EXPLORING THE INTEGRATIVE NATURE OF STEAM THROUGH MATERIAL OBJECTS (penultimate draft)

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Abstract

STEAM has gained traction across informal and formal educational settings, but the connections between STEAM disciplines are not always obvious to youth. We argue that an explicit focus on how art and STEM overlap in the world, and how these overlaps connect personally to learner's interests and concerns, is a way to support the development of STEAM-related identities. We developed a "STEAM objects" pedagogical activity aimed at explicitly surfacing the ways that art and STEM are intertwined in everyday objects, as well as the ways that STEAM is connected to learners' own lives. We piloted the activity with educators, asking what they took up from the experience. Our results show how the educators made connections to land, historicity, their professions, function, aesthetics, and agency of materials during the activity. The STEAM objects served as boundary objects that illustrated the integrative nature of art and STEM in the world, as well as bridging important aspects of their lives and STEAM. We discuss the importance of recognizing and leveraging the multiplicities of meaning and ways of knowing, as well as implications for the classroom.

Key words: STEAM, STEAM objects, integration, personal relevance, boundary objects

Introduction

Much has been written about the underrepresentation of particular groups in science, such as women and individuals from nondominant racial and ethnic groups. Such patterns often have their roots in educational settings, where enactments of science and other STEM subjects frequently do not connect with the identities of girls and/or nondominant youth (Rosebery et al., 2010; Warren et al., 2020). As a result, youth often see science as dull, uncreative, and irrelevant to their interests and concerns (Archer et al., 2013, Miller et al., 2006). In order to build a sense of connection to, and identification with, STEM disciplines, youth must come to see the ways in which science and STEM connect to their everyday lives and cultures. Integrating art with STEM, or STEAM, has been proposed as such a strategy (e.g., Buchholz, et al., 2014; Peppler, 2013; Peppler & Wohlwend, 2018), as this approach allows learners to conduct STEM inquiries in ways that leverage young people's interests and cultural resources by personalizing the experience (Bevan et al., 2017; Carsten Conner et al. 2017) and including an aesthetic component that is often absent from STEM alone (Gettings, 2016).

As educators create STEAM programming, they often work from the idea that art and STEM overlap in meaningful ways. Peppler and Wohlwend (2018) argue that, while there are particular sets of practices associated with STEM disciplines that are distinct from practices in arts disciplines, there are some practices that are common to both STEM and art, such as close

observation, open experimentation, and analysis. Dispositions such as creativity are essential to both, as well. Indeed, many argue that STEAM reflects the nature of the world, in that innovations and the production of "things" often stem from practices that cannot squarely be categorized as either "art" or "STEM" (Bevan et al., 2019; Bush et al., 2022; Mejias et al., 2020; Quigley & Herro, 2016). However, while the educators designing these experiences may see overlaps between STEM and art, these overlaps are often invisible to the *learners*, even when they are engaged in doing STEAM-oriented projects. We argue that focusing learners' attention *explicitly* on ways that STEM and art overlap can result in new forms of learning (Root-Bernstein et al., 2011; Siler, 2011; Ulbricht, 1998). We further argue that, when art and STEM overlapping practices are emphasized as integrated STEAM, rather than being presented as distinct from each other, traditional ideas about STEM and art knowledge, tools, and materials, as well as who does STEM and art, are disrupted. Such disruptions lead to new ideas about the nature of STEM, which, when paired with considerations about the personal relevance of STEAM, can in turn support identification with STEM.

Here, we put forth a "STEAM objects" activity as a novel pedagogical strategy designed to support learners in explicitly seeing the overlaps between art and STEM that occur all around us. The activity also was intended to support learners in make connections between STEAM and their own lives. The activity asks learners to select and share an object that represents STEAM to them, and that also has personal meaning, and report out their thoughts. We piloted the activity with a group of educators who were participating in a larger STEAM professional development workshop. In this way, educators could reflect on their own connections to, and ideas about, STEAM. Participating in the activity themselves prior to implementation better positions educators to support students as they wrestle with their own conceptions about STEAM. In this

paper, we explore the ways that educators took up the activity, asking the following questions: 1) In what ways does the STEAM objects activity support educators in seeing the integrated nature of STEAM? and 2) In what ways does the STEAM objects activity support educators in connecting STEAM to their own identities? What kinds of connections were made to everyday life and personally relevant phenomena? We explore these questions through an investigation of the nature of educators' talk around the STEAM objects.

