

In May 2016, 35-yr-old Tonya was taken to the emergency room at Mary Black Hospital after complaining of a headache, some muscle pain and a fever. "Tonya" arrived with a slight fever (101°°F) and a severe case of conjunctivitis (pink eye). Doctors noted she had returned from a family vacation in Puerto Rico 3 days earlier, where she reported reading on the beach most days, eating at the hotel and local restaurants, and going on a snorkeling excursion. She had three noticeable mosquito bites. After running some blood tests to confirm their suspicions, Tonya was diagnosed with a mosquito-borne infection.

Mosquitoes are the deadliest animal on earth, leading to the death of over 1 million people each year just through transmission of malaria. Although malaria was eradicated from the US, new mosquito borne diseases such as West Nile Virus, Dengue, Zika, and Chikungunya have arrived. No vaccine or specific treatment exists for any of these illnesses. As such prevention is essential and health organizations are searching for ways to target and control problem mosquito populations.

You are member of a group working for the CDC assigned to identify Tonya's mosquito-borne illness and identify ways to control the spread and transmission of virus. In order to propose a solution, you must take numerous issues into consideration. Some of the issues include: mosquito habitat, life cycle and ecology; efficiency of virus transmission and persistence within the mosquito population; efficacy of current and new mosquito prevention technologies; ecological impacts of reducing and/or eliminating mosquitoes; and risk assessment of the case, social and economic impacts of travel bans to infected countries, and likelihood Tonya's infection may lead to an epidemic. Your proposal will be presented to the Secretary of Health and Human Services and her department. It should include evidence that multiple ideas were carefully examined to propose a solution in the best interest for the general population.

Discipline-focused teaching

Explain how mosquitos transmit diseases. Compare and contrast the diseases discussing the difference between bacteria and virus transmission including mosquito habitat, life cycle and ecology; efficiency of virus transmission and persistence within the mosquito population. Present your findings in a poster that highlights the differences between the diseases.

The differences between the approaches are (a) the STEAM teaching addresses problem-solving through a real-world application in which there is not a definite answer (e.g., the students are asked *to identify Tonya's mosquito-borne illness and identify ways to control the spread and transmission of virus*); (b) collaborative skills are required to present a solution in that the students will be placed in teams to solve the problem; and (c) multiple disciplines are acknowledged in that the scenario incorporates several disciplines. For example, engineering practices are used in determining the virus efficiency and technological advancements; English Language Arts (ELA) are addressed during the communication of evidence and persuasive essay writing during the formation of final ideas; science concepts are addressed during the investigations on viruses, transmission rates, and understanding the human body systems that are affected; technology is integrated through the use of visualization tools (e.g., Google Maps to see rates of infections) or videos (e.g., iMovie); social studies could be integrated in terms of exploring which countries are successfully battling these diseases and why (e.g., there is evidence that certain climates and geological landforms are more prone to Zika); and the students could incorporate the creative arts through creating music that evokes the feelings of contracting with a disease or writing a poem about emotions that arise during an outbreak.

This approach is sharply contrasted with the discipline-focused approach which relies heavily on science standards to have students explore the problem, with a goal of producing the same answer. One might argue the former is a more authentic teaching and learning approach as we would anticipate students encountering new questions, as they become curious about why certain people and countries are at greater risk, what the gender-bias is for certain diseases, and the technologies available to control mosquito growth. Additionally, we posit the transdisciplinary nature of the STEAM problems provides a context for creating social practices in K-12 settings.

Methodology

During our 3-year qualitative study, we determined several implementation successes and challenges STEAM teaching. We used multiple data sources including observations of teachers implementing STEAM units and teacher-designed STEAM curricula—including lesson and unit plans and teacher's reflective journals (for years 1 and 2). As the goal of this study was the transdisciplinarity component of STEAM, the data analysis focused on this aspect of STEAM.

