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Transdisciplinary Approach in Middle School: A Case Study of Co-teaching Practices in STEAM Teams

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Abstract

A call for educational reform motivated this school system to devise an enhanced version of STEM in their middle school. This case provides rich descriptions of how eighth grade middle school teachers, from multiple disciplines, enacted a STEAM team model that integrated Language Arts into STEM. These STEAM team teachers were systematically studied during field observations of 100+ class sessions using what they referred to as *transdisciplinary co-teaching*, flexible scheduling, and multiple types of physical spaces to further engage students. Different dimensions of co-teaching were observed. The most frequently observed was *reconstructed*, followed by *predisciplinary*, *correlated*, and *shared*. Types of instruction other than *reconstructed*, did not fit the school's proposed definitions of *transdisciplinary co-teaching.* Thoughts are shared on lessons learned.

Introduction

NSF and other institutions have called for reforms in STEM education to enhance the authenticity of STEM curriculum and emphasize the development of 21st Century Skills, e.g., communication, collaboration, critical thinking, media/technology literacies (National Research Council, 2007; National Science Board, 2009; National Science Teachers Association, 2010). It was suggested that transdisciplinary curricular efforts showed great promise in such reforms by offering teaching approaches that better connected individual disciplines (Meier, Hovde, & Meier, 2010; Honey, Pearson, & Schweingruber, 2014). Sengupta et. al (2020) more recently agreed that this emergent trend in STEM education can be understood through the lens of transdisciplinary approaches or the confluence of disciplines. These ideas revolutionize the focus of education toward career development and meaning making across integrated curriculum rather than maintain a focus on non-contextualized, discipline-specific learning.

Duerr (2008) posited that a transdisciplinary approach was especially important to middle school education since students of that age are in the early processes of becoming more independent and confident learners. Middle schoolers are also in a developmental phase where they are beginning to gain interest in careers and selecting or de-selecting career domains based on influences from family, peers, and educational experiences

(Koszalka, et al., 2005). Thus, Middle School STEM education has great potential to support students in developing interests, knowledge, and skills to make, and persist in, STEM career choices. Further, by integrating Language Arts into traditional STEM models, an opportunity is open to help students develop skills in articulating relevance and meaning of subject matter as they experience STEM learning (Duerr, 2008).

Transdisciplinary approaches attempt to dissolve the boundaries between conventional disciplines and then organize teaching and learning around the construction of meaning in the context of authentic, real-world themes (Exter, Gray, & Fernandez, 2019). Teachers from different disciplines share roles and systematically cross discipline boundaries while planning, teaching, and working together to help their students accomplish common transdisciplinary educational goals. Although the use of transdisciplinary approaches is a growing phenomenon in education, and greatly supported by governments and educational institutions around the world, little is known about how educators practice transdisciplinary teaching on a day-to-day basis (Li & Chiang, 2019; Thomas & Waters, 2015; Wong, Dillon, & King, 2016). There is also a lack of systematic research exploring transdisciplinary teaching approaches in the context of K-12 STEM education (Applebee et al., 2007; Sengupta, Shanahan & Kim, 2019). Thus, the goal of this study was to provide a rich case study of day-to-day teaching in a transdisciplinary STEAM team that incorporated 21st Century skills in an educational environment built around authentic theme- and case-based instruction.

Literature Review

Several descriptions of STEM education exist in the literature. Each describes the nature of, and approaches to, successfully facilitating STEM education in different ways. This literature does describe transdisciplinary and co-teaching approaches, however often these descriptions are disconnected and vague in illustrating actual teaching practices. This suggests that most teachers determine, on their own or in teaching teams, how to incorporate these co-teaching practices into STEM education. Various definitions are summarized in the next section.

Defining Transdisciplinary

The terms and definitions used to describe education that strategically merges two or more disciplines (subject areas) into a cohesive lesson, vary. *Multidisciplinary* lessons are defined as disciplines being additive to each other, not integrative (Exter, Gray, & Fernandez, 2019). This suggests that different teachers serve as content experts in different aspects of one topic at the same time. *Interdisciplinary* defines lessons that integrate knowledge from two or more disciplines into teaching and learning events (Duerr, 2008). For example, integrating math and science concepts when teaching about energy consumption.

Transdisciplinary defines a system that involves merging disciplines beyond their disciplinary boundaries, creating new conceptions of disciplines and how they work together authentically (in real life situations) during learning and problem-solving sessions (Choi & Pak, 2006; Godemann, 2008). For example, a transdisciplinary lesson may include merging science, technology and writing disciplines together to teach descriptive writing skills in the context of interpreting science experiments through writing summary reports that communicate energy research results to different audiences using integrated text, graphic, and numeric symbols. Transdisciplinary therefore is an attempt to understand the complexity of the world through a unity of disciplines (Martin, 2017). The difference among these types of disciplinary education appear to be the degree of cooperation and integration among the blendedness of the disciplines. These terms thus provide a spectrum of definitions about the goals teachers can set while designing and teaching lessons that blend disciplines. Yet each is rather vague in specifying how teaching practices should be implemented to support learning in such attempts.

Adler & Flihan (1997) developed a scale for an interdisciplinary continuum that represents the stages of discipline knowledge as the discipline becomes more blended with other disciplines. The stages in the continuum progress from least interdisciplinary -- *Predisciplinary*, *Disciplinary*, *Correlated*, *Shared*, *Reconstructed* – to most interdisciplinary or transdisciplinary. Each stage in the continuum has goals and characteristics that define it.

Predisciplinary refers to teachers trying to connect subject content within a lesson to real world examples, using everyday knowledge as bridges to arouse student interest in the subject content. There is no real blending among multiple disciplines. *Disciplinary* suggests that traditional school subject areas, math, science, social studies, are being taught independently, not blended (Applebee, 2007). *Correlated* refers to teaching common topics through different disciplines. For example, English Language Arts (ELA) reading activities might be correlated with a history lesson by teaching students to read using books on historical events. Disciplines are not merged, rather one is dominate in one lesson while the other is dominant in another. *Shared* interdisciplinary instruction refers to two subjects within the shared lesson mutually supporting each other. For example, teaching mathematical formulas that support calculations of a physics phenomenon like gravity or forces. *Reconstructed*, the highest level on the interdisciplinary continuum, means teaching concepts beyond each discipline requiring a full integration or synthesis of multiple disciplines into a lesson; new ways are proposed to construct different concepts from the multiple disciplines. There is a merger and redefining of the disciplines. Thus, reconstructed aligns most fully with the definition of a transdisciplinary curriculum, whereas pre-disciplinary appears as an early stage attempt to help learners connect learning of one discipline to examples of that discipline in practice.

Although the continuum was developed to further define stages of interdisciplinary knowledge, higher levels of the interdisciplinary continuum support the definition of transdisciplinary education (Martin, 2017). *Pre-disciplinary*, *disciplinary*, and *correlated* are clearly interdisciplinary approaches, whereas *shared* and *reconstructed* levels more clearly suggest levels of merging multiple disciplines. In the *Shared* level, there are blended strategies across independent disciplines. The *Reconstructed* level suggests a merger that refocuses attention away from specific disciplines to a confluence of disciplines, closely matching the definition of transdisciplinary, except in its elimination of disciplinary boundaries (see Table 1).

