Teachers' Values in Co-Design of an Art-Science-Computation Unit

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Abstract: Creating learning environments that bring together the arts, sciences, and computing in education could provide avenues for changing stagnant practices within those disciplines that currently marginalize people with non-normative identities and practices. We examine the co-design process of an interdisciplinary group of teachers crafting a transdisciplinary art-science-computation curriculum unit for their classrooms. Within this context, teachers engaged in richly metarepresentational discussions wherein they applied values and practices from all three constituent fields of study in their design work. We present the results of a qualitative analysis of teacher discourse, showing the wide variety of epistemic criteria marshalled by teachers within design discussions as they connected their ordinarily separate disciplines.

Introduction

Educational researchers have consistently called for more interdisciplinary approaches to education, especially for nurturing stronger, making-oriented synergies between Science, Technology, Engineering, and Math (STEM) and the Arts (STEAM) (Guzdial, 2010; Peppler, 2013; Regalla, 2016), and for valuing a broader set of emotional and epistemic relationships to STEM (Turkle & Papert, 1992). Peppler and Wohlwend (2017) argue that one barrier to equitable participation in STEM is the stagnancy of knowledge development and representation practices, and maker pedagogies that support STEAM learning could broaden participation. For instance, schools expect students in science to produce a small number of canonical representations (e.g. bar graphs) that do little to invite students with experience producing other representations (e.g. art) to apply skills and identities that they already have within science education. They envision the design of *nexus* learning environments where science-art-computation practices mediate learning and offer new, inclusive affordances for thinking and learning.

Much literature about STEAM describes learning in informal environments (Marallo, 2014; Searle & Kafai, 2015), with some work showing how STEAM can embrace diverse, culturally varying epistemologies (Bang & Medin, 2010). We know little about how nexus learning experiences can unfold within middle and high school classrooms; how new computational-artistic representational practices can be integrated with the existing school curriculum, what kinds of professional development experiences can foster disciplinary teachers' learning about how to teach using new representational infrastructures (Hall & Jurow, 2015), and what structural barriers within schooling might prevent their implementation.

We present a case study of a multi-school, multi-disciplinary group of teachers co-designing a shared unit that uses artistic and computational representational practices to support investigation and representation of the biology of classroom gardens. We examine how teachers navigate disciplinary values and content expertise in co-designing transdisciplinary projects for their classrooms. We show how metarepresentational discussion (diSessa, 2004) played a crucial role in their making process, including their learning from one another, and shed light on what properties teachers might value in representations that are both scientific and artistic.

Background

On representation as disciplinary practice

Representational infrastructures are the norms for communication about information in disciplines; they are historically embedded, transparent, taken-for-granted, visible only upon breakdown, and stretch across time, space, and social participation structures (Hall & Jurow, 2015; Hall, Stevens, & Torralba, 2002). Often these infrastructures are exclusive, only permitting people to legitimately participate in disciplines in a small set of canonical ways, while excluding people when their backgrounds offer them different representational and epistemic approaches (Bang & Medin, 2010). Nexus learning environments could create room to reimagine representational infrastructures, thereby shaping new forms of induction into disciplinary participation through valuing a multiplicity of ways to contribute. For example e-textiles can change the materiality, the domain of application, and the gendered practices of learning electronics (Peppler & Wohlwend, 2017).

Related to the study of how representational infrastructures define fields is the study of how learning metarepresentational skills can further disciplinary learning. *Metarepresentational competence* refers to the skills involved in constructing or parsing new representations, comparing sets of representations, and describing the purpose of a representation (diSessa, 2004). Research on metarepresentation examines both what metarepresentational competence is, and how it develops over time (Danish & Enyedy, 2006; diSessa, Hammer, Sherin, & Kolpakowski, 1991). One strand of that research examines student and teacher thinking about models as representations of scientific phenomena, and in particular, what *epistemic criteria* they use to evaluate whether a model is a good one (Pluta, Chinn, & Duncan, 2011).

Other work addresses the broader question of how new representational media can support novel ways of learning about and conceptualizing disciplinary content (diSessa, 2001; Greeno & Hall, 1997). Nexus learning environments may provide expansive opportunities for imagining, discussing, and practicing new representational infrastructures, including through the melding of representational techniques across ordinarily separate disciplines. However, there has been little empirical examination of the benefits and drawbacks of such approaches, and we are unaware of any research that investigates how the expansion of teachers' representational tools and skills can support their development of more representationally and epistemologically ecumenical teaching practices. In this study, we examine teachers' epistemic criteria within the collaborative construction of artistic and computational representations of scientific phenomena.

