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Arts-Based Data Visualization Professional Development: Art, Mathematics, and Science Teacher Outcomes

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Abstract

Arts-based data visualizations have been touted for making data and data visualization practices more accessible, engaging, and empowering. Though initial research suggests the potential of such approaches in educational contexts, little research has focused on professional development that might support teachers in developing and implementing such interventions. For this study, we designed and implemented a STEAM, arts-based data visualization professional development program. Our research objective was to understand teachers' conceptions and valuations of art and art education, data visualization, and STEAM, and confidence in teaching data visualization through their

program participation. Employing a design-based research methodology, we found teachers regularly intertwined these concepts and demonstrated positive attitudinal growth, though only moderately emphasizing social and ecological engagement. These findings suggest key program elements, such as visual arts facilitators and multi-disciplinary collaborations, could have played a role in participants' strengthened understandings.

Arts-Based Data Visualization Professional Development: Art, Mathematics, and Science Teacher Outcomes

In the early aughts, diverse data visualization forms emerged that leveraged affect, sensory engagement, and metaphorical ambiguity. For instance, artist Kathryn Clark (2015) mapped foreclosure data on quilts, and design students Mario Klemm and José Ernesto Rodriguez (2017) signified countries' carbon dioxide emissions through a large-scale sculptural installation of red-orange balloons. Such practices have implications for the ways in which audiences interact with and respond to data. Namely, arts-based data visualizations have been touted for making data and data visualization practices more accessible, engaging, and empowering for youth and communities (Bhargava & D'Ignazio, 2017; DesPortes et al., 2022; Woods et al., 2024).

Importantly, these practices are inherently inter- and transdisciplinary and, consequently, in alignment with contemporary art and educational trends. As contemporary art has been intervening for decades in social, political, and economic domains in ways that defy disciplinary framings (Canclini, 2014), the field of art education has embraced these de-siloed, experimental forms of inquiry (Marshall & Donahue, 2014), including data visualization practices in recent years (Graham & Lewis, 2023; Sweeny, 2023; Ward, 2021). Moreover, this transdisciplinary turn is evident in the broader field of education, as transdisciplinary educational movements like science, technology, engineering, and mathematics (STEM) and science, technology, engineering, art, and mathematics (STEAM) education have gained considerable educational momentum broadly and in art education contexts (National Art Education Association, 2022; Rolling, 2016). Notably, STEAM curricula have begun to integrate data science (Liston et al., 2022), including arts-based data visualization practices (Bertling et al., 2024; Bhargava & D'Ignazio, 2017; Taylor et al., 2019). However, such innovative, boundary-crossing curricular endeavors are relatively new and, thus, under-researched.

Existing literature has begun to explore STEAM and data visualization-oriented curricular interventions, with initial research (Bertling et al., 2024; Bhargava & D'Ignazio, 2017; Matuk et al., 2022) suggesting the exciting potential of such approaches. However, with the possible exception of a brief case study of an arts-based data visualization professional development icebreaker activity (Bhargava & D'Ignazio, 2017), no research has focused on professional

development that might support teachers in designing and implementing such interventions. Studies looking specifically at teachers' conceptions, valuations, and other affective orientations towards these data visualization curricular foci are important for the transformation of teaching practices (Fives & Buehl, 2012).

For this design-based research study, we developed and implemented a STEAM, arts-based data visualization professional development program and examined teacher outcomes. Specifically, we sought to understand teachers' conceptions and valuations of relevant topics, like art and art education, data visualization, and STEAM, and confidence in teaching data visualization through their participation in the professional development program. Research questions included:

1. How do *visual arts teachers*, who participated in an arts-based data visualization professional development program, conceptualize and value art and art education, data visualization, and STEAM? (RQ1)
2. How do *math and science teachers,* who participated in an arts-based data visualization professional development program, conceptualize and value art and art education, data visualization, and STEAM? (RQ2)
3. How do teachers, through their participation in an arts-based data visualization professional development program, exhibit confidence in teaching data visualization? (RQ3)

The "A" in STEAM

Over the past two decades, as STEAM education has arisen (Maeda, 2013) and coalesced as a robust pedagogy and educational movement, educational scholars have continued to examine the synergies among S-T-E-A-M content areas (Braund & Reiss, 2019; Costantino, 2018; Liao, 2016). Though some scholars have questioned the depth of learning in specific S-T-E-A-M disciplines (Diego-Mantecon et al., 2021; Mejias et al., 2021; Peppler & Wohlwend, 2018), among the five letters represented in the "STEAM" acronym, the "A" has garnered the most discussion and debate. Despite some consensus surrounding the "A's" linguistic signification as "art," "arts," or "art and design," understandings of the nature of art and design fields' role within STEAM education are mixed. Scholars have emphasized the arts' contribution through creativity (Marín-Marín et al., 2021); design content and processes (Henrikson, 2017); affect, embodiment, and aesthetics (Mun, 2022); and the "signature pedagogies of art and design education" (Costantino, 2018, p. 100).

