Chapter 4
Design Thinking Gives STEAM to Teaching: A Framework That Breaks Disciplinary Boundaries

Danah Henriksen, Rohit Mehta, and Swati Mehta

Let us search … for an epistemology of practice implicit in the artistic, intuitive processes which practitioners bring to situations of uncertainty, instability, uniqueness, and value conflict.

~ Donald Schön

Introduction: A Design Framework for STEAM

In this chapter, we present a multi-threaded argument to suggest how design thinking can be an excellent framework for developing STEAM education. We note that STEAM is broader than mere arts integration in STEM. It reflects a view of education that is more creative, real-world-driven, and problem- or project-based in nature. To develop learning content and experiences that offer creative, authentic, real-world, and problem- or project-driven focus, teachers need more than an argument—they need a guiding framework. We suggest that design and design thinking are natural areas of interconnection with STEAM, both for learners and teachers. These ideas can be used to frame STEAM-based experiences that are more open, creative, project-based, and real-world-driven. Here, we discuss the nature of the connections between design and STEAM and focus on how teachers can use design

D. Henriksen (✉)
Arizona State University, Tempe, AZ, USA
e-mail: danah.henriksen@asu.edu

R. Mehta
California State University, Fresno, CA, USA
e-mail: mehta@csufresno.edu

S. Mehta
Michigan State University, East Lansing, MI, USA
e-mail: mehtaswa@msu.edu

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thinking practices to help them redesign curriculum to transition from STEM to STEAM.

Integrating the arts and sciences in educational settings is essential, as historical evidence demonstrates that the most effective and innovative STEM practitioners draw on both scientific and artistic knowledge and experience (Piro, 2010; Shlain, 1991; Simonton, 1988). However, in practice, the field of education has struggled to realistically blend these disciplines into a STEAM approach (Jolly, 2014, 2016). In part, this may be because the acronym of STEAM suggests that the approach is merely as simple as plugging art into the STEM fields (Piro, 2010). But we suggest that STEAM, in educational terms, may often be far more intricate than any simple combination of the arts with science, technology, engineering, and/or mathematics. Both the arts and STEM disciplines have long suffered from narrow stereotypes that position the sciences as rigid, analytic, cold, and logical and the arts as softer, more intuitive and emotional, and less logical (Feist, 1998). Yet research and expert practitioner experience often show us that this is not true (Henriksen, 2011; Henriksen & Mishra, 2015; Root-Bernstein & Root-Bernstein, 1999; Simonton, 1988). At times, or in certain contexts, these distinctions may hold. But in many other contexts, the sciences in practice often have elements that are aesthetic, interpretative, intuitive, and cultural, while the arts can also be logical, analytical, rational, and process-driven (Caper, 1996; Snow, 1959).

Disciplinary knowledge and practice varies across contexts, and creative thinking drives much progress and knowledge construction—in the arts, STEM, and other disciplines (Root-Bernstein & Root-Bernstein, 1999). The core of STEAM is about learning that blurs the lines of disciplines and is creative and problem- or project-oriented, with real-world complexity. Thus, STEAM learning, teacher cognition, and teaching practices need to have processes that respect this richness and that help teachers develop creative curricula that is instantiated in real-world learning connections. We propose that design as a discipline and a thinking process is an ideal theoretical framework to tie all these threads together. We argue that design can help teachers think in ways that are more problem-oriented, creative, and real-world in their approaches, thereby blurring the disciplinary boundaries across STEAM.

The arts and STEM disciplines both function in ways that intersect within, between, and across disciplinary lines (Mishra, Henriksen, and Deep-Play Research Group, 2012). More importantly, real-world discovery and knowledge building in STEM disciplines revolve around skills and contexts—like creativity, problem-solving, and authentic, real-world problems and projects (Connor, Karmokar, & Whittington, 2015)—that are often associated with arts. The heart of STEAM projects is not just about the application of the arts to the sciences or vice-versa. This is not to say that simple combinations of different subject matters like art or STEM might not produce interesting or fruitful approaches to STEAM. But we do assert that STEAM as an educational paradigm is broad and there is immense value in expanding the perspectives on the intersections of arts and STEM that go beyond simple combinations. A simple inclusion of arts in STEM as an additional, occasionally visited lens, may certainly be part of the picture. But as others have recently begun to suggest (Jolly, 2014, 2016; Madden et al., 2013), the heart of STEAM education lies in an interdisciplinary approach, which respects the arts and the sciences alongside other disciplines, by equally engaging the analytical and intuitive, the logical, and the aesthetic. The core of STEAM then is not about just STEM or the arts. STEAM learning is about richly integrating subject matters in transdisciplinary ways that engage people in creativity, problem-solving, and project- or problem-based learning, in issues of real-world impact. This implies moving STEAM into a more inclusive paradigm, beyond the mere connection of art and science, and into an arena that speaks broadly to creative, interdisciplinary, real-world, and inquiry-based learning. Along these lines, STEAM has been defined as such:

> STEAM is an educational approach to learning that uses Science, Technology, Engineering, the Arts and Mathematics as access points for guiding student inquiry, dialogue, and critical thinking. The end results are students who take thoughtful risks, engage in experiential learning, persist in problem-solving, embrace collaboration, and work through the creative process. (Education Closet, n.d.)

Design Melds STEAM Together

While scholars have suggested recent different frameworks for STEAM pedagogy (Kim & Park, 2012), few have considered design thinking as a natural and logical approach to STEAM curriculum design for teachers. By focusing on a theoretical framing that inherently connects the arts and sciences, teachers as well as students can engage in work that integrates disciplines.