On co-design

Collaborative design, or co-design, is a strategy for increasing teacher agency and practical implementation by forming teams of teachers and researchers to design, implement and test new educational innovations (Severance, Penuel, Sumner, & Leary, 2016). Co-design allows for teachers to ensure that reforms amplify their own voices through addressing the contexts, needs, and routines of their practices (Severance et al., 2016).

Storyline authoring is a promising process for science education curriculum co-design (Reiser, 2013). A storyline is a conjecture about how a coherent flow of instruction could be driven by student questions grounded in phenomena that lead to investigations, modeling, and argumentation (Reiser, 2013; Next Generation Science Storylines, n.d.). Thus far, the storylining approach has only been used in contexts where all of the participating teachers are science educators. In this study, we brought together teachers from several different disciplines to collaboratively storyline a nexus unit that blends their expertise in art, science, and computation.

Luminous Science as science-art-computation nexus learning experience

Luminous Science (LS) is an approach developed by the authors that uses art and computation to create dynamic representations of scientific phenomena. This approach was developed to both expand the representational infrastructures of science classrooms, and to create stronger affinities between the values and practices of art, science, and computing education, including artistic inspiration in science. We used a traditional Japanese style of lantern making, Nebuta, and combined it with networked sensors in a garden to create dynamic illuminations in the lantern that are indicators of biochemical phenomena inside the plants. The first author began this project by building her own prototype lantern (Figure 1a) and garden. The Nebuta lanterns use familiar and flexible craft materials (e.g. wire, paper, glue, string, and paint) which allow for many choices in form and aesthetics for visual storytelling. We integrate technology into the lanterns through individually addressable RGB LEDs that are controlled by a programmable microcontroller that communicates wirelessly with another microcontroller and its sensors in a hydroponic garden. Computation, therefore, bridges the artistic and scientific practices of LS.

To tell the story of scientific phenomena in the garden through the lantern, the scientist-artist must make metarepresentational choices about what data to use and then how to visualize the data within the physical shape and dynamic lighting of the lantern. By increasing the scope of possible representational choices, we hope to expand the metarepresentational choice space that students and teachers enjoy. Two scientist-artists making separate lanterns could receive the same data streams but tell quite different stories about the garden through differing choices about how to model and represent the data. Our prototype used data about humidity, temperature, soil moisture, and light as input to a computational model we made about photosynthesis and transpiration. The output of the model is rendered in the body of the lantern via luminous molecules, "sugars" and water, moving through the sculpture, simulating the generation, collection and transportation of molecules in the plant.

We wish to understand how approaches like LS, through creating a nexus of science, art, and computation, could open up science education to a more diverse array of people and practices. As we seek to change science education, we believe it is crucial to study innovations like LS within school, and not just in informal learning spaces. To do so, we must train teachers in the technical facets of the work, work with them to co-design units that they could pilot in their own classroom, and then study the resulting instructional contexts.

Toward that end, we organized a co-design workshop with multi-disciplinary group of teachers, and guided them through a process of transdisciplinary collaboration wherein they made their own LS lanterns and co-wrote unit plans and storylines. Our **research questions** are:

RQ1: How do teachers discuss the representational values and practices of each other's disciplines within the co-design process, particularly within transdisciplinary designing and making?

RQ2: What epistemic criteria for science and art do teachers use to make design choices?

Figure 1. a) 9-ft tall prototype Nebuta-style sculpture created by the first author. b-d) 2-4-ft artistic data-driven lanterns made by teachers in the co-design workshop.

Methods

Workshop design

The goal of the workshop was to design a classroom unit around artistically focused data-driven representations of scientific phenomena in gardens that the teachers would deploy in their classrooms. We anticipated that the resulting nexus learning environment designs might necessitate more flexible eventual implementations since an art teacher might have different needs than a science teacher. Therefore, we collaborated with teachers within a framework of co-design to develop storylines for LS that each teacher felt was appropriate for their context.

