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Transdisciplinary Inquiry that Elevates the Arts? Insights from a Data-Visualization Pilot Project

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Abstract

Over the past decade, the arts' potential role in advancing mainstream transdisciplinary curriculum models, like STEM, has been more overtly recognized, both within arts and STEM communities. In this study, we explored STEAM curricula centered around data visualization, a transdisciplinary practice commonly utilized in design and STEM fields and increasingly practiced in contemporary art.

Through addressing the research question "What opportunities and challenges for learning does arts-based data visualization provide Grade 4-8 students?," this study highlights the value of transdisciplinary curriculum models that incorporate the arts for fostering K-12 students' learning. However, the findings related to student engagement and teacher perceptions also raised some important questions. Which classroom contexts are most conducive to such inquiry? And, which contexts and conditions will avoid reinforcing the disciplinary hegemony that marginalizes the arts, a crucial, yet increasingly underappreciated, system of inquiry and knowledge needed for navigating life in the twenty-first century?

Introduction

Transdisciplinary inquiry is founded on the premise that problems can transcend disciplinary boundaries through their broadness and complexity, and that for inquiry to address these problems effectively, it, too, must surpass disciplinary bounds (Kreber, 2009). From this perspective, knowledge domains, skill sets, and inquiry methods associated with various disciplines can be drawn upon and synthesized to create novel frameworks for addressing important problems (Costantino, 2018; Craft & Wegerif, 2006; Kreber, 2009). In the twenty-first century, science, technology, engineering, and mathematics (STEM) education has represented the most prominent model of transdisciplinary learning. While definitions of STEM can be diverse, and questions within these fields remain, one fairly clear consensus is that design and design thinking are central to the integration of the respective S-T-E-M fields into a cohesive STEM model (Li et al., 2019).

Over the past decade, the arts' potential role in advancing mainstream transdisciplinary curriculum models, like STEM, has been more overtly recognized, both within arts (e.g., Allina, 2018; Costantino, 2018) and STEM communities (e.g., Segarra et al., 2018). In 2013, John Maeda, then President of Rhode Island School of Design, argued the established STEM model be reconceived—as science, technology, engineering, *art*, and mathematics (STEAM). Maeda (2013) explained STEM's need for art and design: "Design creates the innovative products and solutions that will propel our economy forward, and artists ask the deep questions about humanity that reveal which way forward actually is" (p. 1). Within the field of STEM education, scholars have cited a multitude of reasons why the arts are integral to effective STEM education, including the arts' emphasis on aesthetics and beauty, divergent thinking and creativity, openness to ambiguity (Panke, 2019), emotion (Bailey, 2015), and empathy, a central component of the design thinking required in STEM education (Bush et al., 2022). Additionally, Maeda (2013) and others (e.g., Allina, 2018; Watson & Watson, 2013) have highlighted the inherent connections between art and design and other disciplines, such as science, that render art and design compatible with STEAM frameworks.

As diverse forms of disciplinary knowledge and skills have been drawn upon in transdisciplinary curriculum models, like STEAM, their integration into schooling has encountered challenges (Boice et al., 2021; Herro et al., 2019) somewhat different in nature from those affecting more widely implemented models like STEM (Margot & Kettler, 2019; Shernoff et al., 2017). When STEAM is implemented in STEM classrooms, STEM teachers can feel ill equipped to ensure STEAM's "A" functions as a valid and well-implemented component (Quigley & Herro, 2016). Correspondingly, within arts-classroom contexts, research into arts integrated learning, an educational approach with many similarities to STEAM, has identified obstacles like limited art class time and opportunities for arts-content instruction (May & Robinson, 2015). The reduced class time associated with the arts in kindergarten through Grade 12 (K-12) schooling can be a key barrier. Despite challenges, STEAM models have been shown to have many affective and cognitive benefits (Belbase et al., 2021; Wilson et al., 2021). Models could be developed to delineate how STEAM, or other transdisciplinary curriculum models integrating the arts, might unfold to position the arts as integral to learning within K-12 school contexts.

This study explored STE<u>A</u>M[1] curricula centered around data visualization, a transdisciplinary practice commonly utilized in design and STEM fields and increasingly practiced in and reinterpreted through contemporary art. Using a design-based research (DBR) model, we explored the following research questions:

> What opportunities and challenges for learning does arts-based data visualization provide Grade 4-8 students?
>
> a. How engaged are students during an arts-based data visualization/STE<u>A</u>M curriculum?
> b. How do teachers perceive these opportunities and challenges, particularly in relation to their future teaching plans?

Through this research, we identified opportunities and challenges associated with transdisciplinary learning as it unfolded in art and non-art contexts. These challenges were especially marked for a STE<u>A</u>M model like ours that positioned the arts as an esteemed, integral component—embracing forms of knowledge, thinking, and inquiry that surpass instrumentalist positionings of the arts. Noting insights from this study, including those related to student engagement and teacher perceptions, we conclude with a structural proposal for how the arts might be elevated when transdisciplinary frameworks are implemented in K-12 school contexts. In the following sections, we explore conceptions of disciplinary

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[1] We underline the "A" to underscore the important role of art and design, in coactive relation with one or more STEM disciplines, in this STEAM model.

hegemony, marginalization and the arts that inform our study and review literature related to student engagement and STEAM and arts-based data visualization as a transdisciplinary practice.