Design as a creative and flexible discipline epitomizes the intentional blurring of disciplinary boundaries. It is an interdisciplinary area in which art, science, and other disciplines can intersect around human-centric problems (Buchanan, 2001). However, how researchers perceive the role of design in STEAM varies. Recently, a few scholars noted how design as an art form can function as a useful space for teachers to bring STEAM into their classrooms (Bequette & Bequette, 2012; Peppler, 2013). While this approach may offer STEAM opportunities, it is still limited by the fact that it connects the disciplines at their surfaces, while true integration remains a challenge (Radziwill, Benton, & Moellers, 2015). Instead, it may be helpful to consider design at its deeper interdisciplinary roots as a field and view it as a framework of thinking about STEAM in which artistic and scientific disciplines naturally intersect and in which, the core of STEAM is not just about this intersection but about what it means for learning and inquiry.

In this chapter, we suggest that STEAM involves blurring disciplinary boundaries to frame and solve problems—it involves thinking creatively and working on projects that aim at real-world inquiry. We argue that design thinking provides a framework to streamline this disciplinary integration. In teacher education, we have recently begun to use design thinking as a framework and a way for teachers to reframe their thinking about classroom curricula. While this is significant in student learning contexts, we believe design thinking is also a useful framework for teachers to use as they develop more STEAM-based curriculum. Teachers are the central drivers of the work that students do in the classroom, and a significant problem of practice they often encounter involves lesson design and how to make it more project-based, more creative, and thus for STEM teachers, more STEAM-based.

In this piece, we tackle such problems of practice through a design thinking approach in examples of teachers' processes. We initially discuss how design thinking relates to STEAM, by describing design as a disciplinary crossroads between the arts and sciences and a space for creative problem-solving. We suggest that design thinking provides a framework that STEM (and other) teachers can use in their own thinking and curricular design processes, to construct more creative, engaging, and project-based curriculum. We also present three illustrative case examples of educators who have applied design thinking processes in their own lesson design, as part of their work in a design thinking course in teacher education. In this, they used design thinking as part of their teacher education training, to creatively redesign curriculum to be more creative, more problem- or project-based, and driven by authentic real-world learning. In short, to make lessons more STEAM-based.

In summary, we describe the connections between design thinking as a framework for STEAM more generally and exemplify how STEM educators may themselves work through design thinking to build STEAM curriculum. We begin by providing the theoretical foundations of design as a discipline, arguing for its role as an artistic, scientific discipline for human-centered problem-solving and creativity.

Design and STEAM: Creative, Interdisciplinary, Human-Centered Problem-Solving

Educational policy is often constraining and unsupportive of teacher creativity in lesson or curriculum design (Cohen, McCabe, Michelli, & Pickeral, 2009), particularly for teachers attempting to build integrated or STEM approaches that veer away from textbook curriculum. Teachers, like many people, often feel uncertainty about their own individual creative potential (Cropley, 2016)—making it difficult to identify and enact good solutions in lesson design. Scholars have recently begun to discuss possible approaches toward creative thinking via the path of design thinking. As an interdisciplinary realm, design employs approaches, tools, and thinking skills aimed at helping designers devise more and better ideas toward creative solutions (Kelley & Kelley, 2013). The term "design thinking" refers to cognitive processes of design work (Cross, 2001, 2011; Simon, 1969)—or the thinking skills and practices designers use to create new artifacts or ideas or solve problems in practice. In many ways, the interdisciplinary nature of design, and creative, problem-based approach, makes it a useful framework for STEAM integration—for students certainly but also for teachers. In understanding how design and design thinking can function as an area that connects to STEAM, it is helpful to examine the foundations

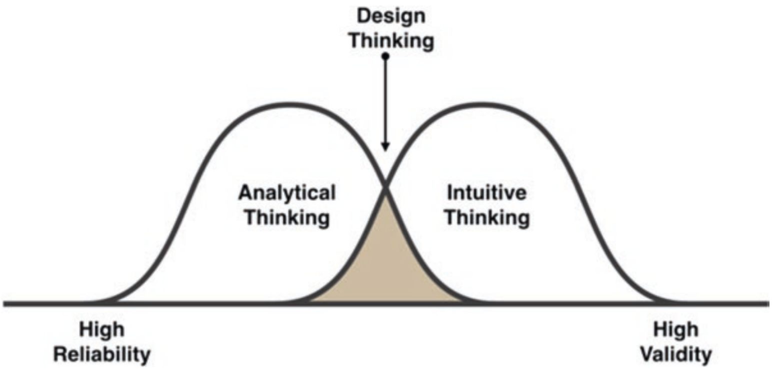

Fig. 4.1 Design thinking

of the discipline. At some level, what we assert here is that design is inherently, in and of itself, STEAM—because it engages the analytical and intuitive both jointly in artistic and scientific ways (see Fig. 4.1).

The arts and sciences are often traditionally spoken of as distinctly different realms which call on different skills. There is a mythology around the idea of the "hard sciences" versus the softer more inimitable artistic disciplines. But creativity researchers and designers both have often pointed out that this is a false dichotomy (Root-Bernstein & Root-Bernstein, 1999). Creativity, as a meta-level thinking skill, is central to STEAM as well as to design, in that it drives most impactful thinking not only in the arts but also in the STEM disciplines. Design highlights the falseness of this dichotomy between arts and STEM, as it naturally fuses them together and acts as a reminder that disciplinary boundaries are blurrier than we often think.