Table 1. Interdisciplinary and Transdisciplinary in Interdisciplinary Continuum

Stage of Interdisciplinary	Transdisciplinary
Predisciplinary	No
Disciplinary	No
Correlated	No
Shared	Low
Reconstructed	Yes

Applebee, Adler, & Flihan (2007) used this interdisciplinary continuum as a framework to examine approaches to interdisciplinary practices of eleven interdisciplinary teams at secondary schools. They found that there were vast differences in curriculum design, instructional activities, and teaching strategies across the eleven teams. They concluded that interdisciplinary curriculum is neither a problem nor solution to student achievement, rather it requires a number of teaching and learning trade-offs to be successful. Although the results in interdisciplinary curriculum are varied, this interdisciplinary continuum is useful in deconstructing teaching practices as they are observed during purported interdisciplinary and transdisciplinary STEM education. Thus, these stages may be most helpful in classifying and interpreting co-teaching observed in a study when exploring a research question like how well do teachers demonstrate transdisciplinary co-teaching.

More recently, Clark and Burton (2011) studied transdisciplinary curricula enacted within a single school and then across a collaborative community of institutions (serving as out-of-school resources). This *community of practice approach* was identified as a potential way to overcome barriers, like lack of teacher disciplinary knowledge or lack of discipline merging due to lack of abilities in applying discipline to real-world context, to enact transdisciplinary practices. Their study was contextualized in a sustainability curriculum that brought science, art, and community together, much like the school we studied who enacted an energy theme across the year. The Clark and Burton (2011) study investigated a community of 19 institutions in their STEM network, including secondary schools, universities, museums, and farms, in collaborative teaching and learning activities.

The network of assembled experts designed activities that linked art galleries and sustainability challenges. These linkages provided both K-12 and university students with avenues to discuss sustainability issues with civic leaders and artists. Thus, their implementation of transdisciplinary teaching required endeavors from both professional educators and relevant community members. This strategy embraced the characteristics of transdisciplinary of teaching beyond each discipline and provided a model in which to understand transdisciplinary education. The STEAM team approach in our case attempted to use many of the same types of community member (e.g., energy workers/experts in the local community) involvement strategies, however at a much lessor scale.

Co-teaching

When exploring the effectiveness of transdisciplinary curricula it is important to consider teaching and instructional approaches (Adler & Flihan, 1997). Cook and Friend (1995) defined co-teaching using four dimensions: (i) co-teaching that involves two teachers, occasionally more; (ii) co-teachers both delivering substantive instruction in one setting; (iii) diverse sets of students, including students with disabilities, being taught together by multiple teachers; and (iv) co-teaching instruction delivered primarily within a single physical space. Thus, teachers were working along-side each other in different ways to support student learning based on the each teacher's discipline perspective.

Fenty and Mecuffie-Landrum (2011) expanded the practice definitions of co-teaching further by suggesting five types of co-teaching: *one teach, one assistant*; *station teaching*; *parallel teaching*; *alternative teaching*; and *team teaching*. *One teach, one assist* approach is similar to Cook and Friend's (1995) ideas where one teacher takes the lead role in presenting the lesson, while the other provides support. *Station teaching, parallel teaching,* and *alternative teaching* approaches include assigning students to different groups, each group being taught separately, however in the same time and space. *Team teaching* involves multiple teachers actively teaching in close association with each other. Perry & Stewart (2005) added a dimension to team teaching by defining the low end as faculty planning together while teaching apart, individually, and the high end as faculty co-planning and co-teaching.

These different approaches to defining co-teaching provide insights into operational types, quality, and arrangements of collaborations among teachers that inform observations of transformative co-teaching practices. The quality of these collaboration among teachers affect the success of co-teaching. Bacharach, Heck, & Dahlberg (2008) identified five important factors leading to successful co-teaching. These included "sharing leadership in the classroom, planning together for co-taught instruction, respecting and trusting each other, communicating honestly with each other, and the teacher candidate assuming leadership in planning and teaching lessons" (p.45). Thus, there are many factors that may impact how transdisciplinary co-teaching can be successfully implemented. These factors, along with definitions and characteristics of the interdisciplinary continuum can inform studies of co-teaching practices.

Unpacking Transdisciplinary Co-teaching in Practice

In this study, the transdisciplinary curricula refer to a newly designed STEAM team curriculum and learning outcomes implemented with 8^{th} grade students. A theme was to be selected by teacher teams prior to the school year and community members (expert practitioners) where invited to support lessons around the theme. A co-teaching approach, supporting transdisciplinary cases and problems, was proposed as the generally accepted practice for STEAM team teachers.

The curriculum integrated science, math, engineering, and technology subject matter with language arts and social studies (peripherally considered part of ELA). However, the STEAM team documentation lacked rich descriptions of how these co-teaching approaches were actually to be enacted in practice during the school year. The questions at the foundation of this study - How was co-teaching integrated into transdisciplinary curriculum? and How were time and space flexibility used to support transdisciplinary co-teaching?

The STEAM Team Teachers, Students, Environment, and Study Context

Teachers. The STEAM team teachers studied in this case represented different content disciplines, e.g., science, language arts, social studies, math, special education, and technology in 8th grade. The teachers attended professional development sessions on the school district's STEAM team guidelines that included policies allowing teacher teams to schedule lessons outside of traditional 40- or 80-minute block schedule models as necessary to allow focus on the confluence of disciplines. The flexible scheduling provided time to promote critical thinking, collaboration, communications, and other 21st Century Skills during learning.

Together, through summer and on-going planning periods, the teachers collaboratively developed transdisciplinary learning outcomes (objectives) for the school year based on a district-level definition of STEAM education, education standards, and an agreed upon curricular theme of energy for the upcoming year. They also engaged local specialists from the community to help develop and present authentic learning activities based in energy, environmental, and civics topics. The teachers then reframed their teaching into co-teaching approaches that blended content from these multiple disciplines and themes (transdisciplinary) into focused problem- and case-based lessons. Based on the school's STEAM team definitions, this co-teaching required that multiple teachers play a shared role during all lessons, focusing both on the overall transdisciplinary learning outcomes and the confluence of their discipline *with* the other(s).

Students. The STEAM team was made up of approximately 100 middle school 8th grade students, randomly chosen through a 8th grade-wide lottery. The students were separated from all of other 8th graders who received education through traditional disciplinary methods in other wings of the school building. STEAM team students spent a majority of their time together, however had afternoon periods each week to participate with their peers in other activities like physical education, music, and art. This paper focuses on the teachers' roles during STEAM team events. The students were present during the observations, however were not the focus of this study.