Context

Data was collected for three years at three districts in the Southeast of US. There were seventeen schools in the study: 14 middle schools, two elementary schools. Of the three school districts, one district was in the "upstate" which had a higher SES stastus, one district is in the rural part of the state (low SES and highly diverse with a large immigrant population of largely Latino and Eastern European), and one district on the coast (racially and economically diverse). Seventy-two teachers participated in the study from across the three districts. All of the teachers participated in STEAM professional development (PD). While the specifics of the PD depended on the needs of the district, essentially, each teacher underwent at least a 1-week intensive STEAM training (40 h). During this PD, the teachers experienced a STEAM unit as students and then designed a STEAM unit for their classroom. The authors provided feedback on the units to ensure that the problem scenarios were relevant, problem-based, and transdisciplinary. We also ensured that standards were aligned and made suggestions for authentic assessment creation and ways to embed formative assessment. During the implementation of the STEAM units, the teachers were observed two times by the authors. These observations utilized the observation tool described below.

Observation Tool

Each teacher was observed at least two times by the research team. During the first year, the observation tool included brief descriptive information about the class (i.e., class size, grade level, content area); the purpose of the lesson, activities, and student arrangement (group work, teacher directed, etc.); and a narrative portion detailing what happened during the lesson. The narrative portion also focused on the success with STEAM practices and areas to further STEAM implementation. The authors completed the tool during the observation and conferenced with the teachers directly after the observation. During years 2 and 3, the authors refined the observation rubric to include STEAM-specific instructional approaches including discipline integration, problem-based approach, authentic tasks, inquiry-rich methods, student choice, technology integration, teacher facilitation, and assessments that were connected to the problem to be solved.

STEAM Curricula

Each teacher designed at least two units which included a daily plan, explicit description of components of STEAM (see observation rubric for specifics), standards, and community experts that will be involved.

Reflective Journal

Teachers kept a weekly, digital reflective journal throughout the STEAM unit (about 12–16 weeks) using it to discuss the STEAM practices they implemented, challenges, and successes they had with the implementation. Journal entries ranged from one paragraph to four paragraphs each week. These data were used as a primary data source to track the trajectory and frequency of implementation of the STEAM practices and to understand impediments to implementing STEAM practices.

Data Analysis

We analyzed the primary data sources (observations and reflections) using a priori codes. These a priori codes were taken from theoretical approaches discussed in the literature and noted from analyzing the pre-/post-data in the first phase of this study (see Quigley & Herro, 2016). These codes were discipline integration, problem-based approach, authentic tasks, inquiry-rich methods, student choice, technology integration, teacher facilitation, and assessments that were connected to the problem to be solved. Then, we conducted a second round of analysis to focus on the transdisciplinarity component. This included the level of relevant, problem-based approach, discipline integration, and the multiple ways to solve the problem. This allowed us to conceptualize transdisciplinarity similar to Kaufman and his colleagues but also expand on their work by attending to the relevance that engages students with social practice theory.

Vignettes: Understanding Transdisciplinarity in STEAM Contexts

As stated earlier, this study focused on one component of STEAM that throughout our prior research teachers found the most critical to the success of the STEAM units and at the same time the most challenging. Interestingly, this was true across all settings—regardless of the age of the students or subject area of the teacher. Transdisciplinarity includes three components: relevant, problem-based approach; discipline integration; and multiple ways to solve the problem. During our analysis, we found there were three components that led to either success or challenges in regard to STEAM implementation. These were *conceptualization of STEAM, relevant problem-based curricula design, and flexibility in enactment.* Overwhelming, without conceptualization, the teachers were not able to plan transdisciplinary units or implement them. However, there were cases were teachers had solid conceptualization and developed transdisciplinary units but were not able to enact these practices in their classrooms. The contexts within classroom impact implementation; thus we provide a variety of examples detailing the components mentioned above. We also highlight six examples of varying levels of conceptualization, curricular design, and enactment of STEAM transdisciplinarity.

Example 1 Embracing Flexibility in Planned Lessons

In grade 5, the teaching team developed a unit with the following STEAM problem scenario:

> Conde Nast Traveler and Travel and Leisure magazine just named Charleston, South Carolina the world's best city. This impressive ranking is attributed to the arts, dining, shopping and the rich history of this great American city. South Carolina coastal cities are among the fastest growing in the nation. While Charleston can be very proud of its ability

> to attract people to visit and live in the area, this honor also comes with some consequences for the city. The area faces the challenge of growing at an average daily rate of 48 people per day. Rapid population growth can create a plethora of issues and problems like repairs for big-ticket road projects, lack of parking issues, overcrowded beaches, and the need for new schools. For example, in Baskerville School District, the district plans to add 3 new schools each year! One particular area of focus is that transportation engineers are looking for solutions to determine what is best for residents and the community including easing traffic congestion and facilitating faster commutes with safety and procedures. However, there are many other concerns. The Tri-county government is interested in learning about ways other cities have dealt with these issues and have asked for your help in deciding what is the most important issue. You and your team will research and decide which area the government should focus on (e.g. environmental issues, social services, tourism, education, traffic plans). At the end of this investigation, you will create a proposal for the government to review as well as a persuasive infomercial trying to convince them to choose your area.