Design lies at the intersection of art and science and applies to a wide range of human-centered disciplines through creative work (Cross, 2011; Weisman, 2012). It is a creative process of intentionally developing something that does not yet exist—something that is novel and effective, and therefore, inherently creative (Cropley, 2001; Fox & Fox, 2000; Oldham & Cummings, 1996; Zhou & George, 2001). Thus, both analytical thinking and divergent creative thinking are keys to design processes (Kelley & Kelley, 2013). A designer's work is iterative and often idiosyncratic, but designers' creativity and design choices are scaffolded and informed by common processes (Buchanan, 2001). These design thinking skills give flexible support and grounding to the open-ended arena of creative practice that lies at the intersection of the arts and sciences (Hoadley & Cox, 2009; Watson, 2015).

Herbert Simon (the Nobel Laureate who founded design as a professional field) offered a definition of design that reflects how applicable it is to human-centered problem-solving:

> Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state. (Simon, 1969 p. 130)

Here, design crosses many fields of human endeavor around complex problems and creative solutions—most notably, constructing knowledge and enacting change. This is evident in the statement that "everyone designs" provided that their goals include "changing existing situations into preferred ones." Buchanan (2001) notes that design involves using human ability for creative problem-solving around ideas, processes, or systems that serve needs. Design involves directing creativity toward goals, actions, and purpose around real-world issues (Collins, Joseph & Bielaczyc, 2004; Hoadley & Cox, 2009). This situates design as a creative problem-solving and thinking approach at the core of human-centered problems and areas, such as teaching, learning, and problem-solving within a STEAM paradigm.

While design has increasingly been noted as a framework for integrating STEAM into what students do, it may also be a productive avenue for teachers to use in their thinking processes as they look toward curriculum design. Using design processes in their own thinking, they may be better able to enact change in the classroom and rethink curricula or lesson design toward more STEAM approaches that are interdisciplinary, creative, and project-oriented. In this, design becomes a way of thinking for teachers as well as learners.

Design Thinking and Teachers: A Path to Creative Learning Design

Many scholars (Kirschner, 2015; Koehler & Mishra, 2005; Norton & Hathaway, 2015) have discussed design as a theoretical lens for teaching and learning. But it has not always been explicitly connected to STEAM, though some have drawn implicit connections. Donald Schön (1983) integrated design as a creative thinking process across disciplines. Schön described how human-centered professions call for "an epistemology of practice implicit in the artistic, intuitive processes which [design and other] practitioners bring to situations of uncertainty, instability, uniqueness and value conflict" (1983, p. 49). This emphasizes design as a creative and reflective action—an ongoing dialogue between processes, people, and materials in real-world problems and work.

Mishra and Koehler (2006) developed their theory of teacher knowledge around the concept of teachers as designers. They underscored the role of educators in working with tools, content, and ideas to design experiences for learners. This suggests that teachers need experiences which place them distinctly in the role of designer, to enhance their knowledge for creative lesson design and crafting learning experiences.

Norton and Hathaway (2015) have noted that teachers are increasingly challenged to be creative in building innovative practices for twenty-first century educational contexts, such as taking STEM to STEAM. Kirschner (2015) describes how the demands of the twenty-first century education, and the creative design aspect of teachers' work, are different from traditional views of teaching as doing or implementing something that already exists. Teachers must be able to be creative designers of learning experiences for students, and this often requires moving traditional STEM work into more STEAM-based learning. Scholars have noted that the professional and creative capacity of teachers is a primary driver and determinant of the experiences of students in school and the types of twenty-first century skills they develop (Darling-Hammond, 2001; Kalantzis & Cope, 2010). But teacher education and professional development has often struggled to give educators specific tools and ways of thinking that help them confront complex and diverse educational problems of practice. For example, a key problem of practice involves creating learning experiences that are more STEAM-based, by way of being more project-based and real-world oriented with a focus on creativity or problem-solving.

As part of our work in teacher education, we developed a course in design thinking, for graduate-level teachers to use in addressing problems of practice. The teachers learn about design thinking and use it to work on and create solutions around their classroom practice. Many of the teachers choose to use design thinking as a framework for helping them to redesign lessons and curricula. Several have aimed at creating lessons that have more elements of a broad STEAM paradigm—in creating curricula that are more creative, project-based, and focused on real-world relevance. In these endeavors, they demonstrate how design thinking is a useful teacher thinking framework, for helping teachers redevelop curricula or lessons toward STEAM. We share several in-depth examples of teachers' design work from the course along these lines. But first, to provide readers more context, we begin with a brief overview of the design thinking model we used: *the Stanford design school model*. Then, we share a brief overview of the course structure and assignments to get a sense of what the teachers were asked to do. Finally, we provide more details through the examples of the teachers' work, followed by synthesizing conclusions and implications about design thinking, STEAM, learning, and teacher education.

Design Thinking in the Stanford Design Model

Design thinking as a term denotes the cognitive processes or thinking skills that designers use to do their work (Watson, 2015). There are many different variations of design thinking models available in the field, most of which have areas of similarity or overlap in themes. And as there is no one best way to approach design thinking, it comes down to exploring and choosing a model that fits well. Design thinking has increasingly been discussed and used to integrate STEAM into more engineering domains, but it also stands by itself as a framework for thinking and problem-solving that spans the arts and sciences. Engineers may use design thinking, but so may visual artists (Boy, 2013; Brophy, Klein, Portsmore, & Rogers, 2008). One of the most popular, commonly noted, and well-established design thinking models is the Stanford design model—created within the Stanford School of Design (Plattner, 2015). This was the guiding model for our teachers to use as they rethought their curriculum in STEAM-based ways, so we provide an overview of it below.