Within the workshop we asked teachers to 1) make an artistic sensor-data-driven representation of the garden in the form of a lantern and 2) draft a storyline plan for implementation in their classrooms. Our goals for the making activity were to have teachers learn the lantern making process and to facilitate conversations amongst the group of us about how to consider artistic and computational values and practices within science classes, and vice versa. We asked teachers to use a storyline process to develop a sequence of student questions, situated in phenomena, that organize the flow of a unit. Our work here expands on typically mono-subject storyline co-design by bringing together a disciplinarily diverse group of teachers to co-design a nexus storyline.

The workshop ran for five four-hour days. On day 1, we introduced the LS project goals and storylining, sketched lanterns in small groups, and discussed implementation in the classroom. On day 2, we introduced wire frame making and papering, made the wire frames, worked within subject areas on storylines, and the teachers sketched lanterns around a specific garden scenario: Inspired by diSessa et al. (1991), we asked groups to sketch and compare lantern designs that would show the transformation of the garden over time if a water pump failed. On day 3, we introduced data visualization techniques, soldering, and the BBC micro:bit hardware, then groups designed mappings between data and the dynamic lights in their lanterns, then finished wire frames and soldered lights. On day 4, the teachers papered and at least partially painted their lanterns, then shared storylines and planned across schools and subjects. On day 5, we introduced programming sensors and LEDs, and teachers programmed the lights for their lanterns to display data (Figure 1b-d) and worked on their storylines.

Participants

We partnered with six teachers: Hannah (math and computing) and Kate (science), teach in a rural public middle school. Adam (art), Susan (environmental science), Elena (physics), and James (chemistry and earth science) teach in a large public urban high school. Both schools are located in the Rocky Mountain region of the United States. Maggie and Bob, two engineers from a local company that manufactures some of the hardware we used, joined the group for 4 days of the workshop. Bob is a former high school physics teacher, and Maggie is a pre-service teacher. The first author is also a former high school art and chemistry teacher.

Data collection

All workshop activities were recorded using four video and four audio recorders. Two cameras' locations were fixed and showed an overview of the whole room, but the other two shifted in location based on the evolving focus of group work. The audio recorders supplemented the camera's audio, and were placed on tables near groups. We took still photos of the groupwork, including photos at the end of each day to document teachers' products (e.g. plans, lanterns). The teachers wrote their storyline unit outlines and how they would differentiate the unit for their own classes in a shared Google Doc. The teachers wrote responses to a set of daily reflection questions in a Google Form, and we asked additional reflection questions at the end of the week.

Data analysis

Our analysis examined the entire week of video (~70 hrs) and audio data. We took a grounded theory approach (Strauss & Corbin, 1997) to understanding what kinds of discussions about how to represent data occurred within lantern making or unit planning interactions. We performed an exhaustive, low inference search of all the video data to identify metarepresentational discussions, transcribed these, and then grouped the transcribed interactions by their use of common epistemic criteria. The conversations in this paper were transcribed verbatim, and our emphasis was on accuracy of content and sequence rather than on intonation or other markers.

Results

Meta-representational conversations within the nexus of disciplines

Throughout the week, teachers designed and built artistic data-driven lanterns that told an empirical story about a hydroponic garden in our working space. We observed practices and conversations that connected the arts, computing, biology, and physical sciences. The teachers' interactions with one another were supported by the ways in which the lanterns, garden, and technology provided a context for conversations about what to represent and how to do so using the affordances of the tools at hand. These choices were based on aspects of each discipline that spanned aesthetics, scientific reasoning, and technical possibilities of the hardware and software, showing different areas of expertise, entry points and knowledge sharing. Often, these discussions surfaced epistemic criteria for making design choices. We present a sampling of these metarepresentational discussions below, selected to illustrate the ways in which teachers' epistemic criteria were raised in design discussions.

Communicative design criteria

Teachers often discussed the aesthetics of their lanterns in terms of communication with a viewer, addressing concerns like how well the form *corresponded* to the data or the source of the data (the garden), how visually *interesting* a lantern would be, and the relationship between aesthetic choices and how *comprehensible* a lantern would be. Some teachers took the stance that the data should drive choices about the aesthetics of their lantern:

> *Adam: The first thing I'm interested in is finding out is what the data is that we are going to measure.*
>
> *Kate: That's going to help to pick the shape of the lantern, for sure.*

Other teachers in their group also emphasized correspondences between the visuality of their lantern and the dynamics of the data. Hannah, who, along with Maggie, worked with Adam and Kate, made the case for ensuring that their lantern was visually interesting. Their design had two parts, a box on top that would show incoming data "marching like ants" each time a new data point was received, and the bottom would show a variety of data in three hanging tube structures that would blink or change drastically in color when the values were not in the "normal" range. As they finalized this idea Hannah began to question the visual interestingness of the lantern:

> *Hannah: [There is] going to be very little of this [lantern] that has any movement to it except for the box which shows the data coming in. The rest of the stuff is just going to be on at a certain level until something goes very wrong, until it's dying and then it will blink. If I'm a kid that makes me want to kill the plant to see it blink.*

Hannah realized that the lantern would always appear the same unless there were something wrong in the plants, making it, in her opinion, somewhat of a boring visualization. So she suggested that they modify the design so that an animation was constantly happening, even if the garden was in normal ranges, and figuring out how students might create more dynamic visuals was a topic that she repeatedly returned to later. However, not all groups seemed to value this correspondence principle; in the next section we describe how Bob and James seemed to make arbitrary decisions about how to connect the form and the data within their design.

Besides being visually appealing, teachers discussed additional epistemic criteria that attended to the distinct but related concerns of *simplicity* and comprehensibility. Simplicity was valued both in the parsimony of the data presented, as well as in regard to visual complexity. The following interaction illustrates the former:

> *Bob: So these are three good [types of sensor data] is there anything else we want to add? And I think we might want to keep it simple.*

James: I think those three, I think with those three would be the most simple we could make it.

Simplicity of visual representation was sometimes discussed as a way to achieve comprehensibility: paint colors, patterns, structure shapes, or light colors were often chosen based on how easily a viewer would be able to "read" the lantern. Kate expressed a common sentiment of the teachers that overly complex visuals would confuse a viewer when she noted, "But not too much movement though, because then it gets muddied." instead she emphasized showing a clear, simple story. Other times this visual literacy shaped artistic choices in the paint or lighting patterns, such as when Adam alluded to his expertise in how the light and paint might interact "we could keep the paint pretty neutral because we are using pretty fine color [gradations in the] lights." The comprehensibility criterion also affected the technical elements of one project. In the following example, Hannah explains to her group why she thinks they should program the lights to be on or off rather than show brightness:

Hannah: We might want to rather than adjusting the brightness of the LEDs we might want to turn more LEDs off or on. Just from playing with the strip of LEDs you can't tell that much. Like there is a huge range, what I thought was going to be all the way on, medium and off was like medium and all the way on are looking the same to me.

We see here that Hannah noticed a limitation of the effective expressive utility of the lights, specifically that small changes in their brightness are often imperceptible to the human eye (human brightness perception is logarithmic), leading her to recommend a different representation that would still be able to communicate similar information.

Informational design criteria

Within discussions of science and lantern design, teachers mixed concerns for correspondence with other criteria about the need for *content coverage* and emphasis on "*important*" scientific information. For instance, one group wanted to add physical motion to their lanterns. In a conversation about when they might use a computer-controlled fan to move paper streamers dangling from their lantern, the group discussed what scientific ideas might be appropriate to represent that way, settling on photosynthesis and respiration:

Maggie: I thought [turning the fan on] was a change in a process? Like when the plant does start to produce O_2 rather than taking oxygen in. [the group looked to Kate to explain the biology]

Adam: Do we have the sensitivity to record that?

Kate: Not being a plant biologist and or even being a biologist, my understanding is that it is always simultaneously happening. You know, we are pretty much constantly taking in oxygen and breathing out CO_2 and plants are pretty much constantly taking in CO_2 and putting out oxygen. That's my understanding of it. Like at night they are not taking in the same kind of quantity, because they are not really doing photosynthesis in the same way, so it could be a night versus day thing.

Prior to this conversation the group was planning to have the streamers alert the viewer to any large change in any of the data. In thinking about the technological capabilities of the tools in relation to the aesthetic goal of making the streamers move, the group delved into the science behind what scientific processes are dynamic enough to actually map onto the reaction they envisioned. Here the teachers seem to apply a principle of dynamic correspondence: dynamic representational elements should be associated with dynamic scientific phenomena. Although Kate was incorrect about the plant biology, the problem of what to do with the streamers offered an opportunity to the group to consider how representational practices could link science, measurement, and art.