As STEAM education has translated to practice, one clear critique has involved STEAM education's instrumentalist positionings of specific S-T-E-A-M disciplines, especially of the arts. While these concerns have been expressed in arts education literature since STEAM education's

inception (Graham, 2020; Katz-Buonincontro, 2018), in recent years, STEM education scholars (Colucci-Gray & Burnard, 2020) have also noted the limitations. In practice, this subordination commonly occurs when the arts are used to create an end product but "epistemic practices" (Bevan et al., 2021, p. 457) associated with the arts essentially are neglected, for instance, with the arts not informing inquiry processes. In response, scholars (Colucci-Gray & Burnard, 2020; Costantino, 2018; Mejias et al., 2021) have highlighted the instrumental *and intrinsic* value of the arts and arts education and have called for co-active, multivocal relations between art and STEM. We contend curricula oriented around arts-based data visualization, particularly metaphorically rich practices engaging with data commonly associated with STEM fields, would be likely to exemplify such synergistic relations.

STEAM and Arts-Based Data Visualization Professional Development

A burgeoning body of literature has examined STEAM education professional development and identified some affordances and tensions associated with this programming and teachers' design and implementation of STEAM curriculum following their participation. Outcomes associated with changes in teachers' perceptions and teaching practices have been largely positive. Regarding teacher perceptions, studies have shown teachers' increased self-efficacy for teaching STEAM education (Boice et al., 2021; Romero-Ariza et al., 2021) and understandings of STEAM as a method of teaching content (Herro & Quigley, 2017). Advances in practice include increased incorporation of problem-based curricula with real-world, relevant examples (Quigley & Herro, 2016) and teacher collaborations to support their own learning and curriculum planning (Boice et al., 2021). Yet, as tendencies toward siloed curricula can be ingrained (Herro et al., 2019; Quigley et al., 2020; Quigley & Herro, 2016), Quigley et al. (2020) advocated multidisciplinary collaborations, especially ones that include arts teachers; curriculum oriented around real-world problems; and flexible curriculum and policies to allow adequate time for STEAM education and adequate freedom for inquiry-based learning.

Though a few studies have examined professional development associated with more traditional data visualization practices, as arts-based data visualization is such a nascent practice and its integration into education is so new, no research has explored professional development in this area beyond one case of preliminary research. Bhargava and D'Ignazio's (2017) collective case study briefly described data sculpture practices in a variety of educational contexts, including one professional development context. They illustrated a short ice-breaker activity where teacher participants created data sculptures, or "data physicalizations" (p. 1). Ultimately, they concluded participating teachers were able to engage in data-based storytelling as they made connections between data, narrative, and sculptural processes, which shows promise for future professional development in this area. However, more thorough research will be needed, especially research examining entire programs with arts-based data visualization foci.

Methodology

Within the field of education, design-based research focuses on the iterative design and testing of learning interventions in real-world educational settings (Anderson & Shattuck, 2012; Hjalmarson et al., 2021). In this pilot study, the learning intervention represented the Arts-Based Data Visualization Project's professional development program. We employed a mixed methods research design for complementarity and expansion purposes (Greene, 2007)—to assess the various, complex facets of the phenomena under investigation for better, more comprehensive understanding and to expand the number of phenomena under investigation, including teachers' confidence in teaching data visualization.

Setting and Participants

We piloted the Arts-Based Data Visualization Project's professional development program in East Tennessee, part of the Appalachian region of the United States. The summer institute was held at a high school of a partnering school district in a mid-sized city. The program was open to East Tennessee art, science, mathematics, and STEM/STEAM teachers, who taught at least one grade in the Grade 4-8 range, though, for this pilot, we only recruited within two partnering school districts. We admitted 11 applicants, with 10 elementary and middle-school teachers participating—3 art, 3 science, and 4 mathematics teachers.

The Arts-Based Data Visualization Project

The Arts-Based Data Visualization Project's professional development program centered around a five-day, in-person summer institute. The institute was led by a four-member, multidisciplinary team of teacher facilitators with respective K-12 teaching experience in visual and media arts, mathematics, and science education. Ultimately, this professional development program sought to support teachers in designing and implementing arts-based data visualization curricula. To accomplish this goal, institute activities aimed at exposing teachers to arts-based data visualizations; introducing various critique models that could be applied to arts-based data visualizations; familiarizing teachers with art, STEAM, and data visualization content and practices, including data visual encoding strategies; organizing hands-on opportunities for teachers to create arts-based data visualizations; identifying relevant content-area standards; and offering teachers time, relevant readings, and feedback to support their integration of arts-based data visualization into curricula (see Table 1). Importantly, each day, participants worked in multidisciplinary teams to make sense of a data set related to a social or ecological issue affecting local communities and to visualize one or more aspects of it in response to open-ended prompts. Institute sessions and prompts were designed to engage teachers with increasingly complex art, statistical, and data science concepts and practices.