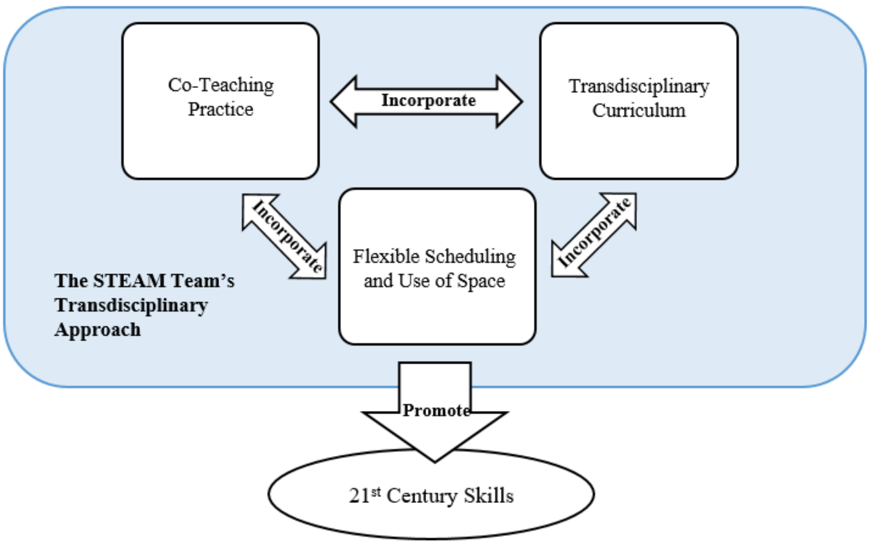

Figure 1 STEAM Team Conceptual Model

Learning environment. The STEAM teams were granted access to a separate wing in the school with all associated hallways, stairways, school labs, and other large and small collaborative spaces fair game for teaching and learning activities. All teachers and students had access to a variety of resources including computers, ipads, projection devices, digital and analogue tools, books, posters, and other resources that supported the energy theme, discipline content, project activities, and STEAM team rules. Together the spaces and resources allowed teachers to provide non-traditional activities and locations for collaborative and presentation sessions, student teamwork, demonstrations, work deliverable showcases, and spontaneous teachable moments. Thus, the STEAM team approach in this school system purportedly incorporated a transdisciplinary curriculum and transdisciplinary co-teaching, extended time periods allowing students to engage in new types of learning experiences, and space configurations to support multiple types of activities involving various numbers of students using a variety of resources. See Figure 1.

The study. This field observation, descriptive study explored middle school teachers in central New York (MSCNY) who embarked on an effort to incorporate transdisciplinary co-teaching, flexible time, and multiple physical spaces to enhance student learning through a modified STEM approach. The teachers created, documented, and implemented a version of STEM curriculum that integrated Language Arts (plus Social Studies) - STEAM. The participating team of teachers used a district-created STEAM model to merge multiple disciplines (subject matter) into problem- and case-based lessons throughout the school year. They also identified and integrated key 21st Century Skills development into the curriculum and ultimately made sure that their curriculum met New York State educational standards.

The lesson plans flexibly incorporated different types of physical spaces to support different types of instructional and learning experiences. For example, weekly planning and synthesizing debrief sessions were planned in a large room; the large room was closed to support small interdisciplinary instructional sessions; and smaller rooms and hallway alcoves were repurposed for individual / small group / large group activity sessions. The digital and analogue resources were used throughout the lessons, large, small, and individual activities, to support learning and practice sessions aligned with learning goals. Each type of activity was able to be conducted in spatial configurations with timing, teaching, learning, and resources that best suited the event. In total this STEAM team effort provided an opportunity to study a transdisciplinary curriculum approach in practice, specifically examining how STEAM team teachers fully implemented, or not, the concepts of transdisciplinary co-teaching in an operating school setting. Further, this case study provides insights on how flexible scheduling and space uses were integrated to support transdisciplinary co-teaching approaches.

Method

A field observation approach was used to investigate research questions focused on identifying actual co-teaching practices and whether they aligned, or did not align, with the STEAM TEAM definitions of transdisciplinary co-teaching. Further, this case study described how flexible scheduling and traditional and non-traditional spaces were integrated into this transdisciplinary co-teaching. Given that the STEAM team documentation was rather vague in describing the mechanics or operationalization of transdisciplinary co-teaching, making it difficult to observe defined practices, the researchers adopted the interdisciplinary continuum as a lens to explore interdisciplinary and transdisciplinary curriculum and co-teaching as demonstrated by the teachers.

Procedure

Permissions (and IRB approval) were sought and approval was granted at all levels of the school district and participating university. At the beginning of the study, the principle investigator and one lead researcher visited the school to establish research logistic for data collection. Data collection took place over the academic year, fall semester was focused on logistical planning and developing an overall understanding of the STEAM team approach and the spring was focused on observing day-to-day co-teaching. This allowed the team to develop both a general and focused understanding of the STEAM team's transdisciplinary co-teaching. The research team was recruited and trained on how to use the observational data collection instruments and protocols and how to collect data in the field, before they went into the school to observe the STEAM team teachers in context.

One teacher on the site agreed to be the liaison with the research team to help plan school visits. On-site observations were conducted weekly with 2 researchers in the same instructional space at the same time, collecting data from different perspectives, e.g., planning, teaching strategies and interactions, resources uses, movements. Informal interviews were conducted with the participating teachers and recorded as part of the observational notes after each observation. All of the researchers were required to document their specific observations, write a post-observation summary, and keep a personal reflection journal noting thoughts after each visit to the STEAM team. They were all directed to be observers and not interfere with or interact with students or teachers. Several pre-observation visits were made to help the teachers and students get accustom to the observers prior to the start of data collection.

Field Site

Participating Teachers. The study participants included eight 8th grade teachers, 2 males, 6 females, working together as the primary STEAM team teaching group. The STEAM team teachers represented five subject areas (math, science, ELA writing, ELA reading, and history) plus one special education teacher, one technology teacher, and one teaching assistant. Formal training about transdisciplinary co-teaching was not provided for teachers before they chose to teach in the STEAM team, however they were provided with workshops on the framework, definitions, and the ideology behind STEAM teams. The research team also attend the workshop to gain background knowledge of the ideology and expectations. Five of the teachers agreed to fully participate in the study, the others agreed to allow the study to be conducted and to respond to questions as necessary.

Site and Resources. The STEAM team was given its own wing in the middle school building. This separated STEAM team students and non-STEAM team students, who were in other wings of the building participating in traditional classroom spaces and educational approaches. Additional spaces that were available to the STEAM

team (in their wing) included hallways, stairways, classrooms (which could be divided and opened), science laboratories, and other small rooms and spaces. Additional moveable furniture was available in the various STEAM team spaces to support small group and individual work. A variety of educational technologies were available for use including computers, tablets, projectors, printers, and various tools. Resources and learning deliverables were posted throughout the classroom and other spaces to display the STEAM team mission, projects, and characteristics. These resources were available to be referred to and used as instructional tools throughout the school year. The school's administration fully supported the teachers by providing authority over curriculum and day-to-day scheduling, resources, planning time, scheduling modifications, and additional instructional spaces to support a conversion to project-based learning curriculum making the STEAM team transdisciplinary curriculum possible.

Instruction. Instruction was designed using a project-based approach with a single robust theme (e.g., energy) which was decided by the STEAM team teachers during planning sessions before the beginning of the school year. Projects, with energy themes, would range from a few hours to several weeks throughout the year. The teachers also established a series of 21st Century skills to focus on during the year. Shorter transdisciplinary lessons (e.g., partial day to one or two weeks) were used throughout the year to help prepare students for longer project-based overall assessment activity that culminated in a final 4- to 6-week project at the end of the school year. All individual discipline educational standards, expected STEAM team learning outcomes, and agreed upon 21st Century skills were accounted for in the project-based approach.