In this example, the teachers planned a unit that begins with a problem for the students to solve: *to investigate the challenges of population growth on the area*. This problem integrates disciplines as all students research a variety of topics before choosing their area of focus and all students needed to create a persuasive essay prior to their infomercial. The students also utilized technology integration during their movie making process (they used iMovie in the process). This is an example of using social practice theory in that the students were attempting to solve a real-world problem, one that many coastal cities are struggling to solve.

During the investigations, the students discovered that many of these challenges were occurring because of another factor not mentioned in the problem scenario: climate change. Their county is in what is called the “low country” and is below sea level. This causes many issues with flooding, and the increased number of hurricanes due to the temperature and sea level rise of the ocean has increased the frequency and severity of the flooding.

When creating authentic STEAM problems from a transdisciplinarity perspective, one of the benefits and challenges is that students end up going down investigatory paths that are different than those the teacher intended. In this classroom, the teacher encouraged this, but she had to be flexible with her plan. One of the side effects of transdisciplinarity curricula that does not position one discipline over another—the methods used to solve the problem can be as varied as the disciplines studied. During discussions with teachers, they stated that although this changed the timeline of their project, they took a look at their yearlong pacing and realized that “impacts on the environment due to humans” would be studied later in the year. Therefore, they incorporated those standards in this unit, providing them with more time to focus on this unit. In this way, the flexibility the teachers had with the curriculum guides permitted the transdisciplinarity learning. Another deviation from the curricula occurred when several students discovered that similar to many cities across the United States, when the population increases, there is an initial tax on the healthcare industry. They discovered that this was already an issue for their area, and the students began to research “why?” Similar to when the students directed the learning about climate change, the teachers used this as an opportunity to historically investigate shortages in social services and the impact on the economy. They were able to connect this to the social studies standards related to reconstruction which state, "*Re*construction was a period of great hope, incredible change, and efforts at rebuilding. To understand Reconstruction and race relations in the United States, the student will Compare the political, economic, and social effects of Reconstruction on different populations in the South and in other regions of the United States" (South Carolina Department of Education, 2011). In this manner, the teachers used this as an opportunity to discuss what happens when cities change, as there are often issues related to acess of social services as well as issues related to racial inequity.

Through this example, we described the way in which STEAM curriculum that is transdisciplinary is problem-based, integrates multiple disciplines, and provides opportunities to solve problems in a variety of ways. Moreover, when it is situated in an authentic problem, there are natural connections between the disciplines (in this case persuasion, history and science). Through our conceptualization of STEAM as transdisciplinary, we are not looking to check off all the boxes of science, technology, engineering, arts, and mathematics. Instead, we found that disciplines that are naturally used to solve the problem provide a pathway for discipline integration instead of forcing *all* the subjects into the problem scenario.

Example 2 Stuck on the Facts

During a school-wide implementation of a STEAM unit about floods, the fourth-grade team designed the following problem scenario:

> On October 1, 2015, the Smithville area experienced a large amount of rain due to a stalled storm offshore. The area received 15–25 inches of rain within 48 hours. This caused a substantial amount of flooding and damage in our community, and forced many community members to be evacuated from their homes. The National Guard was called in to help rescue people, and our elementary was even used as a shelter-in- place during this time. Homes were not constructed to withstand a storm of this magnitude, so nearly a year later, families and community helpers are continuing to rebuild their homes and restore their property. Specifically, what type of preventative measures or steps can Smithville community members take in order to protect and reduce the impact that future? What type of impact does severe weather conditions could have on their homes and their families?