At other times, teachers used concerns about science curriculum content coverage to justify design choices. They began their discussion by focusing on conveying scientific information through the physical shape of their lantern (instantiating the correspondence criterion). They discussed using chemical structures such as buckyballs and DNA, veered off into Viking helmets (tied to the school mascot), and finally settled on mountains. As they proceeded, each story and form they discussed was disjoint from the data and source of that data, the garden, they would be visualizing. The following conversation occurred after they had decided on the structural form of the mountains and were beginning to discuss what biological phenomena they might actually show:

Bob: There could be gnomes… So there are mountain gnomes watching the sensors and that are going to light up, they are going to turn on lights based on what is going on in the plants.

[discussion of keeping the representation simple by only using three data points]

Bob: But I think these three would be, so three peaks… we could also talk about ecosystems. That would be good, so if you drive through the mountains, like certain areas are aspen covered, and other areas are pine, [some are] rocky, the top could be the like the white kind of tundra.

James: That depends on how we paint it, one could be the aspen, one could be the pine…

Bob: So ecosystems [lists ecosystems]

James: I think if we took, like the three peaks, even if we can probably combine them… maybe the trees, and that is soil moisture, tundra and snow can be the light and rocky can be the temperature?

Their depiction of mountain ecosystems enhances their lantern's nominal capacity for content coverage, but the content they add is only loosely connected to observable phenomena within the garden. They seemed to make an arbitrary decision about which data will be shown where on their lantern. We see tensions here between the epistemic criteria of scientific content coverage with both the simplicity and correspondence criteria, as their representation introduces additional visual complexity in order to achieve content coverage, and the visual expression of that content (e.g. snow, trees, rocks) bears no relationship to the particular data they are showing.

We also saw repeated attention to a criterion that Adam called "scientifically interesting data." For instance, Bob and James's mountain sculpture design conversation continued as follows:

James: We should be picking [data] on how many, you know how many peaks we are going to have. Three or four is probably a really good... If we wanna stick to three, and choose the most important three, light - definitely.

Bob: Soil moisture like, did you water the plants.

James: So light and soil moisture should be two that should definitely be there.

While some of James and Bob's choices about *how* to depict data seem arbitrary, at least one choice of *what* data to show considered the contextual needs of a human's care for the garden ("did you water the plants?").

Transdisciplinary linkages between the nexus disciplines

Even as teachers applied disciplinary epistemic criteria within their metarepresentational work, they also developed transdisciplinary perspectives, drawing unifying connections *beyond* their individual disciplines (Stember, 1991). They talked with each other about the kinds of questions their disciplines lead them to pose, and discussed how they would apply the perspectives and practices of others' to expand their own.

Linking ideas and practices between science and art

Though our presentation of some of the epistemic criteria above aligned with a single disciplinary area, teachers' discussions freely veered between fields. They routinely called attention to the differences between their perspectives, and actively constructed connections between them that seemed to dissolve the distinctions between their fields. For instance, the group below discusses how there is room for difference in implementation of LS between their classrooms, while still allowing for and valuing a convergence of disciplines.

Adam: So, you said something about photosynthesis downstairs and it had me thinking about what's the transformation of light into energy. Or light into substance actually. Because it takes light and somehow turns it into sugars through the plant's process… So my questions there was how are things being transformed? Or how do we explore or demonstrate a transformation...

Hannah: So it sounds like your big theme is transformation, where's mine seems to be more about telling a story with data.

Kate: For me it's more along the line, you know, how exactly the plant processes and then representing that. The data that we collect.

Researcher: It is possible that we could all have different big questions and ways to introduce it.

Kate: I think that they all kind of go together. At the same time. I mean this data often shows these transformations. And we can do it through the lens of plant processes.

[conversation about whether to teach art history, art techniques and how to teach art]

Adam: From my perspective I would push them into exploring the material in a deeper way, so we would say, okay this is one way of doing it, but what else is the material capable of? How does the ink flow off a brush? How does it respond to being painted on a flat surface versus a dimensional surface.

How does the object take up space? How does it look from all around? These are the sorts of... that I would have.

Hannah: And I think that makes it so much deeper. Like if you are into understanding the materials and the paint, the construction of that thing in a way, as supposed to it being sort of just another version of a poster that tells you what to know about photosynthesis.

From this conversation we see the value that Adam (art teacher) places on materials and capabilities. This conversation seems to influence Hannah (technology teacher) as she starts to connect the deeper understanding and manipulation of materials with better understanding of the science. Similarly, Kate (science teacher) initially focused solely on the plant processes, but as the conversation progressed she saw all the big ideas as inherently tied together. Through these discussions new types of questions teachers might ask their students or the way they view their content could be reformulated in ways that would not be traditional for their specific classroom.