The STEAM team sessions were designed on a flexible schedule allowing teachers time to setup and conduct sessions without major interruptions (e.g., period ends without completing a key activity or summary). They were able to extend time as needed without interfering with other lessons. Anchor sessions (e.g., introduction, sharing, debrief, summary) were designed each week, and were scheduled at specified times (e.g., Monday morning, Friday afternoon) to help students get into a routine, focus on expected learning, reflect often, and participate in debriefs of their learning (discipline and 21st century skills). Additional daily time was set aside for the STEAM team students to attend other required and optional activities like physical education, music, and art that were outside the STEAM team scope.

Transdisciplinary curriculum. Characteristics of transdisciplinary curriculum, based on review of the STEAM team documents, lesson plans and directions, live observations, and informal interviews with teachers, suggested that the transdisciplinary curriculum approach focused on integrating technology and engineering principles with Science, Math, English Language Arts, and Social Studies education. However, no further concrete definition of operational aspects of transdisciplinary was provided.

Data Collection

This was an observational study in which researchers regularly observed STEAM team teachers over 3 months. The observations were focused on the teachers and how they enacted the defined STEAM team approach, specifically their transdisciplinary co-teaching practices. Data were primarily collected through extended classroom and teacher planning session observations and informal interviews with teachers. Nine trained observers were grouped into four teams of two with one lead researcher. The lead researcher visited the school multiple times each week over the entire school year to collect data and managed the research logistics. A majority of the observations were conducted over a 3-month period by the four teams of researchers, each observing teachers at least twice every week.

Documents on the STEAM team were distributed and reviewed during a STEAM team orientation session. These documents, including the presentation materials were reviewed using a document analysis process to identify key terms, definitions, and operational guidelines. These data provided a starting point for observing the STEAM team teachers and inquiring into their thoughts on transdisciplinary curriculum and practices in co-teaching, noting however that most information was definitional, not descriptive of practices.

During field observations, two researchers were paired in the same location to collect data (using instruments and free-hand field observation notes) on different aspects of teaching including teaching methods/pedagogies, teacher interactions and movements in the teaching space, resources uses, lesson flow, and general observations. Ethnographic field notes were written to include a combination of general observations and focused observations based on specified field observation instruments and observer interests. Each observation was scheduled for full class sessions, typically from 8:30am to 11:30am or 1:30pm to 3:30pm. Researchers noted personal reflections as part of their field notes immediately after each observation period.

Instruments. Three observation instruments were developed for this study to guide data collection. The *Teacher Classroom Checklis*t was an observation instrument developed to collect information specifically on pedagogical practices in classrooms including teacher/student interactions, assessment strategies, technology use, teacher preparation, and overall classroom management. The *Class Observation – Location of Teachers and Level of Interaction* was used to collect data on the types of activities teachers engaged in classes and how they co-taught. By using this instrument, researchers documented data every 15-minute during a 45-minute period of observation. *General observation protocol* was also developed based on the STEAM team characteristics as noted in their documentation. The STEAM team characteristics are general descriptive information that was used to document types of activities being observed, description of the observed activity, observational focus, mapping of space use, 21st century skill integration, and environmental characteristics.

Analyses

Qualitative analyses were used throughout the study to code documents and observations. These date were summarized in the short-term to identify early trends and additional questions and then again at the end of the study to summarize all observations and identify emerging themes. The summary packet of results included nine sets of field notes from the nine researchers with a total of 342 pages of raw data on co-teaching practices. After individually reviewing, coding, and summarizing their own summary packet, the research team met several times to discuss emerging themes within and across packets based on general observations, e.g. numbers and types of activities, movement and interactions, space uses, and focus, e.g. pedagogy of co-teaching, discipline merging, technology uses. With a greater understanding of the overall phenomena observed, the researchers began a re-coding process to achieve more robust understanding of emerging themes in transdisciplinary co-teaching across all field note packets.

The researcher team used NVivo 10 to record data coding. The first and second authors developed initial coding nodes for the re-coding process by referencing initial general codes, provided STEAM team documentation, the disciplinary continuum model (Adler & Flihan, 1997; Applebee et al., 2000), and the types of co-teaching observed. After re-coding a sample of the initially (general) coded data with this code book, the research team created additional codes and revised the coding book to the satisfaction of all researchers. Coding nodes were revised four times until researchers finalized the version used to code all field notes. With multiple coders, an inter-rater reliability check was done at several points to achieve consistency in coding. A 97% level of agreement for inter-rater reliability was achieved before continuing the coding process for all remaining data.

Results and Discussion

General Observations of Instructional Sessions

This study focused on observing and documenting the STEAM team’s daily teaching activities, Overall, 304 instructional sessions demonstrating co-teaching were observed over three months of regular weekly observations. A majority of the teachers most often facilitated small to medium group activities rather than the large (entire grade) group events. Approximately 17% of the sessions included instances where STEAM team teachers and students were all together for a single event, e.g. planning for the week, setting up new cases, summarizing for the week, for example during the Monday morning and Friday afternoons meetings. Small sessions with approximately 25 students were conducted throughout the week (similar to traditional class sessions) to review curricular content or engage in practice sessions. Nearly 83% of the observed sessions were small working sessions. Based on the data analysis, between 30% and 35% of the small sessions were identified as single discipline lessons (e.g., science) and between 60% and 65% were identified as multiple discipline lessons (e.g., math and science) (see Table 2).

Table 2. Observed Instances Co-teaching Sessions - Percentage (n=304)

Instances	Small Session	Large Session
	83%	17%
Single subject	30% - 35%	
Multiple subjects	60% - 65 %	

Teaching strategies/pedagogy: Multiple types of teaching strategies were noted across all the observations. These pedagogical strategies included both teacher-centered and learner-centered approach. For example, teacher-centered approaches included, lecture, teacher-facilitated discussions, and instructional prompts to take notes during session. Most of the student-centered pedagogical strategies that were learner-centered took the form of in-class games, in-class practices, collaboration/team work sessions, student-facilitated question/answer sessions, and small and large group activity debriefing sessions.

Teacher presence. More than one teacher was engaged in more than 80% of the observed sessions. The researchers observed multiple types of co-teaching approaches and multiple types of combining disciplines being used to engage students during sessions. In sum, the teachers used co-teaching approaches and both single- and multiple-discipline teaching techniques. These data were further examined to respond to the first research question concerning transdisciplinary co-teaching practices.

Research Question 1: How Well Did STEAM Team Teachers Enact Transdisciplinary Co-teaching?

Ideally, the STEAM team's intended transdisciplinary co-teaching should fall in the highest level of interdisciplinary continuum: *Reconstructed*. Data suggested that there were approximately 213 cases of transdisciplinary sessions coded based on the STEAM team documented definition of transdisciplinary. However, when closely examining these sessions, using interdisciplinary continuum coding, the STEAM team transdisciplinary curriculum was in fact scattered within the continuum from the lowest level of *Predisciplinary* to the highest level - *Reconstructed*.

Data revealed that only 48% of the lessons were clearly defined as *transdisciplinary*. While 53% were classified in the *predisciplinary* to *disciplinary* stages on the continuum. Even though the STEAM team teachers believed, as evidenced through interviews, their curriculum were centered around the concept of transdisciplinary, a major portion (53%) of the observed sessions were far from reaching the more rigorous literature-based definition of transdisciplinary. These data also suggested that the 53% that was not transdisciplinary was split across the *predisciplinary*, *correlated*, and *shared* cases, each individually was observed far less frequently than *reconstructed*. Only 14% of the cases were coded as *predisciplinary*, 29% coded as *correlated*, and 10% coded as *shared*. Thus, the STEAM team teachers used different types of co-teaching practices that reached different stages in the interdisciplinary continuum. See Table 3.