Disciplinary Hegemony, Marginalization, and the Arts

In calling for a STEAM model, we recognize the institutionalized disciplinary hegemony (Henry, 2005) that fragments knowledge and learning into academic siloes and reproduces academic hierarchies. In such cases, the arts can be artificially disconnected from intersecting and overlapping disciplinary territories, a separation that not only isolates all fields, but particularly leaves the arts vulnerable to “the politics of disciplinary advantage” (Rogers et al., 2003, p. 1). We note two dominant disciplinary dichotomies that increasingly reduce the status of the arts in contemporary K-12 education practice: (1) “core,” standardized-tested subjects versus peripheral, non-tested subjects and (2) STEM versus humanities and arts fields (Watson & Watson, 2013).[2]

In the United States (U.S.) and many Western countries,[3] school subjects are often distinguished, either explicitly or implicitly, at the district and school levels by “core” “academic” subjects like English language arts, mathematics, science, and social studies, positioned as central to students’ education, and less essential subjects on the educational periphery, often labeled “related arts,” “electives,” or, in the case of the first author’s early years as an elementary art teacher, “activity.” Exceeding labels and standardized testing practices, this division manifests in tangible subject-area disparities: hours of instruction per subject (McMurrer, 2008; Milbrandt et al., 2015), subject-specific professional development offerings (Elliott & Stokes-Casey, 2019), and class sizes per subject area (Kimelberg et al., 2019), to name a few. While the *No Child Left Behind Act of 2001* (2002) defined the arts as a “core academic subject” (p. 19), and the *Every Student Succeeds Act* (2015) designated the arts as integral to a “well-rounded education” (p. 299), these policy stances have failed to disrupt the arts’ marginalized status in K-12 schooling.

Beyond the core/elective or tested/non-tested subject separation, the persistent divide between STEM subjects and the arts and humanities has expanded in recent decades. In the U.S., this divide is evident through the federal government’s funding priorities, where large competitive grants, like Race to the Top (U.S. Department of Education, 2010), have prioritized STEM education reforms, and the National Science Foundation’s annual budgets consistently, and

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[2] A range of related, artificial dualisms might be seen as producing and sustaining these hegemonic disciplinary relations: mind/body, cognition/emotion, reason/emotion, thought/feeling, knowledge/imagination, and economic success/arts study.

[3] Including Australia (Bleazby, 2015), England (Fautley, 2019), Ireland (McGarr & Lynch, 2015), and New Zealand (Irwin, 2018).

astronomically, surpass that of the National Endowment for the Arts.[4] In public discourse and messaging from national commissions and science and mathematics professional organizations, STEM education reforms and innovations are positioned as necessary to remain nationally competitive on the global stage; STEM education is touted as an avenue to support workplace readiness, to enhance economic growth and development, spur technological innovation, and maintain national security (Breiner et al., 2012). As STEM as a whole and individual STEM subjects like science and mathematics occupy a prominent station in K-12 schooling with STEM courses and STEM-focused schools and districts proliferating nationwide (Wieselmann et al., 2021), access to arts education in formal schooling has weakened. Since the 1980s and 1990s, the number of arts educators employed in schools (Gara et al., 2022) and number of hours students receive in-school arts instruction (Rabkin & Hedberg, 2011) have decreased significantly, with students of color experiencing the most substantial declines in access to arts instruction during this period (Rabkin & Hedberg, 2011). José Luis Aróstegui (2019) argued this phenomenon of decreased arts instruction is virtually worldwide; art and music education have experienced a "demise" (p. 121) in national curricula across the globe as educational reforms continue to reinforce STEM's high standing.

In both disciplinary dichotomic cases—core/elective and STEM/arts and humanities—the arts have been undervalued. These disciplinary hierarchies restrict students' access to quality arts education and, correspondingly, deny them the opportunity to benefit from the unique cognitive and attitudinal dispositions arts education can foster (Hetland et al., 2013). Such disciplinary orientations have a direct bearing on the ways in which interdisciplinary and transdisciplinary inquiry unfold in school contexts, including the ways in which students and teachers receive such practices.

Student Engagement and STEAM

Student engagement is generally considered a complex, multifaceted concept, emerging from individuals' interactions with their environments and involving three dynamically interconnected factors: behavioral, cognitive, and affective (Fredricks et al., 2004). Behaviorally engaged students exhibit high levels of participation and involvement; they ask and answer questions, demonstrate effort, and participate in relevant conversations (Fredricks et al., 2004). Cognitively engaged students challenge themselves and seek to go beyond basic requirements of the task (Connell & Wellborn, 1991; Fredricks et al., 2004). Affectively engaged students display positive emotions toward the curriculum and exhibit bonds with other students, educators, and learning sites (Connell & Wellborn, 1991; Fredricks et al., 2004).

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[4] For instance, in the 2023 fiscal year, the National Endowment for the Arts had $226.19 million budgetary resources available compared to the $10.92 billion available to the National Science Foundation (USASpending, 2023a, b).