Table 1

The Arts-Based Data Visualization Project's Summer Institute Components by Day

Professional Development Components	Days				
	Monday	Tuesday	Wednesday	Thursday	Friday
Daily foci	Single statistics, symbol repetition, and data contextualizing practices	Symbol repetition, statistical comparison, and data sensemaking processes	Proportion and storytelling	Multivariate datasets, time variables, data visual encoding strategies, and visual metaphor	Data mapping practices, multimedia visualization, and contemporary creative strategies
Data visualization examples	Chalabi (2022), Firstenberg (2021), Grangeon (2016), K-12 student examples	Frick (2010), Klemm and Rodriguez (2017), K-12 student examples	Madsen (2018), Marsh (2014-2018), Rosenstock (2016), Snell et al. (2016), K-12 student examples	Niittyvirta and Aho (2018), D'Efilippo and Pigelet (2014), Pelto (2020), Specter (2016), K-12 student examples	Aho et al., (2020), Clark (2015), Guzauskas (2018), Lin (2009-2022), Miebach (2019)
Data topics	Local unhoused population data	Regional CO2 emissions data	Participant choice: regional bullying or brownfields sites data	Regional rainfall over time data	Local tree canopy data mapped with a data set of participants' choice
Critique models	Feldman Method (Feldman, 1970)	Data Culture Method (Data Culture Project, 2018)	Reading of Data Visualizations for Mathematics Education (Rubel et al., 2021)	Participant choice	Participant choice

Table 2

Research Question and Data Collection Alignment

Research Question	Data Collection Methods			
	Pre/Post Questionnaire	Fieldnotes	Teacher Assessments	Post Focus Groups
1. How do *visual arts teachers*, who participated in an arts-based data visualization professional learning program, conceptualize and value art and arts education, data visualization, and STEAM?	X	X	X	X
2. How do *mathematics and science teachers* who participated in an arts-based data visualization professional learning program conceptualize and value art and arts education, data visualization, and STEAM?	X	X	X	X
3. How do *teachers*, through their participation in an arts-based data visualization professional learning program, exhibit confidence in teaching data visualization?	X			

Data Collection

In this mixed methods pilot study, we utilized multiple data collection methods (see Table 2). The one quantitative method represented an online pre- and post-questionnaire. This questionnaire included four scales, two of which were existing scales we adapted: Luehrman's (2002) attitudes toward art education and art experiences scale and Kim and Bolger's (2017) adaption of Mahoney's (2010) STEAM conceptualizations and values scale. As there were no existing scales addressing teacher data visualization attitudes and confidence in teaching these concepts to students, we adapted a scale we had previously developed for measuring students' data visualization attitudes and confidence (Bertling et al., 2024). This adapted scale included items like "I can teach my students to read a data visualization," [teacher version], changed from "I can read a data visualization" [student version]. Then, we added these items with the two existing scales. Across these four scales, participants self-reported responses to statements using a Likert scale range of 5 for "strongly agree" or "very confident" to 1 for "strongly disagree" or "no confidence." All ten teacher participants completed this questionnaire pre and post program.

Importantly, this questionnaire's attitude scale items had been drawn from previously validated instruments in existing literature (Kim & Bolger, 2017; Luehrman, 2022; Mahoney, 2010) that determined acceptable/good/adequate levels of internal consistency reliability using a Cronbach's alpha procedure (Lambert & Newman, 2023) and established types of validity. For example, the STEM attitudinal instrument piloted in Mahoney (2010) reported internal reliability coefficients for instrument components with Cronbach's alpha scores above .92 alpha. Concurrent validity with a semantic differential instrument indicated an "overall moderately positive significant relationship" (p. 32) with Pearson product moment correlation ($r = .63$, $p = .000$). Kim and Bolger (2017) modified the instrument in Mahoney to develop a Korean language STEAM survey version that observed internal reliability coefficients for instrument components with Cronbach's alpha scores above .80 alpha. Additionally, scale items included from "part one" of a multi-section questionnaire in Luehrman (2002) reported internal reliability with Cronbach's alpha score of .81 alpha. Since the questionnaire adapted and modified scale items from prior scholarship, we calculated a Cronbach's alpha score for each scale of the questionnaire using IBM SPSS Statistics (Version 28). The initial application of the survey instrument in the present study indicated Cronbach's alpha scores comparable to ratings in established research ("attitudes toward art and art experiences scale," .90 alpha; "data visualization and art attitudes scale," .83 alpha; "STEAM conceptualizations and values scale," .80 alpha; "confidence in teaching data visualization scale," .88 alpha). A panel of educational experts examined the clarity and appropriateness of survey items to establish initial content validity and provide feedback on scale development.

Qualitative data collection methods included field notes, reviews of teacher assessments, and post-focus groups. Two researchers, serving primarily as non-participant observers, observed

summer institute sessions and recorded field notes. As teachers participated in institute sessions, they generated various products that could be assessed for evidence of teachers' conceptions or values related to art, data visualization, and STEAM, including written artist statements, a reflection wall, videoed oral critiques, and final curriculum presentations. Immediately following the summer institute, all ten teacher participants, grouped by discipline, participated in focus groups. These 45-minute to 1-hour, focus groups were audio and video recorded. Focus questions related to teachers' experiences in the program, opportunities and challenges they perceived in integrating arts-based data visualization into curricula, and future plans for arts-based data visualization-integrated curricula. The majority of these questions had been piloted in a previous study (Bertling et al., 2024). Moderators were trained in the use of the semi-structured protocol to ensure consistency, reduce bias, and support conversational interaction (Puchta & Potter, 2004).