Table 3. Co-teaching Observed in Transdisciplinary Curriculum (N=213)

		Predisciplinary	Correlated	Shared	Reconstructed
		14%	29%	10%	48%
No co-teaching		x			
Synchronous co-teaching	Parallel Teaching		x		
	One Teach One Assist		x		x
Asynchronous co-teaching	Alternative Teaching			x	x
Mixed	Team Teaching				x

Predisciplinary: no co-teaching involved. In observations coded as *predisciplinary*, STEAM team teachers were not observed co-teaching. Teachers merely attempted to connect subject content with real life scenarios to arouse students' interests in the subject content. For example, in one predisciplinary science class, the teacher embedded subject-related questions that were related to daily phenomenon, such as "When you are by a pool, why does a stick in a pool appear broken?" (Field notes, 04/07/14). These questions focused on phenomena in the science discipline and prompted learners to think about where they may have witnessed these phenomena in their everyday life. He then rephrased student-generated observations into science language. There were no discussions beyond this science phenomena, suggesting only one discipline was part of the lesson.

Synchronous co-teaching – correlated with one teach, one assist or parallel teaching. Data suggested that *correlated* synchronous co-teaching was observed with two types of co-teaching present, *one teach, one assist* and *parallel teaching*. Common topics were covered through different disciplines. Often, correlated disciplinary content is observed in such sessions, but the teachers fail to identify the connection between the two disciplines (Rasi, Ruokamo & Maasiita, 2017). In this case, content from two disciplines were brought together but boundaries between them still existed and no correlated learning objectives were explicitly stated. For example, a science teacher and math teacher separately introduced reflection in Physics and symmetry in Math, respectively, during the same class period. Each failed to identify the connection between both concepts within their own or each other's discipline. The science teacher started the class by leading students in a hands-on activity with three different kinds of mirrors. The math teacher later presented in the same classroom taking over the class. She talked about a homework assignment on symmetry and reflection. There was no debriefing on the connections between math and science. The boundary remained between two subjects during the co-teaching session, even though the science teacher used some mathematics terminology in his portion of the lesson. It was possible that the teachers recognized the strength of teaching these concepts together, but during implementation, they failed to make clear connections between the science and math concepts. As noted in observational field notes…

> "This observation took place within the math class, but science content is embedded as this is a co-teach between Mrs H. and Mr R. The students are learning about the various mirrors, i.e., plane mirrors, concave mirrors and convex mirrors…Mr R. the science teacher led the first half of the class, let students do several hands on activities to learn different kind of mirrors. Then Mrs H. took the second half of the class, led students to figure out some geometry problem on symmetry and reflection, which would be included in their home assignment…Mr. R. and Mrs. H. shared the time, co-teaching, but I wouldn't consider this instruction transdisciplinary, though they were deeply related." (Field notes, 3/27/2014)
>
> "There was also impact on special education, especially with Mrs. P. being present and providing extra assistance to students needing aid." (Field notes, 3/27/2014)

In this illustrative case, the related content was presented separately and no joint learning objectives were presented that suggested a merging of discipline content. The teachers shared the time but each led an individual, topic (discipline) lesson. Additionally, the practice activities within the class did not appear to be thoroughly planned ahead of time as there were many questions about what to do, how to share results, and why the two topics were supposedly connected. Interview data supported this observation suggesting a lack of planning on how to connect the themes (Interview notes with Mr R, 3/27/2014). This co-teaching session matched what was suggested by Fenty and Mcduffie-Landrum (2011) as a co-teaching classification where teachers share time in the class yet lead instructional activities that are separate but related in discipline content. This type of co-teaching was coded as *parallel teaching*.

During the co-teaching described above, the special education teacher was also in the classroom. While one teacher delivered instruction, the other two in the room, including the special education teacher, were providing help to students (e.g., during team activities and individual work) (Field notes, 3/27/2014). In these teaching sessions, as supported by data, the math, science and special education teachers were present together using *one teach, one assist* co-teaching. However, this co-teaching practice was not directly supportive of a transdisciplinary curriculum (Field notes, 3/27/2014). Rather, the co-teaching types were considered synchronous co-teaching, meaning that all teachers were teaching in the same physical space, at the same time, and with the same group of students, just not facilitating in ways that merged multiple disciplines.

Asynchronous co-teaching – shared with alternative teaching. Shared and *alternative teaching* were observed in asynchronous co-teaching techniques. The two disciplines observed during *Shared* co-teaching supported each other. For example an illustration of this shared co-teaching was noted in a Science combined with ELA writing session, teachers co-taught together to improve students writing skills by completing science write-up assignments (Field notes, 4/15/2014). However the teachers were not teaching at the same time. In this instance, ELA writing teacher supported science content by helping students enhance results-oriented writing skills during a writing period. The writing necessary in science to report experiment results offered ELA writing activities that are typical real-world application which can further engage students in learning activities.

Evidence from an illustrated example suggested that these share and alternative co-teaching practices occurred in different classrooms, at different times (Field notes, 4/15/2014), as a form of *asynchronous co-teaching*. Although teachers alternatively taught in the classroom on a shared discipline, one teacher generally played a leading role in his or her own classroom space. None of the teachers in these cases participated in the other teacher's class, rather, each teacher led his or her own instruction using the same theme, in separate classrooms, one after another. Thus, the science teacher and ELA writing teacher were not in the same classroom at the same time, they did not occupy the same physical space at the same time, rather they mutually helped each other when teaching the same group of students at different times and in different spaces. Planning ahead (Interview with Science and ELA teachers, 4/15/2014) ensured both teachers had a mutual understanding and buy-in of the discipline and concepts within their subjects, which helped them coordinate the sequence of the instruction (Exter, Gray & Fernandez, 2019).

> "Science class, the science teacher explained what the students were doing and how they had created some of the notes in ELA to strengthen their scientific writing skills…Co-teaching level of implementation was also demonstrated in this class session, but in a more limited/in-direct way. The students used an activity they created in their ELA writing class to complete the science lab write-up. Within ELA, they assessed one another's labs write-ups using post-it notes. The critique and suggestions provided from their peers was then used as formative feedback." (Personal reflection, 4/15/2014)

> *During a full teacher group planning session discussing the scientific writing lesson* "Mr. R [science teacher] told Mr. S [Social studies teacher] that he'd like to also do a co-teach with him somewhere at the end of the year, perhaps connecting the energy piece with global politics. Mr. R. continued to say that he was going to lay out energy project when he got back from break in a new platform. He was going to look at the various standards and identify how they fit into the project. They then begin to talk about various standards that related either to one another's contents or to the project." (Field notes on planning session, 4/15/14)

The STEAM team teachers planned the activities and topic sharing often during lunchtime planning meetings. They discussed the possibilities of how to manage the lessons individually, made initial draft plans, and after planning together, they implemented instructions separately to help students with different discipline foci. This process aligns with those seen by Perry and Stewart (2005) co-teaching study where their observed teachers also planned together and taught separately.