Theoretical approach(es)

Material objects and materiality

We argue here that the materials used in STEAM, including objects, can help learners see the integrated nature of STEAM, and that such materials are key to helping learners make connections to their own identities. It has been established that material objects shape learning experiences in critical ways and are embedded within human narratives - of their use, cultural significance, connection to family and communities, and identities. For instance, Harré (2002) discusses the importance of material objects in the social world, which is a critical aspect of identity formation. He argues that "An object is transformed from a piece of stuff definable independently of any story-line into a social object by its embedment in a narrative" (p. 25) and that the power of material things lies in the context of their narratives. For example, water, flags, and money can all have different meanings depending upon the context in which they exist. Material objects are also deeply connected to practices and roles within knowledge domains. For example, Nasir and Cooks (2009) explore the importance of material resources as identity resources. Material resources in this context were physical artifacts used in track, and how they support track athletes' connections to learning the practices of track and the particular roles the artifacts such as the track, spikes, hurdles, and starting blocks play in their understanding of

track. Others have argued for the importance of material resources in identification with art. For instance, Blandy and Bolin (2018) state that the "constructed things and spaces around us… become important in helping us understand the values, beliefs, thoughts, skills, qualities, actions, and attributes of the people involved with them" (p. 8). Similarly, Pahl and Rowsell (2010) argue that material objects tell stories; they embody people, thoughts, communities, experiences, identities, and value.

While the examples above focus on the meaning of objects within narratives, Ingold (2011) argues for a focus on *materials and their properties* as a way to understand the meaning of objects. He writes, "the properties of materials… cannot be identified as fixed, essential attributes of things, but are rather processual and relational." (p. 30). In the process of creating or making, we draw out the potential of materials (out of many possible potentials) through our interactions and relations with them (Ingold, 2013). Therefore, it is our experiences and connections to the materials themselves - as part of final objects - from which we can draw meaning and relations. For example, in an Indigenous STEAM context, Barajas-Lopez and Bang (2018) describe "being in relationship with clay" (p. 16), and understanding the deep history and Indigenous practices, including the ways in which the material behaves when mixed with water and is molded, that are connected to clay as a material. They also describe how the finished objects themselves are imbued with stories that refuse Indigenous erasure and enact nature-culture relations in concrete ways. In this way, materials - and their histories and relations to cultural and community practices - are intertwined.

Material objects as boundary objects

In this work, we developed the STEAM objects pedagogical strategy to support people's understanding of the integrated nature of STEAM and its relation to their lives. In this sense,

STEAM objects are "artifacts", or raw material manipulated by humans to create intended forms or physical objects (Ingold, 2013). Artifacts not only embody practices but also serve as objects of "collective remembrance" within and across figured worlds (Holland, et al., 1998, p. 61). We can therefore understand artifacts, and the materials from which they are made, as objects that support people in navigating across epistemic domains and figured worlds. Artifacts can be conceived of as *boundary objects,* or objects that can connect multiple spaces and communities (e.g., science and art, school and home communities) (Akkerman & Bakker, 2011; Cobb et al., 2003; Star & Griesemer, 1989). For example, when a child takes a special object from home, such as a teddy bear, and talks about it in school, a boundary between home and school has been crossed (Pahl & Rowsell, 2010). When students are provided with opportunities to tell stories about objects from home, it also supports their literacy development and can create new ways of learning. It is important to note that boundary objects themselves do not bridge communities; it is how they are taken up by members of the communities that they bridge. We can understand artifacts as objects that support people in navigating across epistemic domains and figured worlds, supporting identity work. Boundary objects can also challenge boundaries (Lee, 2007), such as the boundaries between art and STEM, and transform them (Tsurusaki et al., 2013).

For the purposes of this paper, we are interested in the ways that STEAM objects support participants in reflecting on the integrative nature of STEAM and how STEAM relates to their lives. Boundary objects allow opportunities for reflection, which take the form of *perspective making* and *perspective taking* (Akkerman and Bakker, 2011). *Perspective making* focuses one's attention on the potential of a boundary, considering differences and similarities between practices or communities and *perspective taking* "creates a possibility to look at oneself through the eyes of other worlds" (p. 145). For example, where one used to see a practice as solely a

science practice, reflecting allows one to also see an art or mathematical practice. Perspective taking and perspective making enrich people's ways of looking at the world.

In this paper, we explore the stories that participants tell about their STEAM objects because, "Focusing on things, and especially on those that hold relevance for the talker, encourages narratives to be extended and elaborated, thus offering greater leverage for interpretation and insight" (Sheridan & Chamberlain, 2011, p. 316).

Methods

This study, asking how the STEAM objects pedagogical strategy allowed educators to connect STEAM to their own lives and to see the integrated nature of STEAM, took place in the context of a larger professional development (PD) arc for educators. Specifically, the PD consisted of a two day, in-person workshop, a follow-up online mini-course, and coaching support for developing STEAM programming. Goals included providing a context for educators to reflect on their own ideas about STEAM, and preparing educators to develop and enact STEAM with their students. This paper focuses on the STEAM objects activity that took place during the two day, in-person workshop. We facilitated eight workshops that took place from the spring of 2018 to the winter of 2019 (Table 1). The participants included educators from a variety of institutions, including outside of school youth development programs, public library systems, a science center, after school educators, and formal general education, science and art classroom teachers. The workshops included both informal and formal educators. Both the UAF and UW IRB boards determined that this work was exempt from IRB; nevertheless, informed consent was still required and obtained. The research was conducted according to standard IRB ethical principles.