Data Analysis

Using a mixed methods component design (Greene, 2007), we kept quantitative and qualitative methods largely separate until we integrated these methods at interpretation and conclusion levels. For the quantitative data, we separated the data for the first three scales by art teachers and mathematics and science teachers. Then, we generated and reported descriptive statistics for art teachers' (RQ1) and mathematics and science teachers' (RQ2) reported degree of agreement with the various conceptual and attitudinal statements related to art, art education, data visualization, and STEAM from these three scales. Next, we generated and reported descriptive statistics for teachers' degree of confidence in teaching data visualization (RQ3) from the fourth scale on the pre- and post-questionnaire.

To analyze qualitative data, we color-coded text related to teachers' art, art education, data visualization, and STEAM conceptions and values. Then, we open-coded this highlighted text using line-by-line coding to describe these conceptions and used pattern coding (Saldaña, 2021) to identify any patterns across art teachers' responses (RQ1) and mathematics and science teachers' responses (RQ2). Throughout data analysis, research team members engaged in memoing and then met to compare findings.

Findings

Art Teachers' Conceptions and Values

Quantitative Findings

Art teachers self-reported an overall positive conceptualization and valuation of art and art education, data visualization, and STEAM in both the pre- and post-questionnaire results (see Table 3). In pre-questionnaire responses, art teachers indicated "agree" to "strongly agree," or the equivalent for reverse-coded items, for 88% of items across the three scales: STEAM

conceptualizations and values (M = 3.9 on a scale from 1 = "strongly disagree" to 5 = "strongly agree," SD = 0.8), data visualization and art attitudes (M = 4.4 on a scale from 1 = "strongly disagree" to 5 = "strongly agree," SD = 0.5), and attitudes toward art education and art experiences (M = 4.8 on a scale from 1 = "strongly disagree" to 5 = "strongly agree," SD = 0.6). These initial responses revealed that art teachers generally valued the importance of data visualization, art, and art education.

Post-questionnaire responses tended to maintain or strengthen answers, with 38% mean item scores identical between pre- and post-responses and 56% of mean item scores increasing. Data visualization and art attitudes (M = 4.9, SD = 0.3) and STEAM conceptualizations and values (M = 4.6, SD = 0.6) scales observed the greatest shifts in teacher attitudes with questionnaire items, such as "I think that it's important to teach my students about data visualizations" (pre: M = 4.0, SD = 0; post: M = 5.0, SD = 0), "STEAM is not a vital part of my lesson plan" (pre: M = 2.3, SD = 0.6; post: M = 4.0, SD = 1.0 [reverse-coded]), and "I intend to further develop my abilities in STEAM" (pre: M = 3.3, SD = 1.2; post: M = 4.7, SD = 0.6). Art teachers also maintained their responses to attitudes toward art education and art experiences throughout (M = 4.8, SD = 0.5), indicating their overall valuing of these domains in schooling.

Table 3

Pre and Post Descriptive Statistics Associated with Teachers' Conceptualization and Values, by Disciplinary Grouping

Scale	Art Teachers						Mathematics and Science Teachers					
	Pre			Post			Pre			Post		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Attitudes toward Art Education and Art Experiences[a]	3	4.76	0.57	3	4.80	0.51	6	4.04	0.78	7	4.57	0.96
Data Visualization and Art Attitudes	3	4.42	0.50	3	4.92	0.28	6	3.63	0.84	7	4.73	0.45
STEAM Conceptualizations and Values[b]	3	3.85	0.82	3	4.59	0.57	6	4.54	0.75	7	4.92	0.27

[a]Luehrmann's (2002) modified scale. [b]Kim and Bolger's (2017) modified scale.

Qualitative Findings

From our qualitative data analysis, we found art teachers regularly intertwined conceptions of art and art education, data visualization, and, indirectly, STEAM education. Notably, art and data visualization were equated to such a degree they were difficult to discern. Though art educators made no mention of "STEAM education" in focus groups, we somewhat understood these conceptions to be implied in their discussions of the inter- and transdisciplinary engagement associated with art, data visualization, and art education practices. However, this absence of explicit references to STEAM education is worth noting as it could reflect a lower commitment to this form of transdisciplinary education.

Art and art education. Melding notions of art and art education, art teachers tended to adopt a view of these concepts that emphasized creative, real-world, transdisciplinary engagement. As one art teacher articulated, "artwork can also have roots in very tangible things, not just this super heady abstract world that I think a lot of students get frustrated by. . . ." Corresponding with this transdisciplinary notion of art, they approached art education as engaging with big, transdisciplinary ideas and essential questions. Moreover, as art teachers often equated art to data visualization, many of the data visualization conceptions described below could be seen as applying to their conceptions of art and art education.