Mix of synchronous and asynchronous co-teaching – Reconstructed with alternative and team teaching. The data suggested that *Reconstructed* was the most often and highest level in the interdisciplinary continuum observed in the STEAM teams. At this level, the curriculum finally reaches the more rigorously defined stage of transdisciplinary curriculum, that includes merging of discipline knowledge beyond disciplinary boundaries (Choi & Pak, 2006; Godemann, 2008). *Team teaching* and *alternative teaching* were the most common co-teaching types observed in these reconstructed lessons. In these cases, often more than two disciplines were incorporated together, such as ELA writing, social studies, and technology. This triple teacher and discipline merging was different than what was discussed in a co-teaching continuum (Guise, Habib, Thiessen & Robbins, 2017) where only pairs (2) teachers work together in one co-teaching group. In the STEAM team it was observed that many time more than two teachers, from multiple disciplines, taught with common goals.

For example a representative lesson from a larger multidisciplinary unit, on a World War II (WW2) project, was planned to ensure that all the content disciplines involved were under the same learning outcomes and all shared a same final learning goal to create an artifact (Field notes on planning session, 3/24/2014). ELA provided literature for the students to read (e.g., *The Diary of a Young Girl*) and a writing assignment. The writing assignment was focused on developing and practicing reading analysis skills using an article and poems written about WW2 from different perspectives. This provided a disciplinary merger of ELA and Social studies. In addition, a technology discipline, using Photoshop to modify and add picture into a WW2 picture, was merged into the lesson thus incorporating technology learning discipline with the ELA and Social Studies. This illustrative example is one of many that provided evidence of a reconstructed lesson where three disciplines were merged to prompt engagement in learning across multiple disciplines. The teachers sometimes taught together (synchronously) and sometimes separately (asynchronously) using *team* and *alternative teaching* techniques. Each session focused on the same learning goals and outcomes. A noticeable feature in this reconstructed practice was the common goal across the disciplines.

In another example illustrating these transdisciplinary co-teaching practices, the goal of a Great Depression project was to write an essay called *Teenagers in the Great Depression*. Learning objectives for each discipline [ELA, Social Studies, Technology] all served toward this ultimate goal, but from each individual discipline's perspective. With the flexible scheduling in full force, class times were doubled from what was planned to support students who were in need of additional, uninterrupted time to create and refine their essay (interview notes with teachers, 3/27/2014). Multiple spaces were provided to students who worked collaboratively to interpret content and brainstorm essay ideas, or who needed individual time to think and write, or who came together to share their ideas and get feedback (Field notes, 3/26/2014). Thus, the observation data suggested that the boundaries between ELA writing, social studies learning, and technology skill development were eliminated within this project-based lesson and time and space were adapted to student learning needs. Since these projects continued for more than one day, synchronous and asynchronous co-teaching events were observed over multiple school days.

Co-teaching in these *Reconstructed* lessons included *one teach, one assist*; *alternative teaching;* and *team teaching*. Both synchronous and asynchronous co-teaching practice were adopted. Multiple teachers planned and worked together, adjusted their own discipline content to common learning goals, and delivered their instruction in a planned sequence. During the synchronous co-teaching observations, for example, teachers were in the same classroom reviewing content of the assignments, while during asynchronous sessions the technology teacher taught at different times, in different spaces to support technical skill development in the context of the assignment. Each teacher participated in transdisciplinary co-teaching practices to help students achieve the final goal (artifact) at the same time. Then, the teachers brought all the students together to share and debrief the multiple dimensions of their learning and 21st century skills development while developing these artifacts, i.e., writing, social studies, technology (field notes, 3/26/2014).

More specifically the following data suggests how each discipline was supported during this transdisciplinary activity…

> *From the ELA writing and 21st century skills (communication and creativity) perspectives…* "The presentation [writing clarity and on grammar and spelling goals] only lasted about 5 minutes or so. At the conclusion of the presentation, Mr. S asks, "Did the New Deal work?" This is the question students were to answer in their stories. He agrees that this will be a difficult question to answer, but just wanted the students' initial responses. The students then continue to work on developing their stories." (Field notes, 3/26/2014)
>
> *From Social Studies and 21st century skills (critical thinking, interpretation, and creativity) perspectives* ... "Initially I did not see any [learning] objective on the boards, but I did hear potential objectives being articulated verbally. Then, when I looked at a sheet the students had, there was a problem statement written at the top. It read: Problem Statement: Individuals react to significant events differently depending on their point of view. Design Statement: Create a teenage character and in historically based narrative, share their reactions as they experienced the events of the Great Depression." (Researcher C,

03/27/2014)

From the technology and 21st century skills (media and technology literacies) perspective ... "The purpose of this activity was for the students to learn how to use Photoshop. This class is actually a co-teach period between Mr. S, the history teacher, and the technology teacher." (Field notes, 4/15/2014) … "The task called for students to Photoshop themselves (the group picture) within the historical images. They were provided step-by-step instruction, primarily by the technology instructor whom led today's lesson." (Field notes, 4/15/2014)

From a co-teaching collaborative and supportive perspective ... "Mr. S. was also in the class. He primarily stood in the back of the classroom. Offering assistance as needed like when students raised their hands or when he observed potential struggle. Though Mr. S. is not leading instruction he is very actively involved." (Field notes, 4/15/2014)

Synchronous co-teaching between Social Studies (history) & Technology in the World War II project were also observed and noted. The co-teaching was *one teach one assist*. The technology teacher took the leading role during instruction to help students learn Photoshop techniques, while social studies teacher facilitated activities to ensure students followed the technology skill instructions while creating artifacts related to WWII. The ELA teacher supported writing activities while checking grammar and spelling and providing help as needed. Each co-teacher was present in each learning session and supported students in meeting the merged learning outcome.

On additional strategy observed, although not often observed outside of an occasional science lesson, was that the STEAM teachers engaged outside resources like local energy experts from the community or outside the community (e.g., NASA scientists through virtual collaborations) to support aspects of the transdisciplinary curriculum in science class sessions. One session was conducted with a video conference with a NASA scientist talking in the large classroom with all students and teachers in attendance (Field notes, 4/12/2013). Other sessions either were planned to include visitors talking about specific of the science of energy or being mentors to student teams creating arguments for different types of energy, e., oil/gas, nuclear, geo-thermal (Field notes on planning meeting, 3/25/2014). It was also planned that these outside mentors would act as judges during final team presentations.

Summary. Throughout the STEAM team observation period multiple types of co-teaching, from planning to implementing lessons together or separately, and integrating community members to support lessons, were observed across different times and projects. Just as Pancsofar and Petroff (2016) found, the time the STEAM team teachers spent co-planning classes was highly associated with the co-teaching approaches they adopted and applied in the classroom. All the STEAM team teachers co-planned the small and large projects before the school year began and continued to adjust in planning sessions within the school year. This provided them a foundation to adopt more co-teaching approaches during transdisciplinary projects as they themselves learned how to teach in the STEAM team. Moreover, they often enacted the STEAM team transdisciplinary approach in various ways and took advantage of flexible time and spaces strategies.

These observations suggested, that transdisciplinary co-teaching was enacted often, however inconsistently. Some instruction was disciplinary, while others were closer to multidisciplinary and transdisciplinary. Co-teaching practices were also inconsistent, ranging from predisciplinary through the continuum to transdisciplinary. Thus the transdisciplinary co-teaching practice were not always present as described in the STEAM team documentation. This suggest that the teachers may likely have been in early stages of learning how to transition to STEAM team transdisciplinary co-teaching approaches and making progress toward the defined practices of transdisciplinary co-teaching.