Learning computing through attention to artistic and scientific criteria

At times, their aesthetic or scientific aims motivated teachers to learn computing and electronics skills, such as when Adam identified the electronics skills he would need to learn to implement a design goal of the group, by asking how to "arrange the circuits". In another episode, James and Bob wanted a string of lights to blink at a speed proportional to light sensor data. They had an aesthetic desire to depict the garden data a certain way, but to do that James, who had never programmed before, needed to learn about variables, how to manipulate incoming data, and how to create an animation of moving lights. In this episode, James programs and Bob helps him:

James: So now if we set the light level [sets the incoming light data to a variable named "light level"]

James: So now it will go faster if [the incoming light] is brighter? [finishes the program and they test it]

Bob: So now let's add more light. [physically shines a flashlight at the sensor; lantern responds by having a slower movement of the lights in a chasing motion]

James: Right, so a longer pause because it's a bigger number, right that makes sense, so it actually blinks slower.

Their representational choice originally had been that more light would make the lights go faster, but because they used a linear mapping from the sensor data to pause time, James found it had the inverse effect. The overlapping of art, science, and technology practices within this project allowed James to learn not just about the science, but created a meaningful context to learn programming from Bob in order to achieve the artistic representational ends he desired, and to observe the cause of an unintended relationship between data and their visual representation.

Discussion and conclusion

Through this weeklong transdisciplinary teacher workshop, we examined how co-design of a nexus learning environment could support teachers' explorations of representational practices and values from each other's disciplines. As they prototyped lanterns to visualize scientific data, they learned to use new representational forms (e.g. Nebuta lanterns, computer code) and tools (e.g. programmable micro-controllers).

Metarepresentational competence has generally been valued in the literature as mastery over a set of skills that support students' science learning. In some of that work, students are invited to invent their own representations, before being pushed to work with canonical representations (diSessa et al., 1991). In contrast, our co-design processes envisioned learning experiences that value students' artistic representational inventions in and of themselves. Further, teachers' lantern construction work functioned as a nexus learning environment for them, with metarepresentational discourse being central to the teachers' collaborations with one another. In particular, the question of how to present a meaningful representation of data was a critical thread that connected disciplinary practices and values from the arts, computing, and sciences. The project allowed for multiple ways to be recognized as expert within the teachers' collaborations, illustrating how nexus learning environments can create room to value a more diverse set of skills and perspectives within STEM education, and change what "counts" as a science representation, or even as a way of "doing science" or "doing art." We note that teachers' discussions of criteria for their lanterns seemed to address a larger terrain than prior research on epistemic criteria has attended to; while we can conceive of the lanterns as models of biological phenomena (as in Pluta, Chinn, & Duncan, 2011), we, the researchers, and the teachers both valued elements of them that went beyond representing scientific processes (e.g., Bob and James' gnomes, and the face of the "tree spirit" in our own lantern).

A limitation of the workshop was that it only included one active art teacher, so each group did not have as much direct access to the perspectives and practices of an expert art teacher; the metarepresentational talk within the most diverse group (with CS, art, and science teachers) seemed especially rich to us. Adam's expertise on art and art teaching was called upon by other groups. Additionally, groups tended to have only a single teacher from each discipline, so there were times when scientific misinformation went unchallenged, something less likely to occur within mono-discipline co-design. An intriguing result of the group's work together was the production of several storylines with overlapping but divergent narratives. The teachers discussed values and practices from each other's disciplines, noting affordances for their own work, which led to overlaps in storylines; but also noting challenges due to differing contexts (e.g. schools, concepts) which led to differentiations in storylines. We will address these convergences and divergences during the co-design process in future papers.

As this was a study of teachers' collaborating in co-design, and not a classroom implementation, we do not yet know how this nexus approach would create opportunities for more inclusive student participation in science. We are optimistic that the generousness with which the teachers embraced each other's perspectives within the co-design would translate to their classroom practices. The teachers who participated in this study are currently implementing LS in their classrooms; in a future paper we will examine how these implementations realize our aims of expanding the kinds of values and practices that can exist simultaneously in the classroom, and how doing so creates space for teachers to apply their disciplinary expertise in support of learning experiences for students that embrace a variety of identities, values, and practices for learning.

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Acknowledgements

We thank Oracle and the National Science Foundation (awards 1227530 and 1562040) for supporting this work.