Table 1. Workshop location, Number of Participants, and Number of STEAM objects

Location	Number of Participants	Number of STEAM objects
Far Northwest city 1, U.S.	12	16
Northwest, U.S.	26	28
Northwest, U.S. make-up session*	3	4
Southwest I, U.S.	16	16
Midwest, U.S.	23	23
Far Northwest city 2, U.S.	15	16
West, U.S.	23	24
Southwest II, U.S.	11	12
Total	**129**	**147**

*This workshop was for the educators who were not able to participate in the initial workshop with other educators in the Northwest U.S. workshop.

In the STEAM objects activity, participants were asked to bring in a physical STEAM object that had personal meaning to them. They were not given examples of STEAM objects; they were instructed to bring in an object that they thought was related to STEAM in whatever way they conceived of STEAM. The educators were asked to "turn and talk" with their table mates, telling the story of their object, why they chose it, and what kind of meaning it held for them. The facilitators then asked for volunteers to share out with the whole group, if they felt comfortable sharing about their object. During table group discussion and whole group discussion, the facilitators prompted deeper reflection about the objects, such as how their own objects, and the objects that others chose, deepened their own understandings of STEAM, and how doing this

activity with students might help support student's conceptions about the ways that art and STEM are integrated in the world of "things."

In some cases, participants chose to bring in and share more than one object. A total of 129 educators participated in this activity and shared a total of 147 objects (Table 1). Data for this paper come from videotaped observations, as well as audio recordings of the STEAM objects activity during the PD. The video and audio were transcribed and we analyzed the transcripts using emergent coding (Strauss & Corbin, 1998). We looked at each participant's turn at talk and studied how participants described the objects and their relationships to those objects. The codes developed from looking for themes across practitioners' talk about the objects. From our analysis, six codes arose from the data: *connection to land, historicity, professional, agency of materials, function, and aesthetics* (Table 2).

Table 2. STEAM object codes

Code	Definition	Example
Connection to land	Object connected to land or place, often referred to connection to nature or home	Sunflower tattoo that reminded the participant of sunflowers where she grew up
Historicity	Object has historical or cultural significance	Stereoscope that was commonly found in households in her hometown in her youth and used by the women to visually explore places
Professional	Object used in or part of professional work	Noisemakers, such as bazookas, participant used as part of his educational programming with youth

Agency of materials	Materials used to create object and how the materials act in various ways	Chocolate, which represented a participant's chocolate-making hobby and how materials are manipulated through heating, mixing, and cooling to create chocolate
Function	Object's function	Smart watch that the participant used to track her movement, heat rate, and calories
Aesthetics	Object's beauty	A wooden box the participant thought was beautiful

Connection to land (including place) code was applied when a participant discussed how their object was connected to land or place, and often referred to a connection to the natural world, such as parks, flowers, trees, or their homes. *Historicity* was coded when objects were described as an object that had historical or cultural significance, was passed on from one generation to another, or an object that had historical value during one's lifetime (something that had meaning throughout one's life). *Professional* was coded when the participant described how s/he/they used the object in her/his/their professional work. *Agency of materials* was coded when the participant talked about the behaviors of materials that were used to make the object and how those materials act in various ways. For example, one participant described how the glass was used to make glass beads and how heat and other aspects changed the behavior of glass bead that was created. *Function* was coded when the participant described the function of the object in its final form, such as a camera that is used to take photographs. This is different than agency of

materials because agency of materials, in the case of a camera, would refer to the materials that created the camera. *Aesthetics* refers to the beauty of the object.

Once the codes were refined, the first two authors then coded data from two of the PD workshops, which represented 16% of the data to check for interrater reliability. After the first round of independent coding, the interrater reliability was 86%. After discussing discrepancies in coding and revising codes, interrater reliability was 97%. The first author then coded the remaining data. From the six codes, we found two themes in how the participants talked about the significance of the STEAM objects they shared: 1) the invocation of the objects and 2) the material aspects/properties of the object. The invocation of the objects, or the larger meanings the objects conveyed, included the following codes: connection to land, historicity, and profession. The material aspects/properties of the object included the codes function, aesthetics, and agency. As can be seen in Table 3, each code was applied between 27-92 times, illustrating that these themes were representative of the corpus.