Research Question 2: How Was Flexible Scheduling and Space Uses Practiced with Transdisciplinary Co-teaching Sessions?

Literature suggests that a common challenge of co-teaching is scheduling and having enough time at one point in a traditional day to present, practice, debrief, and assess multidisciplinary learning (Johnson & Brumback, 2013; Fenty & Mecuffie-Landrum, 2011). The STEAM team approach attempted to overcome scheduling issues by incorporating a flexible scheduling process. Lessons were not inhibited by typical 40-minute class boundaries, rather the length of class sessions was defined by the teachers during planning sessions, based on projects and their expected learning outcomes, and modified live, through negotiation as needed. It was the judgment of the teachers as to how well students were progressing in learning and reaching project goals that determined if more or less time was required to achieve learning outcomes and complete project work. Thus, time was organized and scheduled around complexity of learning, team activities, practice sessions, assessment activities, reflection and debrief activities rather then fixed time periods. The STEAM team documentation labeled this scheduling method as *flexible scheduling*.

The field observation and interview data noted that there was a typical weekly schedule incorporated into the school year that guided and supported students in this project- and case-based learner-centered curriculum. For example, on Monday mornings, all teachers and students attended in a 20-minute meeting to summarize activities from the previous week and introduce the coming week's agenda. This helped to remind students of the previous week's learning and activities, set context for the upcoming week, and provide advance organizers to focus the students on expectations for learning (Field notes from teacher planning session, 3/4/2014). The introduction to the week generally included an overview of the content and activities for the week (or beyond for longer projects) and provided an overview of the 21st Century skills that were focused on that week.

Several times throughout each week there were also 20-minute time slot designed as *differentiation* or *Fly time* (Field notes from teacher planning session, 3/4/2014). These time slots provided opportunities to debrief and assess learning progress to assure students were reaching satisfactory levels of required content knowledge to support their success in the projects or upcoming 8th grade standardized tests. Students complete Math and ELA tests at the end of 8th grade, thus the teachers spend disciplinary time making sure students were prepared for these tests. As observed in field notes….

Differentiated Math Lesson to review for NY State test… "The teaching assistant (T2) told us that this is part of a new initiative to offer differentiated lessons before class begins. The sessions are held Tuesday, Wednesday and Thursday, and are 20 minutes … teachers can say when they need days/weeks for their subject. Currently, the focus is on preparing students for upcoming math and English standardized tests." (Field notes, 3/26/2014)

Fly time… "20-minute morning session. It was called Fly time. Students are divided into different groups based on certain test scores, e.g., Math, ELA. Teachers help students to improve in their areas of weakness. The room I observed was where students were working on math vocabulary. There were 32 students in the room with the ELA teachers." teachers divided students into groups and reviewed content with them" (Field notes, 4/9/2014)

The flexible scheduling allowed the STEAM team teachers to customize their class time based on project inquiry and student levels of knowledge to support students in preparation for standardized exams without overly interfering with STEAM team projects. For example, the science teacher offered 10 minutes from his class to a co-teaching ELA and Social Studies team who were helping students with complex reading assignments in a Social Studies context (Field notes, 4/9/2012). Thus, whether flexing time was used to help with STEAM team projects or to support students in preparing for the non-STEAM team required standardized tests, the daily and weekly schedules could be easily be negotiated and adjusted to meet learning needs, rather than be based on strict periods.

Another advantage to the STEAM team approach was that this entire group had its own wing in the middle school building. All of the spaces in the wing, including hallways, stairways, small alcoves, and classrooms could be used in anyway to support learning. Decorations and educational materials were posted in classrooms and hallways to emphasize and remind students of STEAM team rules and the energy theme that permeated the year (Field notes, 3/12/2104). Projects, key content concepts, process instructions, and characteristics of the STEAM team were strategically placed to support individual, team, and full grade sessions (Field notes, 3/19/2104). These resources were used as reminders and additional instructional resources to support lessons. For example, in one morning meeting, a team of students was asked to use an application called Aurasma on the iPad to find particular words describing the STEAM team that were secretly embedded on the walls of their wing (Field notes, 3/19/2104). The activity was aimed at deepening students' understanding of STEAM education and improving their articulation, of the meaning of STEAM and the 21st Century learner. Other posted resources were used to prompt thinking and reflection on project content, energy concepts, procedures to follow during activities, and expectations for excellence in learning. There were also moveable furniture (e.g., tables chairs) in the hallways and alcoves that allowed students to rearrange spaces for study or collaborative projects.

The large gathering room also had a rolling wall that allowed more flexible use of a defined instructional space. The wall was removed so that all student teams could be together for larger class events and debriefs (Field notes, 3/4/2104 and 3/8/2014). These adaptions of space offered the STEAM team opportunities to engage all 100+ students together. During these sessions *Team teaching* and *alternative teaching* were the most frequent used co-teaching strategies, allowing all teachers to support the larger group of students. The hallways were used primarily for *one teach, one assist* co-teach sessions. For example, one representative observation noted that for a math-focused session one Math teacher was in the classroom helping students collaborate during a Math game, while another co-teacher used the hallway to help individual students who had special needs or required additional tutoring in the Math content (Field notes, 3/28/2104).

Summary. The flexible use of time, spaces, resources, and asynchronous co-teaching were merged in different ways to support different configurations of students, learning goals, and types of student needs. The space arrangement also were flexible to accommodate large and small group work as well as individual study. Students took advantage of open spaces and walls to organize and showcase their work. Teachers took advantage of spaces and moveable furniture to offer small group or individual mentoring. Teachers used extra time to help students complete work or further develop complex understanding by simply negotiating with other teachers, just-in-time, to add or give away time. Such flexibility was supportive to the multiple types of co-teaching observed throughout the year.

Conclusions

The effort undertaken in the STEAM team transdisciplinary curriculum was complex. There were many moving parts that were flexibly woven into a year-long, themed, project-based effort to engage students in an integrated STEM plus ELA and Social studies curriculum. Community members from near (e.g., local area energy specialists) and far (e.g., NASA scientists) were invited to support STEAM team teaching and learning sessions. The school entitled this STEAM team effort as a transdisciplinary co-teaching design. The documentation for the STEAM teams laid out expectations for the teachers and provided support for re-designing a multidisciplinary approach to education. The documentation however was not always clear on the actual techniques teachers should use to practice transdisciplinary co-teaching, leaving implementation decisions up to the teacher team. This study was conducted to explore how the teachers demonstrated transdisciplinary co-teaching.

The field observation, document analysis, and interview data suggested that teacher both met with successes and challenges in creating a transdisciplinary curriculum in which transdisciplinary co-teaching was practiced. There was evidence that they shared leadership, planned together, co-taught often, and communicated when making decisions. They took advantage of multiple types of spaces, a variety of digital (e.g., computer, internet tools) and analogue (e.g., posters, books) resources to support authentic project-based learning with frequent assessments and summarizing sessions. Although effort was made to authentically relate the multiple disciplines to each other in transdisciplinary ways, in some cases the teachers failed to identify these connections or even merge disciplines.