The Stanford model has five phases or stages of design thinking, also referred to as modes, which are worked through toward a problem solution or resolution. These five modes are *empathize, define, ideate, prototype,* and *test*. While we describe them in linear fashion, design thinking is actually an iterative process (Plattner, Meinel, & Leifer, 2010). Designers, teachers, and others can cycle through the process or reenter modes as needed, to understand or explore problems and solutions.

The first mode is **empathize**. Empathy is at the foundation of human-centered design and an essential starting point for any type of design work (Plattner et al., 2010). In this mode designers observe users and their behaviors, interact with and interview them, and try to immerse themselves in understanding the experience and perspective of the user. One might ask questions, listen to stories and experiences, observe their interactions, or explore their world to understand their feelings, ideas, and reasons for behavior. These insights allow designers to approach the rest of the design process with a stronger understanding of the context and problem. Many design models begin the design process with problem identification. The Stanford model requires the designers to first empathize with the people that are experiencing the problem.

In the second mode, the **define** mode, designers use the insights gathered from empathizing to focus in on the problem. They purposefully go beyond a simple definition as they describe the complexities of the user, the problem, and the context. The problem solutions depend on how the problem has been defined. In this mode designers articulate a problem statement based on the understanding they have gained previously. They focus and frame the problem, to guide the design efforts moving forward (Plattner, 2015).

The third mode, **ideate**, explores a wide volume and variety of solutions and ideas (bootcamp bootleg). The goal is to go beyond the obvious to generate far-ranging ideas, solutions, and approaches connected to the problem. Designers must go wide with ideas, keeping the problem in mind but also letting flights of fancy bring up new and creative ideas. Deferring judgment on evaluating ideas provides a sense of freedom and allows for the unconstrained development of ideas.

After designers have generated numerous ideas, they put those ideas into action in the fourth mode of **prototype**, by creating a possible prototype or a model of a solution(s) to the problem (which can later be tested). Prototyping is the act of making ideas concrete. It is not an attempt to arrive at a final solution but an opportunity to jump in and make ideas concrete. A prototype might be a physical object, but it also might be a storyboard, an activity, a drawing, or more.

In the fifth mode of **test**, designers test the prototype with actual or representative users/stakeholders. Designers might interview users, observe them interacting with the prototype, or use any other process to gather feedback for refinement of the solutions. Testing may show that a designer must refine the prototype, or redefine and reexamine the original point of view, or possibly revisit the empathize mode to understand users, or return to the ideate mode to explore alternative solutions.

The framework of these design thinking modes and tools was beneficial in guiding these educators toward new possibilities and solutions. In the next section, we describe the course itself and how the model was applied to the structure of the course and assignments.

Overview of the Course: Design Thinking for Addressing Problems of Practice

"Learning by Design" is an online course offered as part of the Masters of Educational Technology program in a College of Education at a large Midwestern (Big 10) university. The first author of this study was one of the course designers and instructors. The course is fully online, and students were educational professionals from a range of settings and contexts (mostly teachers, with a small mix of administrators, instructional designers, counselors, and others). In this course, design thinking was introduced to be used in ways that serve their own specific and local needs and interests.

The syllabus description states, "this is a course about design. Design as practice and a process. Design as it relates to education and the world around us." The course was broken into seven modules of 2 weeks each, with an introduction module to cover basic ideas about design, followed by a module for each of the phases of the Stanford d-School module (for empathize, define, ideate, prototype, and test) and then a concluding module to finish and summarize. Each module consisted of several key parts, including readings and discussion, a problem of practice project, module labs, and a final reflection paper. A bit more description of each aspect of the work is as follows:

- **Readings and discussion**: This involved ongoing participatory class discourse around design themes, in which individual readings suited to each phase or design topic were assigned, with discussion questions tying these ideas to educational practice and themes. Discussions were both at the whole-class level and in smaller groups.
- **Problem of practice design project**: This was the major semester-long project, in which each student selected a problem of practice area that they approached in their context, and, over the semester, worked on the issue, through each of the phases of the Stanford design model. Each specific phase included associated deliverables, such as an "empathy report" for the empathize phase, to include the findings from their empathy research with the audience/stakeholders, a problem definition statement from the define phase, a record of a brainstorming session (sketches, recordings, images) for the ideate phase, a basic model/mock-up of a possible solution (or solution set) for the prototype phase, and an overview and reflection on the results of a user/audience-test for the test phase.
- **Module labs**: These were shorter, more informal, and creative activities done in each module. Labs were designed to allow students to engage deeply with the phase/theme of the module as an idea, with a focus on creative "out-of-the-box thinking," while engaging with big ideas. Labs were not connected to the larger

design project but simply smaller guided, fun activities. For example, during the empathize phase, students did “A Twice-Told Tale,” in which they told a real short story from their own life (or someone they knew), then reimagined, and retold it from another different perspective of someone else involved in the original event/story. They reflected on how a situation might look completely different when you put yourself in someone else’s shoes. For the ideate phase, students kept an “Incubation/Idea Journal” with them for the week, in which they informally noted or sketched any interesting or creative ideas that emerged in their thoughts, whenever they had them. They then reflected on the practice of actively notating emergent ideas (as an alternative to schedule brainstorm sessions) for ideation. Each module had an associated lab activity which was geared at more informal and creative approaches to the design thinking phase.

- **Reflection paper**: This was a final paper in which students reflected and looked ahead to their learning and goals around design thinking, with an eye to future practice.