Data visualization. Art teachers positioned data visualization in ways that emphasized the communicative potential and reach of these practices. Specifically, they described data visualization as (1) timely, (2) de-siloed and aligning with art, (3) capable of promoting student ownership and voice, and (4) powerful but potentially misleading and requiring critical thinking on the part of viewers. First, art teachers articulated the relevance and power of data visualization "in our wider culture." As one participant said, "it is super important." Accordingly, they stressed the importance of data visualization in schooling, with comments like "I don't think it is being explicitly taught in schools enough so I think that it is extremely important," and expressed concerns about curriculum without such practices:

> I think if a student goes through their whole K-12 without doing this, I do think that's an issue. I don't think it would have been an issue ten years ago, but I do think it's an issue now. It's like if you don't learn that, you're going to not know how to interpret that part of our life.

As art teachers located data visualization practices as integral to contemporary life, they also sited them as art. One teacher explained this broad, inclusive definition of data visualization: "Data visualization is in everything. It all depends on how you define data. I think you can look at any piece of art and say, 'There's a data point. There's a data point. . . .'" Moreover, art teachers saw this positioning of data visualization as art as aligning data visualization with art education and providing opportunities to integrate or transcend disciplinary bounds. At

various points, they expressed enthusiasm for this integration, with comments like "I think it's going to be a staple of my curriculum now for the rest of my life." Likewise, they expressed plans to design inter- or transdisciplinary curricula in ways that seemed to align with STEAM or arts-integrated mathematics or science curriculum: "I also think this is a great opportunity to connect arts with math."

In conceiving data visualization practices, art teachers often emphasized personally relevant practices and accentuated student ownership and voice. For instance, one art teacher explained her data visualization curriculum plans to encourage students to identify "what their unique position affords them access to so whether that's something about their own habits, their commute to school, their journaling, or coding a conversation they have with someone. . . ." She planned to ask students, "What data are you uniquely situated to collect or record?" and "get them to generate things they care about." Other art teachers expressed similar student ownership aims: ". . . giving them that ownership over their own data and seeing that data can be personal and not just sterile and far away and that they can use that as a way to create." However, as art teachers expressed these curricular aims and fledgling ideas, the extent to which this emphasis on personally relevant data might support students' STEAM learning was unclear.

Last, art teachers seemed to adopt aspects of critical data literacy in communicating the power of data visualization practices, not only for youth empowerment but also for miscommunication and abuse. As one teacher claimed, "Data visualizations can skew so much one way or the other. There is so much power in the way that you visualize any given data set," and another teacher labeled a specific data visualization as "so sneaky." Teachers often coupled these recognitions of data visualizations' power and potential with discussions of the opportunities that data visualizations present for cultivating students' critical thinking. As one teacher said, "We got to get those critical thinking skills in there." Data visualization was comprehended as an important site for critical student learning and another avenue for youth empowerment.

Mathematics and Science Teachers' Conceptions and Values

Quantitative Findings

Similar to art teachers, math and science teachers self-reported comparable positive conceptualization and valuation responses in both the pre- and post-questionnaire results (see Table 3). Pre-questionnaire answers indicated "agree" to "strongly agree," or their equivalent for reverse-worded items, for 66% of items across the three scales: STEAM conceptualizations and values ($M = 4.5$ on a scale from 1 = "strongly disagree" to 5 = "strongly agree," $SD = 0.7$), data visualization and art attitudes ($M = 3.6$ on a scale from 1 = "strongly disagree" to 5 = "strongly agree," $SD = 0.8$), and attitudes toward art education and

art experiences (M = 4.0 on a scale from 1 = "strongly disagree" to 5 = "strongly agree," SD = 0.8). These initial responses indicated that math and science teachers generally valued the importance of STEAM and expressed somewhat neutral to moderately positive attitudes toward data visualizations and art and art education prior to their program participation.

Post-questionnaire responses primarily reported a positive increase in answers in all scales with the largest increases occurring in data visualizations and art attitudes (M = 4.7, SD = 0.4) and attitudes toward art education and art experiences (M = 4.6, SD = 1.0). These scales revealed the greatest shifts in teacher attitude with questionnaire items, including "I think that it is important to think of data visualizations as art" (pre: M = 3.2, SD = 0.8, post: M = 4.9, $SD:$ = 0.4), "I can use data visualization in my classes to solve community problems" (pre: M = 3.2, SD = 0.8, post: M = 4.4, SD = 0.5), and "Teaching art is less demanding than teaching other subjects" (pre: M = 3.8, SD = 1.0; post: M = 4.9, SD = 0.4 [reverse-coded]). Notably, mathematics and science teachers fully agreed art education "can provide a central connection for integrating learning in all subjects" (M = 5.0, SD = 0), "teaches critical thinking skills" (M = 5.0, SD = 0), and develops "skills" essential for "literacy" (M = 5.0, SD = 0).

Qualitative Findings

In the qualitative data sources, mathematics and science teachers, like art teachers, discussed art and art education, data visualization, and STEAM such that these concepts were often indistinguishable. However, unlike art educators, mathematics and science teachers openly addressed their notions of STEAM, including ways these conceptions evolved through their participation in the institute. Additionally, the nature of these conceptions differed from those of the art teachers in some respects.