Table 3. Frequency of code of STEAM objects (n = 147)

	Number of objects
Invocation of the objects	
Connection to land	*35*
Historicity	*66*
Professional	*42*
Material aspects/properties of object	
Agency of materials	*47*
Function	*92*
Aesthetics	*27*

Findings

In the findings, we explore two overarching themes that emerged from the data that describe the ways in which educators connected STEAM to their personal lives and how they saw the integrated nature of STEAM: 1) the invocation of the STEAM objects and 2) the material aspects/properties of the object. For the invocation of the objects, or the larger meanings the objects conveyed, we provide examples of how educators discussed connection to land, historicity, and profession. For the material aspects/properties of the object, we show how educators discussed the function, aesthetics, and agency of materials of the objects.

Theme 1: The invocation of STEAM objects

The invocation of the objects refers to the meanings the objects convey in connection to multiple identities and domains of educators' lives. Educators discussed their STEAM objects in ways that related to their connections to land, historicity, and/or their profession, which we explore below.

Invocation of connection to land

Many educators told stories about how their objects held meanings in relation to land or place. As an example, one participant, Maria, brought in a paper wasp nest that grew in the doorway of her house. She shared how the wasp nest motivated a STEAM program she was developing for youth at her library branch; this program was inspired by and incorporated place and the connection between nature and culture. She was creating a program where youth would study the anatomy and life cycle of paper wasps, make paper, and paint the paper. Paper wasps inspired modern day production of paper because they chew wood into pulp and mix it with their saliva to create their paper nests. Maria explained, "So the first day we're gonna do this [holding

up wasp nest] and make paper and then the next time the kids come in, we're gonna paint, we're gonna do Amate painting on the paper that we made." Along with the connection to land through the wasps and wood - which is used to create paper - she also incorporated the interconnection between land and her culture, sharing that she's from Mexico, where Amate bark painting is a traditional art form of creating paper from bark and the paintings often include colorful flowers and animals. Maria's STEAM object bridged connections between her home and land (as well as her profession) and she made connections between these and art and science in an integrative way.

Through their narratives around their STEAM objects, educators embedded their objects within strongly-held connections to land and were tied to their identities, signifying deep nature-culture relations (Bang & Marin, 2015). Their STEAM objects served as boundary objects, allowing them to explore connections between science, art, and culture. For Maria, her object not only bridged disciplines, but also her everyday life and her work life, and she leveraged her experiences and expertise from her everyday life to develop a youth STEAM program for work at the library.

Invocation of historicity

Many educators also discussed the importance of historicity and culture related to the STEAM objects. For instance, Donna brought in a coffee grinder from the early 1800s that was a wedding gift from her parents 42 years ago, and that reminded her of her mother who had recently passed. In addition to this personal history, she describes its more general history, explaining how it was made in Oshkosh, Nebraska, one of the largest coffee roasteries in Nebraska. She also discussed the process of coffee making using the coffee grinder:

> But the technology in this, so there's cast iron burrs inside the coffee. … So, as you turn the handle, the gears grind. And it leaves you with, we call it campfire grind because when we camp, we take our old enamel coffee pot and you always have a raw egg when you make campfire coffee. Because rather than straining it, you can strain the grounds through your teeth. It's an interesting flossing endeavor. But when you're ready to drink that coffee, if you just crack an egg onto the top, as it sinks to the bottom, the albumen, the protein strands grab the coffee grounds and drag it to the bottom.

As can be seen from this excerpt, Donna discussed both technology and the science of the grinder. She also explained how math plays a role, saying that she uses 50 beans per 6 ounce cup of coffee and calculated how many beans would be needed to make 7 cups of coffee. While the process of making coffee takes longer using her coffee grinder, "…if I use this when I grind my coffee it takes 20 times more. But it's meaningful." Donna also talked about the beauty of the grinder, discussing the details of the design in the cast iron. This aesthetic dimension, taken with the science, technology, and math elements discussed above, illustrate how the integrative nature of STEAM emerged for Donna around her object. The history of the coffee grinder as well as the history of the grinder in her own life made it a meaningful and personally relevant STEAM object that represented the integrative nature of STEAM.

Mike works as a carver demonstrator for the Sitka Tribe of Alaska[1] for a national historic park. He answers "…questions about the history of carving and technologies and what did people do to get by." Mike shared a few STEAM objects, including of his mother's alder spoons.

[1]We deliberately do not blind the cultural context of our research setting in an effort to refuse erasure of indigenous peoples from research.

> So these are alder spoons. Traditional shape. And so these actually, my mother in the late 40s, they actually used these. So that's probably halibut soup residue on them. And this is actually a sheep horn spoon. So one could talk about the principles of keratin and how all that works. And so you carve a mold, actually two molds. And you boil the horn for a while. And then squash it into that shape. With that bend on it.