The Stanford model’s modes of empathizing, defining, ideation, prototyping, and testing structured core activities that teachers in the course applied as a lens for their educational problems of practice. In the next section, we discuss several examples of teachers who used their design thinking project work for this course to redesign aspects of their students’ learning. Through this they reflect on the usefulness of design to help create activities for students that have more STEAM elements. These examples are offered not as “case study” per se in methodological terms but rather as descriptions of illustrative cases that allow readers to better grasp how teachers can work toward design thinking processes that rethink curriculum. This rethinking can allow for more STEAM elements of interdisciplinarity, project-based learning, creativity, and open-endedness.

Building Toward STEAM: Examples in Teachers’ Curriculum Development

All teachers in the Learning by Design course identified a problem of practice to focus on and applied design thinking to their problems. The problems of practice that students in the course addressed ranged across many different issues of teaching (from classroom practices, to parent-teacher communication, to varied issues of teaching and learning). As course instructors, we noticed a particular resonance for students who were using design thinking processes to help them rethink curriculum in ways that were more creative and compelling. This rethinking had different aspects based on each teacher’s goals and context. However, all have at least some elements of our expanded interpretation of STEAM, as involving learning that is more student-centered, problem- or project-based, creative, real-world, or interdisciplinary. In this section, we take three of our teachers and share their individual cases of taking a design thinking approach to curriculum development to tease apart the intersections of modes of the Stanford design model.

Design Thinking in Biology: Creative Problem-Solving

Adam, the lead biology teacher at his school, redesigned the ninth grade biology curriculum of his school to align with the Next Generation Science Standards (NGSS) by using the Stanford design thinking model to rethink his current practices. His goal was that, while making curriculum align better with NGSS, he would also try to make learning more engaging, more creative, and more project-based—which fits well with the broader vision of STEAM that we and others (Jolly, 2014, 2016) have noted.

Adam perceived design thinking as a process that guides you to design any kind of product you desire to make—which in Adam's case was a more student-centered, engaging, and project- or inquiry-driven STEAM curriculum. In his five-phase design process, Adam employed the first stage of *empathy* by interviewing his 16 ninth-grade students, one general biology teacher, and one advanced placement biology teacher. All the students were chosen at random from those enrolled in the second trimester of Biology B (the second and final freshmen biology class). Few students were chosen from sophomores, juniors, and seniors who had taken the biology class and were interested in providing input. His main aim in this phase was to understand the perceived strengths and weaknesses within the present curriculum.

Adam wanted his students to be more successful in biology, and toward that end, he wanted them to be more excited and engaged in science. During the interviews, Adam asked his students to provide specific feedback regarding the probable changes that they wished to see in the curriculum, the pacing of each unit, the structure of each unit, and the lab/activities used within a given unit. The teachers were also asked to respond to the same questions. Both the teachers and student responses were obtained through a live lesson teaching demonstration followed by classroom discussions. Adam found that while the student feedback desired more lab activities, teachers focused on "specific units or activities" that needed change and a need for "deeper understanding for concepts." In his work, he commented that:

> The design process of empathy allowed me to understand the current curriculum was not as engaging as the teachers thought. The students desired more lab activities, and more work that connected them to what is going on in their world. They wanted more of a long-term project-based approaches, such as what they've done in other classes, and would like to see in biology.

From the interviews, Adam concluded that a constructive redesign for his biology curriculum would require an interconnection across these two sets of student and teacher feedback.

Moving to the *define* phase, Adam used the *5 Whys model* to explore and define his problems of practice. The *5 Whys model* is a design-based interrogative technique that helps people understand the root causes of a problem, by asking “why?” a problem exists multiple times to uncover the reasons behind an issue. For example, one way a teacher approach engages this *5 Whys* technique after interviewing or observing students to understand why they are not performing might be:

1. Students aren’t performing in biology classes. Why?
2. They are not engaged in coursework or class sessions. Why?
3. They find the content boring or unrelated to their world. They don’t see the excitement or curiosity that’s possible in science. Why?
4. The current curriculum does not reflect any of these things or give them opportunities to see connections or explore. Why?
5. It’s based on outdated methods that don’t reflect constructive, creative, project-based inquiry and needs to be redesigned with these ideas more in mind. Why?

The number of times a designer asks “why?” might vary, and the answers vary with the information they receive in their context, but the core principle remains the same. We need to understand what students need, and in the case of this biology course, what they needed intersected with STEAM principle and new science standards.

Attempting to define his problems led Aaron to explore the reasons for the curriculum revamp. He realized that the reason for him to consider changing his curriculum was based in the fact that, lately, his students were not performing to the standards that teachers and the school had set for them, because the science instruction in its current form allowed for no in-depth creative, project-based work. Hence, Adam’s focus was now to redesign the units with lab activities integrated within them and suggests possible alternative assessments to replace the current exhaustive ones.

Having defined his problem of practice, during the *ideate* phase, Adam held a couple of brainstorming sessions with other science teachers, starting with the following question: “Since the NGSS has been adopted, what are some of the things we need to incorporate into our classrooms to align with the new standards, while making sure we maintain the integrity of our teaching?” In response to this question, teachers’ feedback generated some interesting ideas on how to introduce new units with few essential questions, making groups where student choose which of these essential questions they would like to address at the end of each unit to promote more inquiry-based in-depth learning. He did brainstorming around formative assessments with the students and integrated them within each unit, using engaging discussion questions, aligning lessons across disciplines, and, finally, integrating free response-type questions to allow a more blended and interdisciplinary approach in which students could practice writing and thinking more freely about science content. This is a series of subtle but powerful moves, in which a traditional curriculum moves toward more STEAM-based learning.