Art and art education. Teachers' notions of art, art education, and arts-based data visualization were so intertwined that findings associated with their art and art education conceptions could also apply to their understandings of arts-based data visualization. From our analysis, we found that mathematics and science teachers seemed to perceive these art fields and practices as (1) creative and experiential and (2) generally motivating and fun, but potentially intimidating and challenging for certain students. In these discussions, mathematics and science teachers seemed to establish dichotomies between "artistic" and "math-minded" people. However, in many cases, they also framed these dichotomies as surmountable for themselves and their students and worth making the effort to overcome.

First, mathematics and science teachers emphasized the experiential, creative aspects of art production. Teachers positioned these processes as somewhat different from their standard assessment practices but potentially more affective and memorable. As one teacher articulated:

> But with it being a project and something that they're creating, that's going to stick. They might not remember all the other things on the test but if this is an assessment of what they create, they're going to remember all the other things on the test.. . . They're going to remember the story that they told, and they're also going to remember the story that the class created together because we are doing it.

Teachers positioned art as capable of "build[ing] enthusiasm" for mathematics content that could otherwise receive "unenthusiastic" responses from students. Additionally, they described art as appealing to "artsy kids." Likewise, they repeatedly announced their own "excitement" for integrating art into their curricula and the "fun" they anticipated in revising existing instructional methods, to include three-dimensional art production.

Yet, periodically, mathematics and science teachers also identified affective and cognitive challenges they anticipated. Teachers voiced concerns that students might struggle with "creative freedom," especially given the COVID-19 pandemic. As one teacher explained, "Because for two years they weren't allowed to be creative because we couldn't touch the same objects. We couldn't be around each other. So I'm hoping that . . . their creativity has not been stifled too much." Additionally, teachers worried about students' self-efficacy for art; they wondered if they might say, "I can't do that. I don't know how to do that. I'm not artistic. . ." Moreover, some teachers saw some students' predilections for dichotomous thinking and discomfort with "ambiguity" as inhibitory:

> The students tend to want to be right.. . . So just getting them away from that thinking process—just almost rewiring their brains to know it's okay to not be right or wrong. . . It's okay to have an opinion.

Despite these concerns, in most cases, teachers framed their discussion of these challenges in somewhat empowering terms—as problems to solve rather than serious barriers. During the focus group, teachers described various plans to mitigate these issues, such as through "low-risk entry level" activities like regular warm-ups where students interpret arts-based data visualizations. They also tended to weigh these concerns with the benefits of such approaches, with statements like "I think allowing their brains to have some freedom makes it pretty cool." As one teacher concluded, "—if it's a challenge and if it's an opportunity—I feel like . . . it's both."

Data visualization. In addition to the conceptions of art and art education that overlapped with ideas of data visualization, we also found mathematics and science teachers conceived of data visualization as inter- or transdisciplinary, local and meaningful, and inspiring critical thinking. As one teacher stated, ". . . art can be connected to data and [that] wasn't at all what I expected so it was awesome." They highlighted how this inter- or transdisciplinary

engagement intersected with lived students' experiences and concerns: "We're constantly told as educators to connect to the real world… and this is a way for us to do that." Likewise, they emphasized local data visualization engagement as especially impactful: "There's a local connection. All of those things make it meaningful to me in a way that I can see is important to do for my students…"

Science teachers, in particular, emphasized the critical thinking associated with data visualization as a powerful learning opportunity that could align with science education. For instance, one teacher identified "critical thinking" as the key opportunity associated with data visualization: "For me, it's the critical thinking pieces that I got to experience firsthand from Day One…", and another teacher expressed, "I could see how much critical thinking went into things we naturally teach in science—observing, analyzing, thinking, wondering—but in a new way." As teachers planned to ask their students questions like, "What if this is just manipulation?" their curriculum aims seemed to align with critical data literacy to some extent.

STEAM. In addition to the conceptions above, which seemed to align with STEAM, mathematics and science teachers explicitly addressed their evolving views of STEAM education, which primarily related to the role of art within STEAM. Teachers talked about how they had seen art integrated into subordinate positions previously, often infused at the end of the process when students were ready to generate a culminating product. However, they shared how this institute had exposed them to new art positionings within STEAM: "… making it a real artistic process" in ways they had not conceived previously. As one teacher said:

> I had never thought to bring art into every step of the process—only as kind of like an end product of the concept itself. So, I think that learning that we can apply that mindset to every part of the process was kind of a big deal.

Teachers' Confidence in Teaching Data Visualization

All content area teachers self-reported growth in confidence with teaching data visualization in the post-questionnaire results (see Figure 1). The confidence in teaching data visualization scale collectively observed gains with all post-questionnaire items. All teachers reported improved confidence in instructing students to "read" data visualizations (pre: $M = 2.9$, $SD = 1.4$; post: $M = 4.5$, $SD = 0.7$) and "use data to make their own data visualizations" (pre: $M = 2.8$, $SD = 1.2$; post: $M = 4.6$, $SD = 0.5$). Gains were especially pronounced with items related to teaching students to use data visualization to address "social problems in my community" (pre: $M = 2.1$, $SD = 1.1$; post: $M = 4.1$, $SD = 0.9$) and "environmental problems in my community" (pre: $M = 2.1$, $SD = 1.1$; post: $M = 4.4$, $SD = 0.7$). Yet, these post-score means associated with social and environmental engagement suggest teachers concluded the institute

with some room for growth in these areas. In summary, teachers initially expressed "a little confidence" in teaching students about data visualizations in their pre-questionnaire responses ($M = 2.5$ on a scale from 1 = "not confident" to 5 = "very confident,", $SD = 1.2$) but were "moderately confident" ($M = 4.4$, $SD = 0.7$) after their participation in the professional development program.