Mike shared the historicity and culture of the spoons, describing how they were a "traditional shape" and how his mother used them. He also talked about the material used to make the spoons and the process of creating the spoons, which involves design, science and technology - in other words, integrative STEAM. He also shared a traditional halibut hook, which was created using bulk kelp and nettle rope or cedar. He described how the hook was designed to catch halibut, which included understanding how to form the hook in a way that would catch the halibut based on their feeding behaviors. In other words, this object was a place where biology, design, and culture intersected.

For Donna and Mike, their objects invoked histories across multiple generations and played important roles in their community practices. This underscores the importance of material objects of STEAM, and how knowing their histories allow for different forms of relations and knowledge systems to be brought into the learning space.

Professional invocation

Some participants discussed how they used their objects in their professional life. For example, Lucy brought in cardboard virtual reality (VR) glasses that she used in her programming with youth, which allowed the youth to explore places they had not yet been to. She talked about how the VR glasses were a newer version of stereoscopes, which she used in her childhood growing up in Mexico. Stereoscopes were very popular in her community growing

up. "…they're usually very fancy metal things that you, has a stick and a lens, you look through it. You'd stick card, postcards in that have two images and through the lens you see it as 3 dimensional." She explained:

> You know, their living rooms were sparse except for this beautiful stereoscope. And if you look them up they're just gorgeous. And so they'd have their stereoscope and they'd have a card rack with all their little cards and so if you look at some of the old ones, older ones. I mean amazing photography. And, you know, so if you wanted to visit, you know, someplace virtually, I don't think they used that word then, it's just like that's how you did it.

In Lucy's view, stereoscopes allowed people to "…discover[ed] other types of people, other types of landscapes" and "introduced me to different cultures, too, and so that was really important to me." This integration of technology, science, and art embodied in stereoscopes provided people the opportunity to explore places they could not afford to visit in person, or help people decide where to visit on their vacations. She also reflected on how she was introduced to technology at a young age and how technology expanded her world, which influenced her desire to introduce the youth in her programs to technology and provide them with opportunities to explore technology. When Lucy does presentations, one of the first images she shows is of a ViewMaster, a type of stereoscope that allows people to see color photograph images. She said, "And so for me it's important because of the opportunity offered me to be interested in how that worked. And looking, that curiosity led me into other things. So that's really important to me."

Lucy's STEAM object provided her with opportunities to make connections between STEAM and her work and also to reflect on the integrative nature of STEAM. Lucy was able to share her love of technology, culture and arts with youth.

Theme 2: The material aspects/properties of the object

The second emergent theme related to how the educators discussed the material aspects or properties of the object. Under this theme, we also saw that personal connections to their objects were an important part of their meaning-making about integrated STEAM. There were three subcategories within this theme: agency of materials, function, and aesthetics. We explore each below.

Agency of materials

In this subtheme, many educators described how the *agency* of the materials, or the ways in which they were shaped and their materials properties, allowed them to see the integrated nature of STEAM. In one example, Kira brought in jewelry made from glass beads she had made. As she described the jewelry, she explained how the bead making process itself is a mix of creativity, chemistry, physics, and aesthetics:

> I make glass bead jewelry. …these are with silver. And the silver has a reaction with the ivory colored glass. So the different chemicals in the, the silver or copper react with the color in the glass and it's very interesting. Plus …just making glass itself, with the coefficient of expansion, how glass expands and cools and making sure that you don't break glass. … There's a lot of creativity that goes into making something that looks nice. … But then also, you have to, you have to understand the properties of glass if you're going to make something that doesn't break. So, um, you have to understand the temperatures.

This example illustrated how participants saw the agency of materials being part of the connection they felt to them, and how they saw these objects as example of integrated STEAM. Kira talked about the glass expanding and cooling, understanding the properties of the glass so it

does not break while she is working with it, and how the “silver and copper react with the color”. Her STEAM object also illustrated the integrative nature of STEAM itself - how creativity, properties of matter, and aesthetics all came together into the making of this object.

In another example, Sandra’s STEAM object was a painting that she made using encaustic painting, which uses heated wax. Sandra explained how the materials create the painting.

> So these wax with resin embedded in it, and then pigments. And then you use heat. And you have to fuse each layer. With heat. So you either use a heat gun, or you get to use a little flame torch. … It's definitely a little, kinda technical.

Tools are used to heat and cool the wax so one can work with the materials to create a painting. She also described how you can embed things in the painting and use colored pigments to create the artwork:

> A silk tissue paper with an encaustic medium and it transparentizes thing. And you can sandwich things between the paper. And so I did a like an alter book of an old [inaudible]. And then once it cures, it's flexible. And it's, but your things are transparent.

The encaustic medium allows one to create layers. Once a layer has cooled, more layers can be created. She talked about the importance of ventilation when doing this type of work, and how it is safe if you “keep it at the right temperature” and that an encaustic painting’s melting point is about 210 degrees Fahrenheit. Science is involved in understanding how the heating and color of the waxes allows one to work with the materials, and interactions between the waxes and the pigments, and the layering of the materials to create the painting.