The plan includes a real-world problem to be solved, opportunities for discipline integration, and a specific yet open-ended question of the study allowing for students to investigate multiple paths. However, during the observations, we noted that the enactment of trandisciplinarity was lacking. Instead of investigating ways to reduce the impacts on communities during floods, the students were asked to "choose a type of severe weather" and then record their research on a teacher-created template that asked for specific facts such as "characteristics of the severe weather," "definition," "frequency," "The region(s) where their type of weather is most prevalent," and "Identify appropriate tools used to measure data, for example: anemometer, rain gauge, wind vane, or thermometer." The students were asked to keep track of their references and then create a brochure about their severe weather type.

While creating an educational brochure undoubtedly involves other disciplines (ELA to research and write, technology to create a digital brochure, science to learn about the weather), the connection to solving the problem was missing. It can be argued that these brochures could help people become aware of the weather and therefore prepare for it; however, the types of facts that they were asked to include were narrow and specific. The brochures would likely look very similar across all the severe weather types. More so, this problem did not encourage multiple ways to solve the problem—in fact, we would argue the students did not solve the problem of "*what type of preventative measures or steps can Huger community members take in order to protect and reduce the impact that future,*" instead they created a list of facts about weather types.

Unlike the previous example, the students did not investigate unintended paths. In this way, the curriculum was teacher directed and did not foster opportunities for students to follow their interest. While this problem was initially situated within social practice theory in that this is a problem that has implications for the students' lives and is connected to the social context that they live, the *way* the problem scenario was enacted prohibited the implementation of this social practice theory into action. Interestingly, in this setting, the teacher had the support of the principal in flexibility. The entire school was investigating this STEAM scenario, and there were opportunities to rework the pacing guides. In fact, the principal requested that the pacing guides shift to meet the needs of STEAM education. Yet, the teacher in this example still felt a need to be in control of the curricula.

Many STEAM teachers discuss time as a major challenge. One teacher put it well when she described her middle school math classroom, "I am so impressed with the different directions the students are taking this project. I am excited about their creativity and to see how their individual strengths and interests are highlighted in their work. However, it is still really hard for me to loosen up on my plan. I am getting better but the pressure of 'keeping up' with the pacing is really hard to let go. Even when I know we are covering enough standards and doing real problem solving. It is just hard to let go." In this quote, you can feel the tension between authentic learning, student engagement, and multiple paths with the timelines of the pacing guides. This suggests that even with school supports, teachers need specific strategies to become better at facilitating learning and becoming flexible in their teaching plans.

Example 3 When Pacing Becomes the Focus

The eighth-grade math and English teachers co-planned a unit that connected their disciplines with a scenario that was locally relevant and an issue that had occurred in their city. The problem scenario was:

> The Melville Chamber of Commerce is holding a contest to help aspiring business-owners start their own restaurant. There is an empty store front in downtown Spartanburg and they are looking for the perfect restaurant to fill the space. This first round of the contest will be judged on the menu and marketability. One demographic that they are interested in tapping into is the youth of Melville. They have asked the 8th graders at Northeast middle school to be a part of this contest! With your group, your task is to create a menu inclusive of costs, and to design a marketing plan for your restaurant.

Interestingly, the teaching team held a strong conceptualization of STEAM, and during their reflection journal, the math teacher noted that, "For me, the difference of STEAM teaching is the connection to the real-world. How can I make the curricula relevant to the students' lives? And then what are the disciplines that make sense to solve the problem. When we designed the unit, it made sense that math and ELA would go well together." The ELA teacher held similar conceptions, "For us, it was easy to come up with a real-world problem that the students would need to use both math and English skills to solve." However, during the implementation, the team struggled to support the students in finishing the project. The ELA teacher described some of these challenges, "After we introduced the problem scenario, things sort of fell apart. It was hard for us keep pace together. The students were finished with their part in my class but the math component took longer. As this project relied heavily on the math, we had to wait for them to finish in math. I think this caused it to feel less real-world and the engagement of the students waned. Pacing was the major issue for us."

Pacing was a common issue across grade levels. Specifically, aligning the curricula within their schools yearlong pacing guides was often missing. Without situating the units into the pacing guide, teachers often grew concerned when units took longer than planned. When teachers did utilize long-range planning, they were often more confident about the number of standards they would cover and could alter the timeline of other units if the STEAM unit took longer than planned.