Research suggests that when engaging in STEAM curricula, students exhibit outcomes that parallel the behavioral, affective, and cognitive indicators used to define student engagement (Connell & Wellborn, 1991; Fredricks et al., 2004), including creativity, innovation, critical thinking, self-expression, and interpersonal skills (Burton et al., 2000; Craft & Wegerif, 2006). For instance, when engaged in STEAM, students make more in-depth personal connections to subject content knowledge and are more likely to transfer knowledge beyond their classroom experience into other facets of life (Ernest & Nemirovsky, 2016). Additionally, research (Ernest & Nemirovsky, 2016; Wilson et al., 2021) suggests transdisciplinary inquiry is often appealing and captivating to students.

Arts-Based Data Visualization as Transdisciplinary Practice

In the case of the STEAM curricula we designed and implemented, data visualization served as a key transdisciplinary practice. We approached data visualization from an arts-based orientation, drawing from the data-visualization practices of contemporary artists, who often embrace divergent modes that use pictorial or sculptural elements, sound, movement, or audience interactions to communicate important information and ideas to the public (Galbraith et al., 2024).[5] For instance, Kathryn Clark (2015) fashioned a quilt mapping District-of-Columbia foreclosure data; scientist-artist duo Semiconductor (2014) crafted a hollow wooden sphere, the volume of which was equivalent to the United Kingdom forest's annual carbon sequestration, and rested it in the forest for hikers to encounter; and Greg McNevin (2016) translated radiation levels he measured while walking through a portion of Chernobyl into a light display, captured through long exposure photography. Such arts-based engagements exceed the graphical approaches common to STEM fields as they find ways to make the real-world connections of the data visible—to produce captivating, memorable, action-inducing stories and experiences. Such arts-based data-visualization practices integrate, yet transcend, disciplinary boundaries through the diverse thinking, knowledge, and methods they require and the broad, disciplinary-crossing, real-world problems they address. In the following section, we outline the DBR model we used to investigate these practices in middle school STEM and art classroom settings.

Design-Based Research

DBR evolved in the 21st century as a method of bridging research and practice. Anderson and Shattuck (2012) defined two primary characteristics of DBR: (1) research situated in a real educational context and (2) focused on the design and testing of an intervention. We

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[5] We simultaneously acknowledge the ways in which many historical art forms have also functioned as data visualizations, as in the case of Hmong story cloths, ancient Assyrian relief sculptures, and ancient Egyptian papyrus maps.

employed this approach to understand how data visualization STEAM curriculum might function within middle-school STEM and art/media-arts contexts and, in so doing, developed broader insights into the opportunities and challenges of transdisciplinary learning in K-12 schooling. In engaging in DBR, we utilized a mixed-methods, qualitative-dominant design.

Setting and Participants

This research project took place in two suburban middle schools located within the same school district in the southeastern U.S. Across the two schools, three members of our research team worked with students in three eighth-grade classes. One classroom teacher at each site served as a facilitator. In School A, we worked with one STEM class, with 16 participating students, and, in School B, we worked with two art classes,[6] with 16 participating students in Class 1 and 20 participating students in Class 2. The school demographics were fairly similar in terms of race/ethnic composition and socioeconomic status. The schools' student bodies predominantly identified as White (School A: 60%; School B: 78%), Black (School A: 23%; School B: 6%), and Hispanic/Latinx (School A: 14%; School B: 12%), with less than 5% of students identifying as "other." Students qualifying for free or reduced lunch represented 32% (School A) and 11% (School B) of the respective student populations. See Table 1 for additional contextual information. These schools were selected because of their similar student demographics, shared school district, and the respective presence of STEM classes and art/media-arts classes.

Data Collection

To address the research questions, we utilized multiple data collection methods, to include student questionnaires, observations, reviews of student assessments, pre- and post-drawing exercises, and group interviews. Student questionnaires included daily exit tickets and a post questionnaire. Exit tickets asked students to self-rate their class experience related to enjoyment, thinking, effort, and attention on a five-point scale. Student retrospective post questionnaires asked students to rate their agreement with various statements, like "I know how to read a data visualization," and "I think being able to read a data visualization is important to my future." These items assessed students' perceived ability to read, create, and use data visualizations and conceptions and valuing of art, STEAM, and data visualization before and after the curriculum.

We also conducted structured and unstructured observations of all class sessions. For the structured observations, we used an adaptation of Frensley et al.'s (2020) Student Engagement Structured Observation Protocol, where an observer circles student behaviors they observed in three categories (i.e., signs of negative engagement, signs of non-engagement, and signs of

[6] The "art" classes at this school typically blended art and media arts, although our curriculum relied more upon media-arts processes for data-visualization creation in these classes.

positive engagement) and assigns each classroom activity (e.g. class discussion, group work, and student presentations) an observed student-engagement rating on a five-point scale. Moreover, one researcher took general field notes of classroom occurrences.

Throughout the class sessions, we reviewed major student assessments, to include students' data visualizations and artist statements, to analyze the student learning that occurred. Before and after the curricula, we administered drawing prompts asking students to draw and caption their understandings of data visualization. These drawing exercises allowed us to explore students' potentially evolving conceptions of data visualization.