In both of these examples, Kira and Sandra explained how the behavior of the materials shaped their objects and how they manipulated the materials to create desired effects. They saw how chemical and physical properties of the materials also informed what they are able to create.

In their STEAM objects, they recognized how the art (glass making, encaustic painting), science, and technology (tools used as part of the work, such as heat guns and torches) worked together to allow them to create their objects. In these cases, the agency of the materials intersects with human agency - the materials "transparentize", "react", "fuse" in partnership with human actors to form the STEAM objects.

Function

Some participants described the function of the object in its final form as an example of integrated STEAM, such as the following example of running shoes. Jamie shared that her running shoes were her STEAM object, something that she used often in her daily life. Her shoes were very important for her because of the function they provided; they allowed her to run. Through thinking about how her shoes represented STEAM, she started to examine the design work and engineering involved in creating her shoes.

> Someone spends a lot of time, you know, designing shoes and engineering shoes to work for different people. …I can talk about running shoes for like, a couple hours. To the point of obnoxiousness. But I also thought of it like somebody also in the company spends a lot of time on what the design looks like and how it's going to sell. So it's like this is my little connection to engineering and art.

Jamie talked about how her shoes were designed to support one's ability to run, while paying attention to the aesthetics, or look of the shoe, which may entice some to buy the shoes and be an important to some consumers. Jamie's selection of running shoes as her STEAM object shows both how she connected her daily life to STEAM, and how she saw STEAM as integrated, describing how her shoes represent not only engineering, but also design and technology.

Sam talked about the importance of the function of a carabiner, a metal loop that is used in activities such as climbing. He talked about how the carabiner's design was simple and served its function efficiently, stating: "...you couldn't hardly streamline it to make it better…" The amount of load that it could bear was stated in the metric system, which allowed the information to be understandable by the majority of the world.

Both Jamie and Sam described how the functions of their objects were important features to them, as well as the way in which function represented a blend of art and STEM. The function of their objects allowed them to use the objects in particular ways that were meaningful to them, such as running or supporting a load. The function of the objects was informed by the design, which required the integration of art and STEM.

Aesthetics

This subtheme captures the ways in which educators saw the aesthetics or beauty of objects as important to understanding integrated STEAM. For example, Lily shared a kenzan, a device used in art of Japanese flowering arranging, ikebana.

> … So you put it on the base, So you have, see these little pins. So what you do it, I guess Americans would call it a frog. So because the kenzan is done in the way, you can literally get it at different angles and position it however you like. So of course ikebana is art. I forget, it's the A, right. So it's for creating something aesthetically beautiful, when you do ikebana it's about creating an object of beauty. And people who are really good at this have an aesthetic sense of what colors go together, what textures, what flowers and so forth. But I do think there is mathematics involved because there's certain styles that you're supposed to do it based on how you put the stem. So one of the simplest ones … involves just a few things. There are the 3 main branches. And one is always at a 90

> degree angle. Another one is like a 30 degree angle and another one is like, you know, a 60 degree angle. The people who do it don't get out the little protractor. They can do this by sight. And you do this based on how you look at it from the front. But you're also supposed to be able to look at it from the top and see the different angles like a clock. And those are the main branches of how you, of how you position the main features of it. And then you can put lots of little things around it. But there's the main structure. So it involves angles and things like that. So I think it involves art, but it also, and there are a lot of artistic, aesthetic decisions you're going to make. But …there's also a certain, you have to understand the angles and how things are supposed to look in order to have that particular style.

Lily described how the kenzan is used, "…for creating something aesthetically beautiful, when you do ikebana it's about creating an object of beauty." She went on to explain aspects that are considered when making something aesthetically beautiful, discussing the colors, textures, flowers, and branches that are used to create the flower arrangement. She associated the art of ikebana with aesthetics and reflected on how it involved not only art, but it was the integration of art and math that made it beautiful. The flowers were inserted into the kenzan at particular angles and at angles relative to each other to create the intended aesthetic effect and one needed to understand how the angles create visual images, depending on flower placement. Ikebana involves the mathematical understandings, such as angles, and using understanding of angles and perspectives to create something aesthetically pleasing.