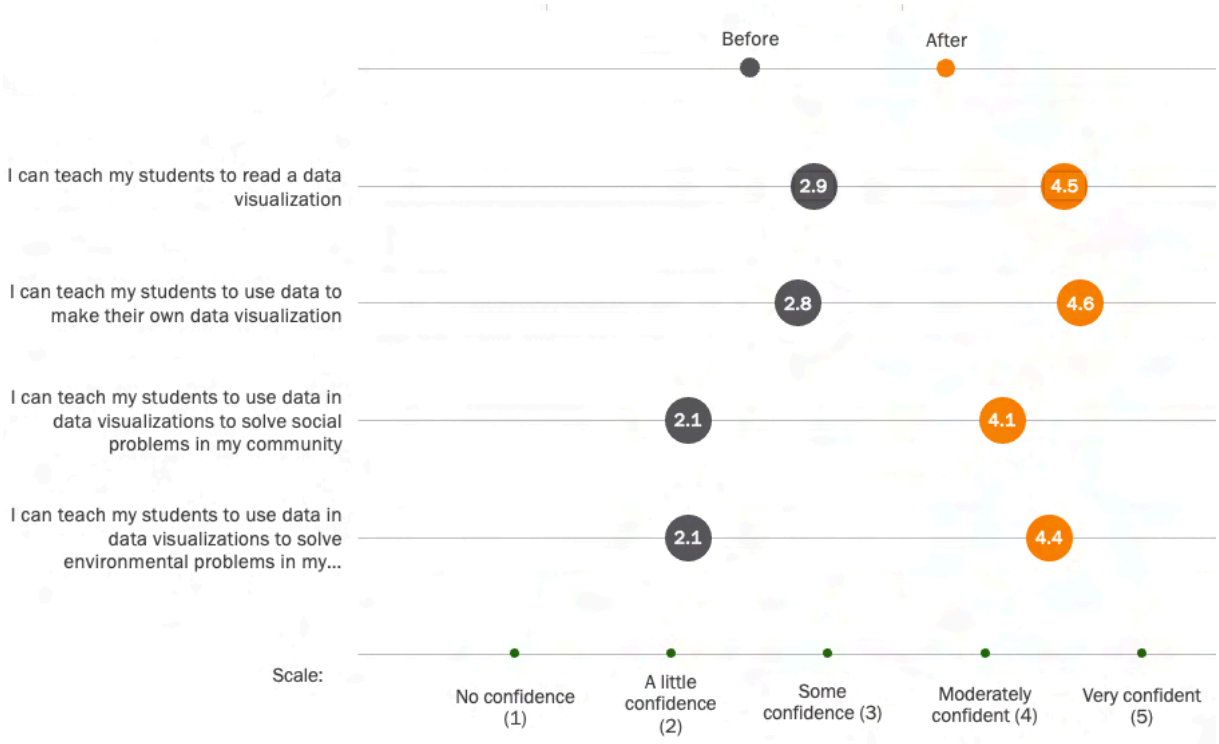

Figure 1. Teachers' Confidence in Teaching Data Visualization.

Discussion

Art teachers and mathematics and science teachers exhibited many commonalities in their conceptions and valuations of art and art education, data visualization, and STEAM after their participation in the program, though with some subtle differences. First, regarding art and art education, both teacher groups exhibited strong positive attitudes, particularly after their participation in the program. As expected, mathematics and science teachers experienced the strongest gains in these areas as they had more potential for growth, given their more moderate pre-questionnaire scores, though after their participation, their responses resembled art teachers' highly positive attitudes.

In conceptualizing art, both teacher sets located art as creative expression and storytelling and compatible with inter- and transdisciplinary inquiry. This conception departs from more

publicly held, individually oriented, somewhat romantic notions of art and art education rooted in 20th-century modern art[1]—conceptions often critiqued by art education scholars (Winner, 2022). As teachers' emergent art conceptions aligned more with contemporary art and art education that center conceptual engagement and divergent inquiries, unframed by disciplinary silos (Marshall & Donahue, 2014), these ideas represent an important foundation for STEAM and data visualization engagements.