One area that seemed especially challenging for the teachers was how Math and Science are implicitly connected. Several instances of this dis-connect were observed throughout the year in these science-math sessions, as described the incidence from the symmetry and reflection lesson. Many other observations also suggested that concepts taught in math and science co-teaching sessions were blended (each teacher talked about a concept from his or her discipline), however often neither of the participating teachers directly stated the additive nor merged relationship among math and science perspectives. Students simply were exposed to the 'science side' and then the 'math side.' There was no explanation of how these disciplines were complimentary in solving the presented project problems. Thus, the idea of transdisciplinary co-teaching was not consistent throughout the year.

Teachers from each discipline were also not equally observed in applying transdisciplinary instruction consistently. Projects did not always appear to be designed to include perspectives from multiple disciplines. For example, Mathematics was the least integrated discipline as compared to ELA as the most integrated. Teachers ultimately revealed in interviews that mathematics concepts were the most difficult to integrate into projects because standardized math testing was done in the 8th grade at the end of the year. The math teacher was more motivated to cover requirements for the Math exam in discipline-specific, math-focused sessions to help students prepare for exams, rather then efforts to teach those concepts in the context of the energy-themed projects. Thus, disciplinary, traditional lessons for mathematics were the norm for the STEAM team students.

The most integrated discipline across the sessions appeared to be ELA – the A in STEAM. Reading and writing were both deemed basic and essential skills for middle school students, thus were represented across all learning experiences throughout the year. It was easy for the teachers to both advocate the importance of reading, writing, and other forms of communication (also aligned with 21st Century Skill) in all units, thus its clear presence across the curriculum. However, overall observations suggested that STEAM team teachers did not have a concrete and consistent understanding of transdisciplinary education.

Our data suggested that the STEAM team teachers were exhibiting multiple types of interdisciplinary levels of co-teaching with less than half approaching transdisciplinary co-teaching. It is likely that a lack of concrete definitions and examples of transdisciplinary curriculum and a lack of professional development on transdisciplinary co-teaching sessions may have been a hindrance. It appears the novelty of the overall STEAM team approach plus the experience of teachers' disciplinary approaches and their lack of full agreement as to how to approach co-teaching might have been at the root of the differences. Although all, but perhaps the math teacher, were open to co-teaching changes to enact the STEAM team approach. This lack of reaching a consistent higher level of transdisciplinary co-teaching may have been due to STEAM model being mis-understood or not accepted by all teachers.

The teachers appeared to struggle with how to merge disciplines in way to support students' knowledge of the disciplines. Thus, most efforts used predisciplinary and parallel efforts that did not indicate blending. Teachers often commented during planning meetings and interviews that there were no specific guidelines on how to merge disciplines and how to be transdisciplinary co-teachers. Our analysis of the documents supported these comments. Thus, there were a variety of co-teaching practices across the curriculum, however many were nearing or demonstrating transdisciplinary co-teaching, especially those that merged writing. In Figure 2, a representation of a successful transdisciplinary co-teaching practices across two or more discipline can be seen.

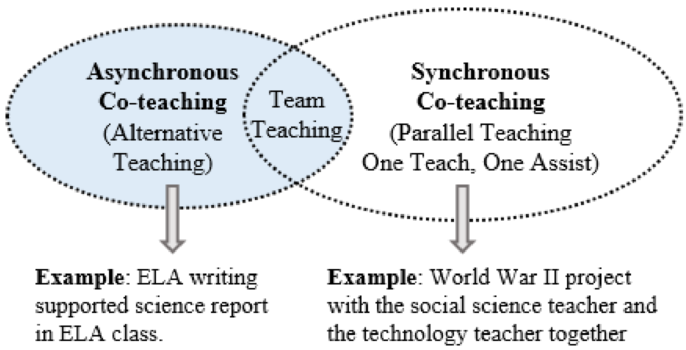

Figure 2. The STEAM Team Co-teaching Example

This indicates that the teachers were able to transition well to transdisciplinary co-teaching for some topics. Perhaps since ELA (e.g., reading, writing) is a shared discipline across all traditional subject areas (e.g., math, science, etc.) it was *easier* for the teachers to plan co-teaching lesson, whether synchronous or asynchronous because they were all likely good readers and writers. Discipline teachers may not be that knowledgeable in other disciplines and how the disciplines are practiced and merged in the *real world*, due to their own education focus, thus making it more difficult to plan and enact lessons that are transdisciplinary. This suggests that STEM professional development may be enhanced using examples of closely aligned – more general – disciplines, like science and writing or math and writing, to help teachers begin the process of learning how to merge disciplines for co-teaching. Then, move toward merging specific disciplines, like math and science, in parallel and connected ways through sharing, ultimately achieving transdisciplinary co-teaching as each learns more about the other topic. The key to becoming more transdisciplinary co-teachers may be in educating teachers in both, the pedagogy or co-teaching and the transdisciplinary connections among disciplines.

Another important aspect of transdisciplinary co-teaching that emerged in this research was that of supporting this new model of education. Transdisciplinary teaching and learning requires more time - more time to prepare and setup teaching and learning logistics and more time dedicated to summarizing learning along the way. Different types of spaces and resources (both material and human) are important as teachers and student explore and develop knowledge of connections among disciplines, and experience teaching and learning in a variety of ways and in authentic contexts. Thus, having flexible time and spaces becomes an essential part of a transdisciplinary approach. In this case the teachers took advantage of the responsibility and authority given them as a team to modify traditional education practices, resources, space, and scheduling. This may help them to enact the STEAM Team transdisciplinary approach and engage themselves and students in new ways of learning. It is important that the school system support such planning and activities when encouraging new curricular, teaching, and learning approaches.

It is likely that it will take additional time and experience for the STEAM team teachers to develop into fully transdisciplinary curriculum and achieve more effective transdisciplinary co-teaching practices. Part of the challenge in this case was an acknowledged lack of clear operational definition of co-teaching practices provided in the STEAM team documentation. This lack of detailed operational guidelines left much of the lesson planning and co-teaching practices up to the teachers who themselves were experienced teachers, but novices to the ideas of transdisciplinary co-teaching. It is likely, based on interviews and field observations, that the teachers relied on their preferred and comfortable pedagogical practices as they transitioned into co-teaching. Further research is need to examine the process of preparing teachers for the rigors of transdisciplinary co-teaching. It will also be helpful to examine expected learning outcomes to determine how well new teaching practices are supporting new types of merged and connected understanding of disciplines.

Transdisciplinary curriculum and co-teaching are complex ideologies that have multiple definitions and approaches. This was evident in the practices of and comments from these STEAM team teachers. It was helpful to unpack how these teachers, from different disciplines and levels of experience, adjusted to these ideas, how they unpacked the ideas of transdisciplinary education as a team, and how they 'repacked' their lessons and teaching practices to enact transdisciplinary co-teaching. The inconsistencies noted in their teaching may have been due to their preparation as teachers. They may simply be experiencing difficulties perceiving how their discipline knowledge can be merged with other discipline knowledge. Thus, it is also important to conduct follow-up studies to investigate how STEM teachers evolve into transdisciplinary teachers.

In this study we investigated a case where STEAM team teachers' developed approaches to an emerging version of STEM education. The evidence suggested that these teachers were growing and adapting to their new pedagogical practices, collaborative activities, curricular models, and environmental aspects as they moved toward meeting their goals of enhanced instruction through transdisciplinary co-teaching. Sharing details about their progress, successes and challenges, is important to supporting others who are also taking this journey in similar, or different, ways.

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