Another participant, Emily, shared a Bakelite camera, which she described as beautiful. Bakelite was a material used to make cameras and other objects in the 1930s through 1960s before modern plastic was invented. Emily explained, "…how beautiful the design of it is" and

how “well designed” the camera was. While she discussed the function of the camera, she extolled the virtues of the compact design. She identified herself as an artist and pointed out things she appreciated about the design of the camera, such as it being a medium format camera that was small, the size of the negatives, and how parts of the camera were designed (e.g., tube unrolls). It was one of the cameras that she had in her collection that had particular meaning because she bought it when her father was ill and it reminded her of her family. She also described photography as an integrative field because it combines science, art, and technology. Not only did the design of the camera bring all of these fields together, but taking pictures also required all of these fields to work in an integrative manner, from the taking of the photos, to the development of the film. Emily’s description of the camera also points to her larger expertise of cameras, photography, and developing film - as she recognizes how this camera is unusual in both its build and its film format.

In these examples, the aesthetics, or beauty of the objects, were important to Lily and Emily both from a personal meaning standpoint and in understanding the integrative nature of STEAM They appreciated the beauty of the objects and recognized the art and STEM that was involved in the creation of their objects.

Discussion and Implications

This study explored how educators used a new pedagogical strategy, STEAM objects, to reflect on the integrative nature of STEAM and the ways in which STEAM relates to their everyday lives. The activity was successful with respect to its aims: 1) allowing the learner (in this case, the educator) to *explicitly* explore the ways that art and STEM overlap in everyday objects that are all around us, and 2) allowing the learner to make personal connections to STEAM. This study makes an important contribution to the literature by documenting specific

ways in which the educators came to see the connections between STEM and art, and how they connected STEAM to their own lives, through a new pedagogical approach. Specifically, we found that educators talked about their STEAM object in relation to two themes: 1) the invocation of the objects as connected to multiple domains of their lives, and 2) the material aspects or properties of the objects. Within the theme of the invocation of the objects, we showed how the educators made connections to land, historicity, and agency of materials. Within the material aspects or properties of the objects theme, they explored the objects' agency of materials, functions, and aesthetics. Across both themes, they made personal connections and explored their understanding of the integrative nature of STEAM.

Through the process of examining material objects and reflecting on their connections to STEAM, the STEAM objects became boundary objects, bridging disciplines that are often viewed as separate in society at large (e.g., Snow, 1998). None of the educators described their objects as only STEM or art objects - what was important to them about the objects was the multiple histories and functions that they signified, and these crossed boundaries between STEM and art. For example, the carabiner is inherently a functional object, but also is simple, aesthetic, and strong in its design - qualities that cross materials science, engineering, technology, and art. The VR glasses have inherent function as transmitting 3D images and experiences to wearers - but also, in the example above, transport users to different parts of the world that they might identify with. Thus, when we begin with the lived experiences and narratives of objects - we quickly get to new understandings of how STEM and art are not only integrated with each other, but how they are lived as integrated in our lives. This is similar to what Pahl and Rowsell (2010) have found in their work, where the disciplinary boundaries were blurred and the youth could not determine if they were learning art or literacy or mathematics.

These emergent areas of personal connection and "boundary blurring"—connections to land, history, aesthetics, function, and agency of materials—have important implications for the classroom. While this activity was conducted with educators, it seems likely that students might find connections with STEAM in similar ways. Educators designing further STEAM programming might consider developing STEAM activities that build on these themes.

Our results also imply that participating in the STEAM objects activity itself might have value to students in the realm of STEAM identity building. That is, because disciplinary identity development is closely tied to the perceived relevance of the discipline to the learner, we argue that these boundary objects might in fact be identity objects. Future studies could focus on the question of how students take up meaning from the activity, as well as focusing on the ways in which STEM identity work might occur among students participating in the activity. In sum, the findings in this study hint at the power of the STEAM object pedagogical activity to connect to learners' identities and to center family, community, and cultural knowledges and ways of knowing in deep ways within STEAM settings, thus forming bridges between STEM, art, and everyday lives of learners.

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References

Akkerman, S., & Akkerman, A. Boundary crossing and boundary objects. *Review of Educational Research, 81*(2), 132-169.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2013). 'Not girly, not sexy, not glamorous': Primary school girls' and parents' constructions of science aspirations. *Pedagogy, Culture & Society*, *21*(1), 171-194.

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*(4), 530-544.

Bajaras-López, F. & Bang, M. (2018). Indigenous making and sharing: Claywork in an Indigenous STEAM program. *Equity & Excellence in Education, 51*(1), 7-20.

Bevan, B., Bell, P., Scarff, L., Stromholt, S., Kong, F., & Chadwick, J. (2017). Art+ Science: Broadening youth participation in STEM learning. *Science Learning+ Phase I Report. Seattle, WA. Retrieved from: http://www. informalscience. org/sites/default/files/Arts% 2BScience_ Report. pdf.*

Bevan, B., Peppler, K., Rosin, M., Scarff, L., Soep, E., & Wong, J. (2020). Purposeful pursuits: Leveraging the epistemic practices of arts and sciences. In A. Stewart, M. P. Mueller, & D. J., Tippins (Eds.), *Converting STEM into STEAM programs: Methods and examples from and for education.* Switzerland: Springer.