Building off ideation, Adam moved to the *prototype* phase, which comprised of setting up a test unit implementing the changes that were highlighted through the design thinking process. He started working on new lab activities, redesigning units/lessons to integrate new activities, create collaborative lessons and activities to integrate teachers' ideas and prepare essential driving questions and presentations, and design alternate, inclusive, and formative assessments decided in the ideate phase. In this final paper, he discussed his process of thinking in the prototype phase:

> For this prototype phase of the process I created a timeline of activities and lessons in a sample unit plan. I wanted my colleague to have the flexibility to utilize their strengths while keeping the format to the unit intact. The changes I made from our traditional unit to this prototype were not radical at all but more practical and based off the input from the empathize phase. Included in the sample unit plan was the inclusion of a long-term alternate assessment of a presentation based upon essential questions. The essential questions were formatted in a way that students had to complete some research and come up with their reasons why the problem exists and how they could solve it or to predict what would happen if the problem continued to exist.

He added all these pieces into a calendar to visualize the teaching plan, keeping them in synchronization with the overarching expectation of integrating the Next Generation Science Standards (NGSS) curriculum.

During the last phase, the *testing* phase, Adam realized that before revising the entire biology ninth grade curriculum to align with current NGSS standards and more STEAM-based instruction, he should best begin in a focused way, by first aligning one unit to the NGSS curriculum and using it as a test to work on the others. This unit was on genetics. Then, he followed the feedback from the empathy interviews and implemented a restructured curriculum design in two classes. This new curriculum included more open-ended inquiry, as well as science project work that framed a genetics topic around a real-world issue that students had to go in-depth around doing more research into, then discuss what the root causes of the problem might be, and creatively brainstorm on multiple in-roads to the problem. This brought the work more clearly into a STEAM paradigm, in which science problems emerge in real-world scenarios that draw upon multiple disciplines, in complex problems that require us to engage multiple possibilities.

Adam added another teacher to test his prototype unit, to get a second perspective (and some validity) on his revised approach. He designed new open-ended questions to obtain feedback from students and a separate set of questions for the teacher. He randomly picked three students from each of the two classes. In his interviews with them, he found that students who had favored new activities in the empathy interviews were appreciative of the change. Others, who were skeptical before, were open to new activities but expected to take some time to get comfortable. The other teacher, on the other hand, noticed more engagement in his class, deeper questions, and better understanding of content. Getting a second perspective on his prototype gave Adam an unbiased take on his design.

Making Design-STEAM Connections

Overall, according to Adam, the process of design thinking allowed him to reflect on his teaching practices and obtaining multiple perspectives on the curriculum. It helped him evaluate issues that were important to both the students and the teachers alike. An important outcome of this design process was the realization and interest of other teachers in redesigning their own curriculum toward more STEAM-based knowing in the sciences. For Adam, this process of design thinking helped him engage his own creativity around a rethinking of curriculum, which allowed for the creation of work that could engage students' creativity, as he noted:

> The design process has forced me to become a little more open minded about solutions and to allow for radical changes. The process allowed me to consider more radical solutions and that is something that I had not always been comfortable doing. When I am considering solutions to a problem or re-designing something, I am normally laser focused with my solution and do not always consider all of my options. The design model has given me the confidence to know that my first idea does not have to be the final answer, and has be rethinking other aspects of my teaching.

He also underscored that he learned how the process of change is slow but constructive feedback from peers and students can lead to effective results, in bringing curriculum from STEM toward STEAM.

Adam's entire search to refine his curriculum while finding innovative ways of integrating new practices taught him that new was made from existing. Creativity is the process of creating something that is *novel* and *effective* (Fox & Fox, 2000). He learned that existing tools and texts could be rearranged in unique combinations to create something that was unique and, therefore, *novel*. However, it also had to be *effective* for his purposes. The design thinking process helped him test that he found something new and whether it was effective or not—thereby thinking creatively all along. Through design thinking, Adam demonstrated how creative problem-solving could make curriculum redesigning an effective process. While we are careful not to suggest that his initial work here is a perfect example of a complete move to STEAM, it is still a step in the right direction, toward a curriculum redesign that is more inquiry-based, project-based, real-world and creative in its approach. It reveals how design thinking becomes a process for rethinking curriculum that naturally engages the analytic and process-based, and the intuitive or creative.

Breaking Traditions in Spanish: Going to the Real World

Katherine, an elementary Spanish teacher in a Midwestern urban school, used design thinking to help her recreate an aspect of her curriculum in a more interdisciplinary, project-based way, by engaging the social aspect of science in an experience for the fourth grade students in her school. Katherine's example is an interesting one in that her teaching content is not STEM but what she designed took a STEAM-related approach. STEAM approaches are often discussed as involving the infusion of arts into sciences, or at least with a focal point on STEM disciplines. But we forget that STEAM also means that STEM disciplines can be woven into art. Root-Bernstein and Root-Bernstein (1999), among others (Simonton, 1988), have noted that exceptional thinkers across disciplines tend to combine ideas across subject matters and that accomplished thinkers working across the arts and humanities often draw upon ideas from STEM disciplines. The essence of STEAM is to cut across disciplinary boundaries to see how projects and learning unfold in more complex real-world terms.

Within her teaching area of Spanish language, Katherine undertook the issue of teaching her students about water crisis, a major community concern in some Spanish-speaking countries, to help students analyze the importance of clean and safe water usage. The main aim of her project was to introduce her students to new Spanish words using water as the center of conversation. She collaborated with two of her elementary Spanish teacher colleagues to ensure multiple perspectives on redesigning the curriculum based on the needs of students. The interdisciplinary STEAM focus of the project she created led students to not only research the scientific dimensions of water usage but to consider problems that occur across countries, learn about the water cycle, and come up with a way to teach other students about the intersection of these issues.