At the conclusion of the curricula, we conducted student post group interviews asking students, in groups of three to five, to discuss their data-visualization projects and process. We also conducted a post teacher group interview asking both teachers to reflect on the curriculum's successes and challenges. See Table 2 for the information about research question and data collection method alignment.

Table 1

Participant, Research-Site, and Curriculum Information

	STEM Class	Art/Media-Arts Class 1	Art/Media-Arts Class 2
Number of Student Participants	16	16	20
Number of Class Periods	15	13	13
Curriculum Themes	Water Quality	Community	Storytelling
Data Topics	Various local water quality issues (e.g., mercury, nitrates, turbidity, e coli)	Social and ecological issues, with an emphasis on issue relevant locally	Social and ecological issues, with an emphasis on issue relevant locally
Group Configurations for Major Data Visualization Project	Groups of two to three students	Individual, plus one whole-class visualization	Mostly individual but with some students working in pairs
Media	Traditional art media and techniques (e.g., papier-mâché, collage) and found object sculpture	Digital collage (and multimedia for the whole-class visualization)	Digital collage

Table 2

Research-Question and Data-Collection-Method Alignment

Research Question Summary	Student Questionnaires	Structured Classroom Observation	Unstructured Classroom Observation	Student Assessments	Pre and Post Drawing Prompts	Student Post Group Interviews	Teacher Post Group Interview
Opportunities and challenges	X		X	X	X	X	
a. Student engagement	X	X	x	X		x	
b. Teacher perceptions of opportunities and challenges							X

Note. X = Primary data collection method; x = Secondary data collection method.

Data Analysis

To analyze the qualitative data, two research team members separately coded the data using an initial and focused coding (Charmaz, 2006) and engaged in memoing before meeting to compare findings. During the initial coding, both researchers used line-by-line coding to code transcribed interview data and open-ended questionnaire comments and incident-by-incident coding to code field notes. They coded students' data visualizations with the corresponding artist statements and drawing exercises with the corresponding captions using a line-by-line coding of the text and then a semiotic analysis (Manning & Cullum-Swan, 1994) of the interconnected imagery. All quantitative data were tabulated and translated using descriptive statistics. Last, qualitative and quantitative findings were integrated. In the following section, we describe the findings associated with our primary research question and sub-questions.

Findings

Across all three classes, we found the majority of students broadened their conceptualization of data visualization to include arts-based approaches and were able to create socially and ecologically engaged, arts-based data visualizations by the end of the instructional unit. In small groups, STEM students tested local water sources and created arts-based data visualizations from larger, pre-existing local data sets about specific local water quality issues, like high mercury levels. Their visualizations were diverse, with the final works varying by size, media, and data-visualization approach (for one example, see Figure 1). In the art classes, students explored social and ecological topics of interest to them and created digital collages visualizing local data related to these topics, to include air and water quality, animal adoption rates, and access to sports participation by income level (for one example, see Figure 2). Following these individual data visualizations, Art/Media-Arts Class 1 created a data visualization installation as a class with images and video to visualize the local water quality and fish population data sets. To inform and inspire their work, all three classes examined professional arts-based data visualizations, worked with complex datasets with multiple variables, and engaged in artistic planning. Additionally, all students wrote artist statements describing and reflecting upon their arts-based data visualizations.

Figure 1. A STEM student group's data visualization of local freshwater plastic pollution with plastic color corresponding to the plastic-waste type present in East Tennessee rivers.

Figure 2. An art student's data visualization of local animal shelter data.