In our research, we found that when first-time teachers implemented a unit, it often took longer than planned. We discovered this occurred for several reasons. First, teachers did not incorporate enough "check points" or opportunities for teachers or peers to provide feedback on the progress of the problem-solving making the project goals difficult for students to meet. Second, during the first implementation, teachers underestimate the amount of skills that students need to support in problem-solving. These may be content-specific skills but also "soft skills" such as collaboration. Teachers found they needed to provide students with opportunities to practice these skills. Third, as STEAM units encourage teacher facilitation, this poses a challenge for teachers as they often have a specific idea of what the final product looks like. When the students move in a different direction, it can be difficult for teachers accept that final products can look different. Despite this challenge at the first implementation, we found that by the second or third implementation of a STEAM unit, the teachers were able to solve the pacing issue. Several things helped them to do this including opportunities for collaborative planning and flexibility with the pacing guides; these greatly improved that success of the transdisciplinarity STEAM implementation.

Example 4 Focus on the Final Product

The art teacher from a middle school designed this problem scenario:

> For many years, Hampton Middle School has struggled with getting our students, parents, and the local community-at-large involved in school events. This year, we aim to begin

> solving that problem by organizing an event that everyone can participate in and enjoy. Therefore, we are creating a Hampton School Arts Fair! Students will be asked to create a craft to sell at the shop.

In this example, while the scenario began with a problem to be solved, the teacher solved the problem before the students began the process. The students might be able to choose the type of art that would increase the likelihood of their parents' participation in the event, but this would be a side effect of how the teacher solved the problem instead of allowing students to investigate why the community feels disconnected from the school. To improve this unit, the teacher might involve students in interviewing their parents and community members to understand why these events are not well attended. This may foster learning about certain issues that were keeping families from attending (schedules, language barriers, cultural considerations around "crafts").

This teacher struggled with conceptualization, a problem that would allow students to take multiple paths. Instead, this was a project that she wanted the students to complete. We often noted that teachers were caught up in projects that students were to complete, instead of involving them in a process to create the project. Here, the focus was on the goods to sell at the shop. While well intended, as the Art Fair is a fund-raising for the school and provides a community space for some of the school, it offered little transdisciplinarity.

Additionally, because the students are not solving a particular problem, it is hard to see how disciplines will be authentically integrated. Similar to the second example, the teacher argued there would be math integration in cost calculation of the goods created, but this was not explicit in the curricula, nor is it required to solve the problem. During the implementation of the unit, students created holiday goods to be sold. The connection to the problem of engaging the community was lost, and there was little evidence that students understood that their goods were to help engage the community in the event. With regard to transdisciplinarity of STEAM, it lacks a problem to be solved by the students, authentic discipline integration, and multiple pathways to solve the problem. In this example, we posit that the teacher's lack of conceptualizing STEAM created difficulty with designing the curricula and implementing a transdisciplinarity STEAM unit.

That said, typically in our research, we found that art teachers are able to design authentically situated problems with art at the center of solving the problem. We will discuss an example of this in the last example.

Example 5 Supporting Early Elementary Students Through Teacher Facilitation

In a kindergarten classroom, the teacher designed a unit based around the connection between science, social studies, and music. The problem scenario was:

> The average person generates 4.3 pounds of trash per day. This is 1.6 pounds more than most produced back in 1960. Where does it all go? Approximately 55% of 220 million tons of waste generated each year in the United States ends up in one of the over 3,500 landfills. At Stone Creek elementary, we are really concerned about the amount of garbage in our area and so we recycle. But what if there are ways to reuse the materials too? Our principal

has suggested that we create a play space and has asked that the Kindergarten class help design it. Can you think of ways we can turn the trash into toys?

This was the second STEAM unit the kindergarten teaching team had developed, and in this unit, they worked to ensure that the students were able to practice problem-solving. One of the challenges they noted in their previous implementation was that there were few opportunities for students to solve the problem. This problem scenario was designed with the opportunity to solve the problem in different ways. They allowed the students to brainstorm, and then, as a class, investigated the different options together. This is one of the differences between early elementary and upper elementary and middle school. The teachers found that while all the students should be given the opportunity to think about solving the problem in unique ways, in order to support the students during the inquiry phase, there needs to be more guidance. For example, once the brainstorming was complete, the class agreed that creating musical instruments was the best way to use the most trash from the school (water bottles, boxes, paper, straws, rubber bands, etc.). The students were encouraged to design their own instruments, create songs, and record their music; however, the notion of student directedness and teacher facilitation looks different in early elementary classrooms. Young students should have opportunities of choice and voice; however, they need guidance in solving the problems, and the teacher noted one way to support the students in this learning was to limit the types of pathways the students took. The authors feel that this is an important distinction to make with STEAM teaching—that across grade levels, the role of the teacher will change according to the content and needs of students.