In her design thinking project, for the *empathy* phase, Katherine focused on understanding students' prior knowledge and experiences on the topic of water crisis. She started by administering a survey comprising five questions to her fourth grade students. An example of one of the survey questions she asked is, "What do you think happens when people don't have clean water?" Following the survey, she randomly selected few of her students to get a better understanding of their daily water usage and their conceptions of the necessity of clean water. Then she introduced her students to a hands-on game where she provided them with clean and dirty water tokens, where dirty water tokens significantly exceeded the clean water tokens in number. This way when they exhausted their clean water tokens, they had to make use of the dirty water tokens. This process helped Katherine gain insight of how her students' experiences of using dirty water shaped their conceptions of water shortage issues at their home and within their own community. She also observed increased sense of empathy among her students, as demonstrated in their acts of sharing clean water tokens with each other to sustain longer.

Having analyzed students conceptual understanding of water issues in the empathy phase, Katherine moved to the *define* phase to explore her problem statement in depth. Like Adam, Katherine used the five-why approach to understand the importance of project-based learning (PBL) in her classroom. Her aim was to understand her students' motivation to engage in project-based learning, their reasons to care about real-world issues in their community, their understanding of the importance of water, and why it is an essential element for human existence. To implement the project-based learning process, Katherine included videos of water usage activities from Spanish-speaking countries to help her students envision theoretical discussions. This was a precursor to helping students integrate both art and science, in designing their own water cycle diagram and labeling at least eight words in Spanish in the diagram. Then the students presented their work to peers in a different section in form of student-created slideshows, posters, or brochures.

Katherine collected data by taking photographs of students' water cycle diagrams, facilitating informal discussions, and recording (audio/video) students' in-class online research activity. Through this process, Katherine observed that students presenting their work to their peers helped them foster meaningful discussions and reflections around community issues in which disciplines connect. Sharing their work helped them gain a sense of ownership, which connected them more to the issue.

Moving to the *ideate* phase of design thinking, Katherine mapped out 6 weeks of project-based classroom activity. Along with her teacher colleagues, she decided to implement formative assessment tests to grade students' progress in their projects. During this phase, she used a journal to record her brainstorming sessions with her colleagues and reflected at the end of each day on the feasibility of implementing these ideas. To keep her students engaged, Katherine also decided to raise funds for a prize for the best presentation and most practically designed water cycle diagram.

In the *prototype* phase, Katherine outlined her observations from the previous phases in a Google document to structure a more organized and shareable conceptualization of her activity. This also helped her to gain a deeper insight into the evolution of her lessons and how she scaffolded her students at each step. This prompted Katherine and her colleagues to realize the complexity of making water issues more understandable and accessible to their students, which resulted in her creating a website for the students: https://sites.google.com/a/apps.harpercreek.net/cleanwaterproject/introduction. The website gave students clear guidelines for the project-based activity and defined the tasks and processes they were required to undertake to complete their projects. Katherine and her colleagues updated this "student-friendly" website with additional resources as an eminent part of her implementation phase, focusing on both student and teacher needs.

The final phase of design, *testing*, helped Katherine reflect on her approach as a two-step process. The first step included conducting interviews and discussions, and observing student knowledge of design and labels in Spanish. The second step consisted of introducing students to different online spaces, providing them with different texts and tools, like games and videos, while she observed their choices and facilitated discussion. Formative assessments allowed her to gain insight into her students' understanding and helped her redefine, modify, and present the problem in different ways to fit the needs of her students. She also ensured that students had time to become familiar with the website, which she used to observe their choices, interact with them, and receive feedback.

Making Design-STEAM Connections

Katherine's real-world approach to problem-based learning provided an opportunity to understand students' individual needs, their interests, and their conceptions of community issues in a STEAM project that blended elements of the arts, humanities, science, and social issues. Her design thinking approach strengthened her bond with her students, which was evidenced in her students' sense of agency in sharing of documentaries and informational videos with each other and her, manifesting their engagement and interest in the activity. For Katherine, this process helped her reflect on her teaching practice, thereby realizing the need for teachers to keep innovating their lessons for student engagement. Reflecting on her traditional curriculum plan, she expressed how design thinking aligned with curriculum development and related to specific components of lesson planning and curriculum development. She credited the cyclical nature of the design process for her enhanced problem-solving skills in building out a STEAM idea into her curriculum and found it to be, in her words, “cohesive to how the brain processes information.” She described how she intends to continue this innovative design thinking process throughout different realms in her professional career toward more creative teaching.

Designing Math for Authentic Engagement: Failing Better

Chloe, a teacher in a Midwestern school, focused on redesigning the second-grade math curriculum of her school to incorporate a student-centered, data-driven curriculum that promotes student interest and engagement along multiple lines.

In the *empathize* phase of design thinking, Chloe started by planning to conduct some research with her students. First, she randomly selected a few students at different academic levels and interviewed them to understand their in- and out-of-school experiences, preferences, and motivations. She also obtained some observational data by sitting in math classrooms where students were engaged with worksheets. One of the classrooms she sat in had a technology-centric opportunity for students to “play and learn” with math. Having access to technologically different classrooms gave Chloe a chance to compare and notice that a student who would be considered disruptive in a “traditional” classroom was constructive, productive, and successful in a thoughtfully instantiated, technology-centric class setting. Through these observations and interviews, she realized the value in seeing math as “multidimensional” and interdisciplinary. She started to experiment integrating activities that revolve around, as she described it, “play, manipulatives, edible creations, reciprocal teaching, and technology.” This infusion of multiple disciplinary approaches, aiming at engaging creativity and different ways of knowing and learning into the mathematics curriculum, started to move her toward a more STEAM-relevant approach.