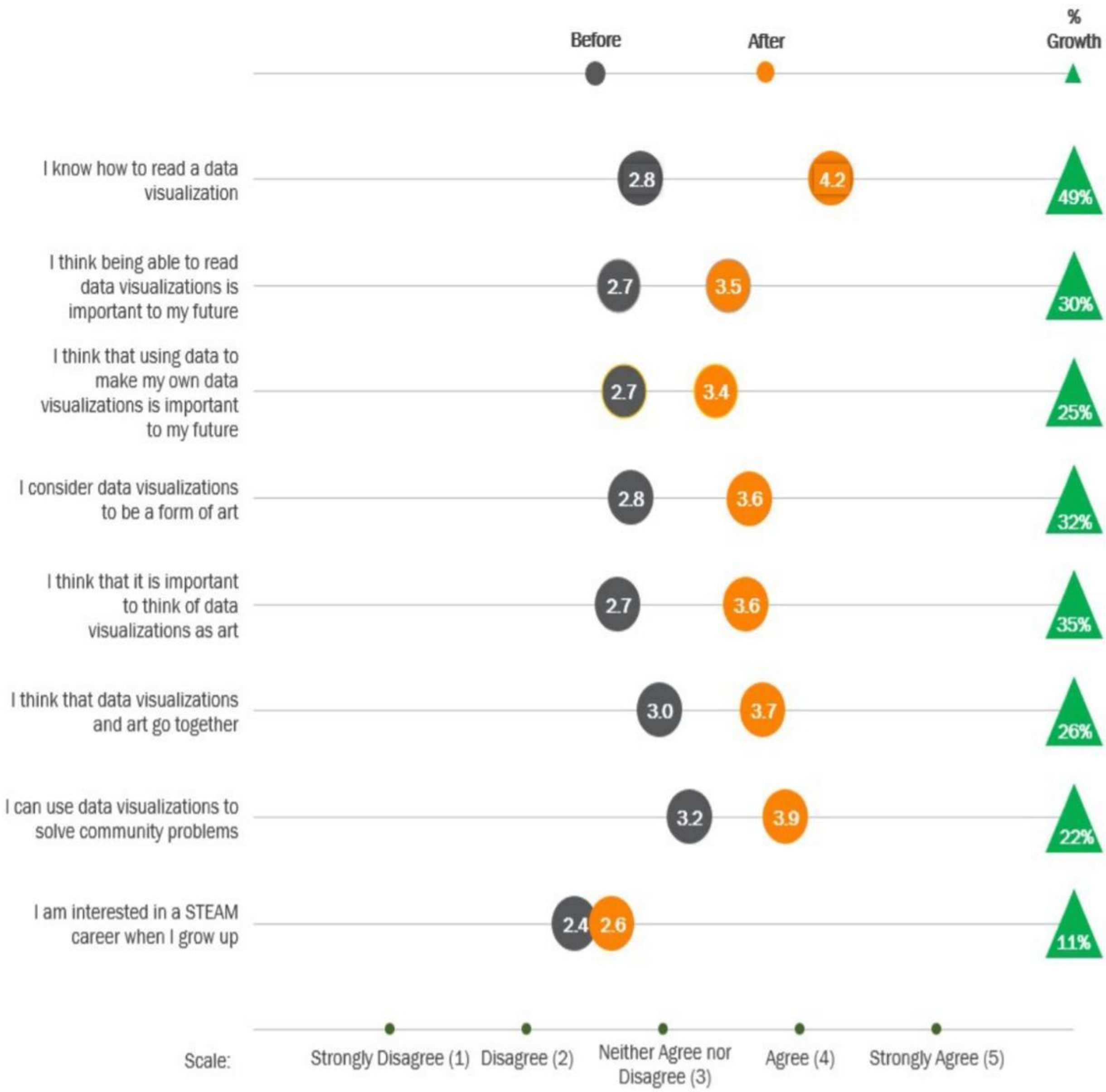

Figure 3. Student responses to post retrospective questionnaire items (n = 70).

Table 3

Supporting Evidence of Opportunities and Challenges

Opportunities	Summary of Supporting Data
Expanded conceptions of data visualization	While students' pre drawings of data visualization primarily referenced graphs or technology, students post drawings almost all included art, images, or objects or referenced divergent approaches. Additionally, students' post questionnaire responses to three items indicated students had broadened their ideas about data visualization to include art (n = 70, M = 3.6 ["important to think of data visualizations as art"], 3.6 ["consider data visualizations to be a form of art"], and 3.7 ["data visualizations and art go together"]), as compared to their "before" rating (M = 2.7, 2.8, and 3.0 in the same order).
Perceived ability to read and create data visualizations	After the curriculum, students rated they "know how to read" data visualizations (n = 70, M = 4.2), as compared to their "before" rating (M = 2.8). Observational data, interviews, and reviews of student assessments supported this self-reported data. Early in the curriculum, many students reported not having been asked to make sense of medium- to large-sized data sets in their previous education and demonstrated a need for instructional supports to aid them in doing so.
Perceived ability to use data visualizations to solve community problems	On the post questionnaire, students agreed they could "use data visualizations to solve community problems" (n = 70, M = 3.9), an increase from their "before" rating (M = 3.2). Additionally, during the interviews and in some artist statements, students often discussed their personal connections to and relevance of the community issues they addressed in their works.

Primary Challenge	Associated Challenges	Summary of Supporting Data
Time	Identification of trends and patterns in the data sets	In post interviews, both teachers expressed students' limited prior experience with reading data sets. In class, students needed time to ask questions and work through the data, including one student that reported she worked for two class periods to understand the data set.
	Selection of effective/divergent symbols	Students explored and discussed layers of meaning more deeply when they had ample time to engage with the material but struggled to select effective symbols when time was more limited.

Table 4

Student Engagement Data from Exit Tickets and Structured Observations (1 = low, 5 = high)

		Enjoyment[a]	Thinking[a]	Effort[a]	Attention[a]	All[b]	Observed[c]
STEM Class	*M*	4.28	4.27	4.43	4.57	4.39	4.63
	SD	(0.48)	(0.34)	(0.29)	(0.25)	(0.07)	(0.55)
Art/Media-Arts Class 1	*M*	3.5	3.52	3.67	3.9	3.65	4.5
	SD	(0.23)	(0.27)	(0.30)	(0.35)	(0.02)	(0.65)
Art/Media-Arts Class 2	*M*	3.18	3.26	3.55	3.91	3.47	4.83
	SD	(0.43)	(0.30)	(0.39)	(0.16)	(0.06)	(0.29)