Example 6 Strong conceptualization, transdisciplinarity design with an arts focus, successful implementation

The sixth-grade art teacher at a STEAM-focused school designed a unit wherein art moved beyond art as creativity but assisted in problem-solving. The problem scenario was:

Each year thousands of hatchling turtles emerge from their nests along the southeast U.S. coast and enter the Atlantic Ocean. Sadly, only an estimated one in 1,000 to 10,000 will survive to adulthood. The natural obstacles faced by young and adult sea turtles are staggering, but it is the increasing threats are causing them to be very close to extinction. Today, all sea turtles found in U.S. waters are federally listed as endangered, except for the loggerhead, which is listed as threatened. The XX Zoo would like to create an educational tool that will be displayed on World Oceans Day next to a student created giant sea turtle that will help visitors learn about this important species and understand the risks that sea turtles face and how they can help. When researching the migration patterns, discuss what the sea turtle is going through. Can you imagine moving from one location to another, leaving loved ones behind?

Have you ever had to go through a "migration" (i.e., life change, new situation, new school, new house)?

In this example, the teacher had strong conceptual understanding of transdisciplinarity and often discussed the importance of having art as expression as a component of the problem-solving stating that, "when student uses art as an actual part of the problem solving, it changes the way they would typically solve that problem. In the sea turtles project, once the students had thought about solving about the problem in relation to arts, their ideas changed." In order to this, the teacher had the student construct a migration relief (an art technique involving layering paper in various sizes), first of the sea turtles' migration, and then she had the students construct a "feelings" relief, describing a time when they "migrated." She found that students needed to personally connect to the migrating turtles, and trials the turtles face, with trials in their own lives. The individual shapes on the reliefs were reflective of their feelings during personal experiences with movement. The students were not simply called upon to relate to feelings but were asked to dig deeper and specify an event in which they had experienced a movement. Some students drew on feelings of moving to middle school from elementary school, moving from one church to another, or moving from one state to another when their parents experienced economic job relocation. Ultimately, they understood that movement is a necessity among all species—including humans. The students reflected on the project afterward by completing artist's statements. The artist statements confirmed that they could respond to their emotion aesthetically and that they could authentically connect with creativity based on core content.

Implications

In this section, we will discuss the implications for teachers and teacher educators who are attempting to utilize transdisciplinarity in STEAM. We frame these implications by discussing three stages of transdisciplinarity: conceptualization, curriculum design, and implementation strategies.

Conceptualization

Being able to conceptualize a new educational practice is a key component to successful implementation of that practice (Herro & Quigley, 2016a). Despite some background in or STEAM training by at least half of the participants before the PD, most had limited understanding of STEAM including transdisciplinary approaches. They viewed STEAM as addressing, but not necessarily integrating, multiple disciplines. This often led to the "ticking off the individual disciplines" as one assistant principal noted. We found that this is consistent with Son et al. (2012), suggesting teachers may understand core concepts of STEAM but struggle to clearly articulate it in theory, much less enactment. While many teachers had a conceptual understanding of how to include the arts and humanities (as part of transdisciplinary teaching), they primarily considered media arts focusing on creative ways to deliver presentations. This points to the need to have teacher educators involve arts and humanities experts in PD efforts and in the curricular design process. The teachers had difficulty moving from inter- or multidisciplinary teaching toward transdisciplinarity as a way to frame the problem-solving. That said, one strategy that assisted in better conceptualization of transdisciplinarity was collaboration. Specifically, the teachers discussed two ways in which collaboration facilitated a move toward transdisciplinary thinking. First, they believed in collaboration by incorporating other disciplines into their teaching (e.g., science teachers considering mathematical concepts). Second, collaboration helped them identify areas where they would need content expertise outside of their specific discipline. The authors agree with this conception and feel this is a way that it can be connected to social practice theory. Because STEAM requires teachers to incorporate multiple content areas, the teachers felt this type of collaboration provided them with the necessary support to incorporate multiple content areas and modes of inquiry.