Regarding data visualization conceptions, both teacher groups positioned data visualization as compatible with art, with both groups experiencing large gains in their attitudes toward data visualization and art and confidence in teaching data visualization before and after the institute. In post-focus groups, teachers expressed, often enthusiastically, plans for integrating data visualization practices into curricula and articulated how these practices might help achieve various intra-, inter-, and transdisciplinary aims crucial for students' navigation of contemporary civic life. As some studies (Herro & Quigley, 2017; Quigley et al., 2019) have found STEM teachers demonstrating some difficulties with conceptualizing and designing inter- and transdisciplinary curricula that recognize the arts, these teachers' integrated conceptions are noteworthy and worth further investigation into the programmatic features that might have contributed to their development, as discussed at the end of this section. Additionally, teachers explored ways in which arts-based data visualization might empower student voice and ownership of their learning and positively impact student motivation. Yet, as participants made connections between data visualization and art, they sometimes established binaries between individuals who might engage in data visualization. While we found some evidence of both teacher groups acknowledging binaries of "artsy" and "math-minded" students and teachers, the mathematics teachers emphasized these differences more frequently, elaborated more, and were the only group to position these differing proclivities as a challenge. One interpretation of their concerns could relate to unequal disciplinary emphases in schooling that result in students having fewer art education experiences such that teachers might question their art proficiencies and predispositions. However, we tend to attribute these responses to the specific mathematics teachers' own initial misgivings about their art abilities and knowledge, which they explicitly identified, though these teachers also articulated ways they were able to overcome these perceived deficiencies during the institute by collaborating heavily with art teachers. Given this pilot study's small sample size, additional research is needed to examine these perceptions of binary art- and mathematics-teacher and student identities that might influence the ways in which data visualization and STEAM curricula are enacted.

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[1] For instance, emphasizing artists' individual expressions of inner emotional life.

In recognizing data visualization as integrated, timely, and relevant, both groups also understood it as open to miscommunication and misuse. Importantly, they not only emphasized the need for students to exercise critical thinking but also positioned data visualization as a vital site for students to develop these critical data literacy skills. As critical data literacy is meant to foster empowered understandings of the "situated, ideological, and racialized nature" (Stornaiuolo, 2020, p. 82) of data and work for more equitable, socially just outcomes (Louie et al., 2022), teachers' demonstration of key components of this literacy and some teachers' establishment of this literacy as a goal for their students is notable. Yet, as research (Louie et al., 2022) suggests, such critical educational endeavors can encounter obstacles when integrated into formal schooling, and additional research is needed to investigate teachers' experiences of supporting students in cultivating these literacies.

Given teachers' emphasis on critical data literacy and the institute's stress on data tied to locally relevant social and ecological issues, like carbon dioxide emissions, homelessness, tree canopy coverage, and heat indexes in East Tennessee, we were surprised to find that both teacher groups placed only a modest emphasis on social and ecological engagement through data visualization. Though teachers showed moderate confidence in teaching students to use data visualization to address social and ecological problems on post-questionnaires, teachers did not consistently foreground student engagement with these issues in their curriculum presentations or post-focus groups. As literature suggests multiple barriers surround teachers' design and implementation of social justice (Pantić & Florian, 2015) and environmental education (Ennes et al., 2021) curricula, we recommend that future research explore teachers' subsequent data visualization curriculum endeavors to assess the extent to which they are socially or ecologically engaged.

Regarding STEAM education, art teachers' and mathematics and science teachers' conceptions initially differed, though they seemed to converge somewhat after program participation in the quantitative data. Both teacher groups experienced increased positive attitudes toward STEAM with art teachers experiencing the most growth, such that they eventually approximated mathematics and science teachers' highly positive attitudes. In post-focus groups, art teachers did not reference STEAM explicitly—an absence that could imply STEAM's de-emphasis in their future teaching plans. However, their stress on inter- and transdisciplinary learning complicates this conclusion as they seemed to exhibit an openness to arts-based, transdisciplinary curricular engagements, which could manifest as STEAM. Importantly, as mathematics and science teachers' conceptions of STEAM evolved to foreground arts processes, their responses exceeded entrenched, superficial conceptions of art's role within STEAM, which, in the literature, have been found to persist sometimes after teachers' participation in STEAM education professional development (Herro & Quigley,

2017). In this study, arts-based data visualization seemed to serve as a catalyzing model for authentic, meaningful arts learning within STEAM educational models. These findings suggest key program elements, such as our inclusion of PD facilitators with visual arts expertise and regular facilitation of multi-disciplinary collaborations—both key recommended practices in STEAM education literature (Quigley et al., 2019)—could have played a role in participants' strengthened understandings.

Conclusions

This study demonstrates that arts-based data visualization, STEAM professional development can support teachers in developing important conceptualizations and valuations surrounding art and art education, data visualization, and STEAM education and confidence for teaching data visualization. These promising results lend support for similar professional development models emphasizing teachers' active, authentic arts learning experiences and in-person, multidisciplinary collaborations. Moreover, it reinforces the potential of arts-based data visualization practices as a means to support teacher understandings of meaningful, arts-centered, transdisciplinary engagements. Yet, this study also raises questions about the implications of teacher attitudes for teaching practice, especially socially and ecologically engaged teaching practices. Since this research was limited in scope to a five-day professional development summer institute and focused primarily on teacher conceptions and valuations of key concepts, future longitudinal research is needed to explore the ways in which teacher attitudes and practices may evolve over time as teachers finalize data visualization curriculum plans and implement such curricula in their classrooms.

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