Note. [a]*Exit ticket dimension (n = 912);* [b]*Combined exit ticket dimensions;* [c]*Combined structured observation dimensions.*

Opportunities and Challenges

In analyzing student data, we identified a number of opportunities and challenges associated with implementing a data visualization curriculum in STEM and art contexts. Opportunities included students' expanded conceptions of data visualization; ability to read and create data visualizations, particularly arts-based data visualizations; and perceived ability to use data visualization to solve community problems (see Figure 3 and Table 3). Primary challenges related to class time, as many of these tasks were relatively new for students. In particular, students needed additional time and instruction to identify trends and patterns in these data sets and select effective symbols. For the purposes of this article, we will focus on the opportunities and challenges most relevant to transdisciplinary learning and its relationship to the arts. Our initial sub-research questions related to student engagement and teacher perceptions were instrumental in exploring this relationship.

Student Engagement

All three forms of student engagement—cognitive, affective, and behavioral—were self-reported through exit tickets. Additionally, we observed behavioral engagement through structured observations, and assessed cognitive engagement through reviews of student assessments. While we found the student-engagement behaviors we observed were moderate to high (observed score: M = 4.63 [STEM] and 4.83 [art]), students' self-reported engagement on the four dimensions was slightly lower in STEM (mean scores of 4.27 to 4.57), and notably lower in art, although still in the moderate to moderately high range (mean scores of 3.18 to 3.91; see Table 4). Reviews of students' assessments, including data visualizations and artist statements, suggest fairly high levels of cognitive engagement across all three classes. Thus, we conclude students' participation was moderately high; exit tickets show they expended effort (with mean scores of 3.55 to 4.43) and attention (with mean scores of 3.9 to 4.57).

While STEM students demonstrated increasing excitement about the project in class, based upon general observations and exit tickets, art students' enthusiasm was less pronounced. Additionally, STEM students' self-reported engagement clearly increased over the course of the STEM curriculum whereas art students' self-reported engagement showed a less consistent upward trend. Early in the STEM unit, three of the seven groups did not complete all the planning sketches initially and wrote comments like "How are we going to represent our findings in art?" and "Why do artists' graphs have to be abstract?" However, as the learning segment progressed, we observed students collaborating to create their visualization using media, such as papier-mâché, fabric, and recycled materials, and found students writing comments like "I'm so glad I switched out of [a different class]" and "Today was probably the most fun" on exit tickets. While some art students clearly connected with the data and enjoyed creating data visualizations, other students failed to see data visualization's relevance to art education or simply preferred typical art education. In person and on sketchbook assignments, we encountered questions like, "Why are we doing this in art?" and "Why are we using our time in art for this?" These different responses may be a result of curricular variations between STEM and art and school-year timing, as the art curriculum occurred a month later in the spring semester. However, they may also point to differences in how transdisciplinary learning involving the arts is perceived by students in art and non-art contexts.

Students' differing affective responses to content and practices outside their class discipline are worth examining from a lens of disciplinary hegemony. While STEM students displayed some early trepidation about engaging in artmaking, especially those who had not taken art recently, they were generally eager to engage in those practices when the time came and increasingly enthusiastic. In contrast, art students verbally demonstrated more resistance to tasks they perceived as outside the realm of their disciplinary class context. These differences might have been further pronounced because STEM students were engaging in more hands-on "art" practices, mostly involving three-dimensional art, whereas art students were creating digital art. Within these contexts, such responses are understandable given the limited opportunities students have to engage in arts instruction in formal schooling, including the schools with which we worked, and students' widely-recognized, general enjoyment of creative artmaking (Dineen & Niu, 2008; Gardiner et al, 1996).

Both schools' student populations had limited annual art exposure—60% annual enrollment at School A and 83% annual enrollment at School B. While the majority of the students at these schools were able to participate in one visual art or media arts course annually, these courses only lasted nine weeks.[7] As art students at School B were only able to enroll in up to one art/media-arts course for one quarter of the school year, they might have perceived their time in this subject as more precious and worth protecting. With only 42% of U.S. eighth-grade students participating in a visual art course annually (U.S. Department of Education et al., 2016), art students' resistance to knowledge domains they perceive as infringing on their already restricted arts experiences could be expected across these contexts.

Teacher Perceptions

Teacher perceptions also differed somewhat between STEM and art. Throughout the teacher post group interview, the STEM teacher articulated successes, such as student interest and curiosity, student appreciation of active learning opportunities, student enjoyment of artmaking, and the high levels of student cognition evident in student presentations. Throughout the interview, he used terms like "genuine interest," "genuine curiosity," and "100% student involvement" to describe student responses to the curriculum; "impressive" to describe student products and

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[7] Art/media-arts classes at School B met for nine-weeks, and School A's art classes met the equivalent of a nine weeks (meeting every other school day for one semester). While limited in availability, School A had advanced art courses that met longer—for the equivalent of one semester (meeting every other day for the entire school year).

presentations; and "big success" to describe the learning segment overall. While the art teacher identified some strengths, such as students' exposure to contemporary artists, a successful whole-class installation with Class 1, some students' personal connections to the data, and one student's "powerful" symbolism, she expressed concerns the curriculum was too challenging, particularly in relation to students reading data sets and identifying divergent symbols. She described her students as being in a developmental stage where they are "very literal" and labeled this literal thinking as a "big roadblock" to their "tak[ing] a data set and creat[ing] something that is symbolic." Repeating the phrase "it is a developmental thing," she positioned the curriculum as developmentally inappropriate.