Curricular Design

The other area that led to the success or difficulty of transdisciplinarity STEAM teaching was the curricular design component. While all teachers developed a STEAM problem scenario, the levels of incorporation of relevance to the students' lives and the degree to which it was problem-based varied. As noted in Example 4, the Art Fair, we noted that at times, teachers had a product in mind that they wanted to tweak to make "STEAM-like." We found this was often very difficult to do, as it would likely be irrelevant to the students' lives or be overly focused on a product making it difficult to add in a problem-solving component.

While the Art Fair example is extreme, we found that for teachers who had solid conceptualization of transdisciplinarity in STEAM, they were often fixated with doing a specific project. For these teachers, we often asked them to refer back to their standards, their long-range pacing guide to map out the breadth of the concepts students should learn in their class. With a breadth of topics in mind, we were able to help them to see the connections to the real world. Not surprisingly, this was often the most difficult part of the curriculum design process. Several supports increased the teachers' ability to do this. The first was time dedicated during the PD to allow the teachers to brainstorm, draft a problem scenario, and collaborate with their colleagues. Teachers note that during the school year, there is very little time to draft these innovative STEAM problem scenarios. The second support was feedback from the authors and their peers. This feedback helped to refine the problem scenarios which often needed more explicit connection to real-world problem-solving and ensuring that there were not disciplines forced into the problem scenario that would make it inauthentic. The last support that increases the likelihood for transdisciplinarity in the curricular design was flexibility with the pacing guide. If teachers were able to move topics around in the pacing guide, they were able to create more authentic problem scenarios that involved more subject areas. We found in our work that most districts were flexible with the pacing guide; however, in one instance, a district was unwilling to allow this flexibility which restricted the teachers' ability to move beyond multidisciplinary curricular design in most cases.

Implementation

In terms of implementation, we found that the only way teachers were able to implement transdisciplinarity was through conceptualization and problem-based curricular design. Even with these two components, all teachers struggled during their first implementation. This is understandable; however, we noted that it was important to support teachers during this process. The teachers wanted to move toward transdisciplinarity and often expressed disappointment when they were unable to do so. In the first example, the teacher understood the importance of teacher facilitation and allows students to solve the problem using different methods. Comparing this to the unit described in the second example, the teacher had difficulty letting go of the necessity for students to understand facts. Being able to connect the tasks that students do in class back to the problem-solving scenario was key. However, often, teachers wanted to guide their students to ensure the content was covered. This is understandable and likely a result of the standard-based reform movements. That said, we found when teachers were given opportunities to reflect and refine their practice in vivo, they saw this as a shortcoming and were able to alter their practice. This points to the importance of reflection and also observation that is focused on STEAM-based practices.

The other issue that helped teachers achieve success was flexibility with their daily plans. As noted in Example 1, the teacher was able to see the benefit in the direction that the students were taking the problem-solving and altered her plans to support the students in this. However, there were a couple of things supporting the teacher. The first was experience. Novice teachers had difficulty in being able to be flexible with their plans; however, more experienced teachers understood the nuances of curricular planning and could alter the trajectory of these plans later to "keep on pace," as one teacher described it. The second was the support from the school. As noted during curricular design, this varied according to district but also by school. This points to the need for consistent messages from administration and specific strategies and time dedicated to help teachers think about their long-range pacing.

As noted in this chapter, the importance of art as a part of problem-solving is critical to STEAM. However, this was often challenging during the implementation process. Primarily because of teachers' conceptions of art as noted in the conceptualization section, however without the support of related arts teachers, this was often absent. Many teachers found success when they were paired with a related arts teacher who had experience in authentic integration of disciplines. However, as noted in the last example, moving beyond integration requires allowing art to guide the solving of the problem. It is our hope that time to conceptualize and design projects with related arts teachers will allow examples such as the sea turtle project to become more prevalent.

Conclusion

This chapter provides examples in a variety of settings, grade levels, and content areas offering context-rich examples of how STEAM looks in practice. Transdisciplinarity can be a difficult strategy for teachers to incorporate. However, overwhelmingly, teachers discussed its importance as a platform for authentic problem-solving for students. As one teacher described it, "I knew I was doing STEAM when the students in my class were using science, technology, social studies and so on to solve the problem. But they were doing it on their own terms. It wasn't like they said 'oh, I am using science now' but it is what made sense to solve the problem."

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