Blandy and Bolin (2018). *Learning Things: Material Culture in Art Education.* New York: Teachers College Press.

Buchholz, B., Shively, K., Peppler, K., & Wohlwend, K. (2014). Hands on, hands off: Gendered access in sewing and electronics practices. *Mind, Culture and Activity, 21*(4), 1–20.

Bush, S. B., Edelen, D., Roberts, T., Maiorca, C., Ivy, J. T., Cook, K., L. Tripp, L. O., Burton, M., Alameh, S., Jackson, C., Mohr-Schroeder, M. J., Schroeder, D. C., McCurdy, R. P., & Cox Jr., R. (2022). Humanistic STE(A)M instruction through empathy: Leveraging design thinking to improve society, *Pedagogies: An International Journal*.

Carsten Conner, L. D., Tzou, C., Tsurusaki, B. K., Guthrie, M., Pompea, S., & Teal-Sullivan, P. (2017). Designing STEAM for broad participation in science. *Creativity Education, 8*(14), 2222–2231. https://doi.org/10.4236/ce.2017.814152

Cobb, P., McClain, K., Lamberg, D. T., & Dean, C. (2003). Situating teachers' instructional practices in the institutional setting of the school and district. *Educational Researcher, 32*(6), 13 – 24.

Gettings, M. (2016). STEAM, PBL, Scientific Method, and the Studio Habits of Mind. *Art Education, 69*(4), 10–11. http://www.jstor.org/stable/45154671

Harré, R. (2002). Material objects in social worlds. *Theory, Culture & Society, 19*(5-6), 23-33.

Holland, D. C., Lachicotte, W., Skinner, D., & Cain, C. (2001). *Identity and agency in cultural worlds*. Harvard University Press.

Ingold, T. (2011). *Being alive: Essays on movement, knowledge and description*. Routledge.

Ingold, T. (2013). *Making: Anthropology, archaeology, art and architecture*. Routledge.

Lee, C. P. (2007). Boundary negotiating artifacts: Unbinding the routine of boundary objects and embracing the chaos in collaborative work. *Computer Supported Cooperative Work, 16,* 307-339.

Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., Roche, J., Wong, J., Hurley, M., Bell, P., & Bevan, B. (2021). The trouble with STEAM and why we use it anyway. *Science Education, 105*(2), 209-231.

Miller, P. H., Blessing, J. S., & Schwartz, S. (2006). Gender differences in high-school students' views about science. *International Journal of Science Education, 28*(4), 363–381.

Nasir, N. S., & Cooks, J. (2009). Becoming a hurdler: How learning settings afford identity. *Anthropology & Education Quarterly, 40*(1), 41-61.

Pahl, K. & Rowsell, J. (2010). *Artifactual literacies: Every object tells a story*. Teachers College Press

Peppler, K. (2013). STEAM-powered computing education: Using e-textiles to integrate the arts and STEM. *Computer, 46,* 33-43.

Peppler, K. & Wohlwend, K. (2018). Theorizing the nexus of STEAM practice. *Arts Education Policy Review*, *119*(2), 88–99.

Quigley, C., & Herro, D. (2016). "Finding the joy in the unknown": Implementation of STEAM teaching practices in middle school science and math classrooms. *Journal of Science Education and Technology, 25*(3), 410-426.

Root-Bernstein, B., Siler, T., Brown, A., & Snelson, K. (2011). ArtScience: Integrative collaboration to create a sustainable future. *Leonardo, 44*(3), 192.

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. *The Journal of the Learning Sciences, 19*(3), 322-357.

Siler, T. The ArtScience program for realizing human potential. *Leonardo, 44*(5), 417-424.

Snow, C. P. 1998 [1959/1964]. *The Two Cultures*. Cambridge & New York: Cambridge University Press.

Sheridan, J. & Chamberlain, K. (2011). The power of things. *Qualitative Research in Psychology*, *8*(4), 315–332.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-1939. *Social Studies of Science, 19*(3), 387-420.

Strauss, A., & Corbin, J. M. (1998). *Basics of qualitative research*. Los Angeles, CA: Sage Publications.

Tsurusaki, B. K., Calabrese Barton, A., Tan, E., Koch, P., & Contento, I. (2013). Using transformative boundary objects to create critical engagement in science: A case study. *Science Education*, *97*(1), 1–31. https://doi.org/10.1002/sce.21037

Ulbricht, J. (1998). Interdisciplinary art education reconsidered. *Art education, 51*(4), 13-17.

Warren, B., Vossoughi, S., Rosebery, A. S., Bang, M., & Taylor, E. V. (2020). Multiple Ways of Knowing: Re-Imagining Disciplinary Learning. In *Handbook of the Cultural Foundations of Learning* (pp. 277-294). Routledge.