Though the teachers' accounts initially seemed dissimilar, with the STEM teacher presenting a glowing account and the art teacher expressing more hesitation, when asked about any future data visualization curriculum plans, both teachers described downscaled, disciplined approaches—more graphical data visualizations in STEM and engagement with single statistics to produce data-inspired art (i.e., art inspired by data but not necessarily tethered to it) in art/media-arts. Specifically, the STEM teacher mentioned engaging students in representing the results of their structural engineering competitions through "traditional" charts, like "bar graphs," and the art teacher described how students might explore single statistics on topics of personal interest to them, like attention-deficit/hyperactivity disorder (ADHD), and then create "propaganda posters." She explained how such engagement with data would be simplified:

> If . . . the students are interested in ADHD data, taking one piece of data. I don't know what it is, if it's a year, if it's like knowledge about ADHD through years or whatever, but they're simplifying it so that they're only looking at one string of data, not 15 categories over 15 years.

This teacher's reluctance to engage with more complex data seemed to reflect her earlier assessment that it was developmentally inappropriate, but this stance also aligned with a more disciplined perspective where non-disciplinary knowledge and practices are typically minimized. Both teachers' ideas for future curriculum did not include arts-based data visualization, either by remaining tied to conventional graphical displays, as with the STEM teacher, or bypassing direct relationships between visual imagery and data, as with the art teacher's interest in data-inspired art over data visualization. Additionally, the STEM example, while making real-world applications, bypassed social and ecological engagement; his engineering competitions related to structural factors like how much weight a model building can physically support while appearing to disregard the human and more-than-human issues that can critically intersect with built environment design.

Such abridged, disciplinary responses might imply these teachers could use training and additional resources to implement such transdisciplinary curriculum effectively. Some pre-existing research supports this tendency; Matuk et al. (2022) found that without special support, teachers tasked with designing cross-domain, "data-art inquiry" (p. 1161) curricula defaulted to disciplinary siloed approaches. In our study, another explanation could be that the curricula were too ambitious to be implemented at current teacher/student ratios. Both teachers mentioned teacher/student ratios as a limiting factor. However, when coupled with the student data, these statements might equally raise questions about the ways in which transdisciplinary inquiry, when integrated into disciplined classes might meet with some resistance. We contend resistance may be particularly pronounced in arts classes, where this inquiry requires involvement in activities traditionally associated with other disciplines that inescapably minimize artmaking time. In such cases, transdisciplinary learning can feel like an "add-on" (Jamil et al., 2018, p. 415), particularly when its contribution to contemporary artistic processes, as with the case of data visualization, may not be understood by art teachers and students fully. In the next section, we explore some modes by which school structures might be adapted to support such transdisciplinary inquiry.

Proposed Models for Transdisciplinary Inquiry in Schooling

This study, in addressing the primary research question "What opportunities and challenges for learning does arts-based data visualization provide Grade 4-8 students?," joins a growing number of studies (e.g. Bertrand & Namukasa, 2020; Gates, 2017; Wilson et al., 2021) in highlighting the value of transdisciplinary curriculum models that incorporate the arts for fostering K-12 students' learning. Reviews of student assessments and student group interviews demonstrated students, through their participation in this STEAM curriculum, were able to analyze, interpret, and create socially and ecologically engaged arts-based data visualizations. They had begun to develop important skills for life in the twenty-first century, an era increasingly defined by Big Data and the existence of large, complex, boundary-surpassing social and ecological problems. However, the findings associated with this study's sub-research questions, related to student engagement and teacher perceptions, also raise some important questions. Which classroom contexts are most conducive to such inquiry? And, which contexts and conditions will avoid reinforcing the disciplinary hegemony that marginalizes the arts, a crucial, yet increasingly underappreciated (Aróstegui, 2019), system of inquiry and knowledge needed for navigating life in the twenty-first century?

Given the value of transdisciplinary inquiry and widely acknowledged (e.g., Herro et al., 2019) need for sufficient time to engage in these practices, K-12 school structures might be adapted to better accommodate them. While some schools already offer "STEAM" courses and these course offerings might be increased, this single-course-based approach still presents some challenges due to the disciplinary hegemony that has shaped current school structures. First, as STEAM courses are taught more often by teachers certified in science or mathematics, STEM/STEAM teachers' wide-scale embrace of high-quality, arts-based practices is uncertain (Quigley & Herro, 2016). Additionally, given that many students have minimal access to arts instruction in formal schooling, a semester-long STEAM course, even if adopting arts-based practices and offered on a yearly basis, seems insufficient to surmount this disparity. To fully support arts-based transdisciplinary education, more large-scale transformations of school structures would be required.

Innovative higher education approaches to transdisciplinary education offer one source of inspiration for revisioning such structures. Aalto University's University-Wide Art Studies (UWAS) program offered one such model. From 2016 to 2022, Aalto University developed a series of diverse transdisciplinary courses that centered arts-based processes and practices, addressing topics at the intersection of creativity and culture (Aalto University, 2022; Tavin, et al., 2018). For instance, their course Design for the Posthuman Era explored "different ideas of the role of humanity in environmental and socio-technical spheres" and engaged students in "designing posthuman technological systems" (Aalto University, 2022, para. 5), and 3D Prototyping in Context of Creative Practice tasked students with studying artists' use of novel materials and technologies to make their visions tangible (Aalto University, 2022). UWAS courses were oriented in a variety of ways, to include orientations around transdisciplinary themes, like the Anthropocene; art and design practices, like game design, that link to other fields; historical and paradigmatic tensions, like colonial and decolonial thinking; modes of communication, like material interaction or virtual-world production; and projects that intersect with contemporary topics and issues, like service applications of emerging technologies. Other universities have also experimented with transdisciplinary departments and coursework; the Hasso Plattner Institute of Design at Stanford, or "d.school," offers a range of transdisciplinary courses, most of which center design thinking, to include Needfinding for Activists, Design for Play, and Inventing the Future (Stanford d.school, 2023). These various formulations demonstrate the range of transdisciplinary coursework that might be possible in K-12 schools, particularly at secondary levels, with modifications for K-12 learners, and potential anchoring points that might be considered.

In K-12 schools, data visualization, or arts-based data visualization, could represent one such course, or set of courses, opening up space for such transdisciplinarity. These courses would be designed to supplement rather than supplant existing arts offerings. Thus, they would provide students with additional opportunities for arts engagement in schools while circumventing the often deeply rooted expectations for disciplinary study associated with courses defined by field. While we have seen middle and high schools offer a smattering of courses in fields that seem ripe for transdisciplinary inquiry, like "Video Gaming" (Greenville County Schools, 2022, p. 4), we are calling for varied, widespread course offerings that center inquiry and deep thematic engagement, much as Aalto University's UWAS program and Stanford's d.school have offered.

Until such transdisciplinary courses that make critical space for the arts are widespread at K-12 levels, disciplined classroom contexts will, by default, remain the primary sites in which transdisciplinary inquiry might occur in schools. In such cases, widespread professional development for administrators and teachers will be needed to loosen the current excessive disciplinary curriculum structuring and instill the value of the arts for these forms of learning. We recommend any such professional learning target collectives—school districts and schools, or, at minimum, multi-disciplinary teams of teachers from the same school sites. A collaborative stance to professional learning seems most conducive for fostering the necessary cultures of creative practice and transdisciplinary engagement. Moreover, such cultures may be the most capable of nurturing the sense of "trust and reciprocity" (Davison et al., 2011, p. 3) needed, particularly, for arts teachers and students to commit to such curricular approaches amidst the continued presence of disciplinary compartmentalization and marginalization. As arts teachers and students understand that other (non-art) teachers are integrating transdisciplinary inquiry in their classrooms, increasing the likelihood that arts knowledge, forms of inquiry, and practices will extend beyond the confines of arts classroom, they may develop an increased commitment to transdisciplinary approaches.

Conclusion

The value of arts-oriented, transdisciplinary learning has been established in previous studies, and this study bolsters these findings. Expressly, this study demonstrates that, through data-visualization-oriented, STEAM curricula, students can broaden conceptions of data visualization, to include arts-based approaches; develop and strengthen data visualization practices; and increase confidence in their use of data visualization for addressing community issues. Accordingly, this research aligns with other studies related to data science and the arts that have found young people can use arts-based practices to make sense of and story data (Bhargava et al., 2016; Matuk et al, 2022); develop increased comfort with data (Bhargava et al., 2016; Stornaiuolo, 2020); and engage with data in ways that address community issues and work toward social change (Bhargava et al., 2016; Matuk et al, 2022).

In lieu of this burgeoning body of research, critical research questions in this field might begin to shift from whether these forms of inquiry are effective to how best to sustain such work. We reason discipline-based school structures and cultures will need to adapt to center, rather than complicate and "other" these currently precarious boundary-transcending ways of learning and doing. Given the magnitude of the obstacles for transdisciplinary inquiry and the role that systems play in producing disciplined educational cultures, systemic responses are needed to "de-silo" curriculum (Hannon et al., 2018, p. 1432) and open third spaces for transdisciplinary engagement (Costantino, 2018). In the process, academic identities, currently located within disciplines, will need to be reformed and defined (Hannon et al., 2018) more in relation to issues relevant to students and communities and through methods compatible with the embodied nature of learning. New academic identities might be centered around critical, complex, and "real-world" problems, questions, themes, tensions, and practices, while embracing the power of art and design for grappling with and responding to these topics. As arts-based data visualization represents one such practice, it might serve as an exemplar of the curricular possibilities associated with such educational re-imaginings and critical starting point for any restructuring endeavors. We recommend future research examine the means by which transdisciplinary third spaces, to include those oriented around arts-based data visualization, might be realized and sustained in diverse educational settings.

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