Chloe’s *define* phase was comprised of *why-how* steps of visualizing the problem. First, the *why’s* helped Chloe understand the problem of time constraint. Math teachers in her school wanted to add new coursework to the existing content. Chloe noted that when the existing curriculum had been developed, the approach taken involved using confusing and incomprehensible math binders. Chloe’s biggest challenge, therefore, was now to find a balance in the existing content and new, innovative coursework, so she could replace the existing incomprehensible material with exciting, creative, and more project-based material. Her task was to address a group of second-grade students who were excited and eager to work with an innovative math curriculum that challenged them intellectually. Taking a problem-solving approach, she saw potential in seamless integration of technology into the lessons, such as hands-on activities with tools, videos, computer lab time, project-based work, and game-based learning, that help students tie in the concepts taught in the lessons to “out-of-school” experiences. She also saw potential in individualized tablet use as a way of practice for each student. She identified greater problems with assessment when assessing student worksheets in math, since they provided a partial understanding. To make help visualize this problem better, she decided to focus on just one unit and make changes to it according to her plan.

During the *ideate* phase, Chloe brainstormed ideas with colleagues during one of her grade-level team meetings. She approached this by introducing her fellow teachers to her problem of practice and possible solutions, looking for ideas to brainstorm. She asked her peers to think freely on the ideas to replace the lesson worksheets, and she focused on keeping the brainstorming coherent. She jotted down all these ideas on a Stormboard (an online brainstorming and planning space), helping everyone to visualize the brainstormed ideas. This helped her reframe her own ideas as well to better suit the students’ needs. This collective reflection process prompted her to look forward to the prototype stage and to refine some of her ideas before adding them to the curriculum.

Following ideation, in the *prototype* phase, Chloe created a structured plan for the new math curriculum that was flexible enough for her peers to use in the future. She aimed at redesigning one unit and prepared activities for 1 week, which focused on first introducing the topic to the students, introducing new learning activities, and through them, on three main components: exploration, collaboration, and evaluation. Each day of her math lessons had a theme that each activity was blanketed under to give students a more coherent experience and a big picture view.

The *test* phase in her redesign included two activities. The first focused on an activity called “Scoot” and the second on taking students to computer labs and using MobyMax to measure their conceptions of math. Scoot involved a set of task cards—with a unique problem on each card, along with a number—that was distributed across the room. Students were asked to walk around at a musical prompt and stop when the music stopped. Then, they had to pick a card closest to them and write down their responses on a record sheet. Throughout this time, they were not supposed to speak to each other nor be on the same task simultaneously. At end of the activity, students discussed their solutions and compared notes. They found this collective problem-solving to be more productive and collaborative. In the MobyMax activity in the computer lab, students went on the MobyMax website to check their mathematical concepts. MobyMax is designed to help identify students’ conceptual gaps. After these activities ended, Chloe chose five students to interview in addition to recording her own observations during the activities. Her analysis of the responses and observations yielded a “hundred percent engagement” among students. Her students loved the Scoot activity and preferred it over MobyMax. Students seemed to enjoy MobyMax the most when there were incentives to earn a high score (for example, earning game time or a badge for every five high scores)—but across the board she found success in her endeavor to make mathematics more creative and engaging for students.

Making Design-STEAM Connections

In addition to the success she found in increasing student engagement through more STEAM-based learning, an important takeaway for Chloe was the relevance she saw in looking at failure as a constructive factor. She realized that it was important to allow failure to ensure explorations toward the best solution for the problem at hand—both as a teacher and as a learner. This is significant in that a willingness to fail and see failure as a productive thing has frequently been noted as a part of most creative thinking, work, and processes (Smith & Henriksen, 2016). Chloe also appreciated the significance of empathizing with her students and gaining an in-depth perspective on what is most important to them. She found value in reiteration and repurposing as a productive step in problem-solving. Creating authentic STEAM-related learning experiences for her students involved going through an iterative process of defining problems and then designing a path to finding solutions for those problems. It involved failing several times and then learning from those failures. In process, Chloe learned that her journey of failing again and failing better was the perfect example of what she wanted her students to experience, because learning through failure was what made it authentic and ultimately led to a more creative result.

Conclusions

Across these illustrative mini-cases, we have tried to exemplify and tie together several ideas. The first is to present the process of design thinking (demonstrated here in the specifics of the Stanford design model) as a viable path for teachers to work through in redesigning or rethinking curriculum, to move toward more STEAM-based learning. We suggest that design has a multi-threaded connection to STEAM, both in providing teachers with a process to reconsider curriculum design and also in that design itself intricately weaves between STEM, the arts, and other disciplinary content. In offering examples in action from several teachers in this course, we hope to show how teacher education might consider design as a framework for teachers, to blend the analytic with the creative in how they think about curriculum. Through this intricate synthesis of analytic and creative thinking, design is itself a form of STEAM-based learning.

In considering how multiple disciplines intersect in the field of design around human-centered problems, we must also realize that most human-centered problems represent a mixture of disciplines (Buchanan, 2001). And within those problems, disciplinary stereotypes do not always hold true. For example, the sciences can have strong social justice sensibilities when STEM fields come to bear on real-world problems, just as mathematics may have a sense of artistic beauty and awe in a language that explains universal laws. Conversely, the arts can have clean lines, edged precision, skill-based processes, or a sense of straightforward purpose in message. Disciplinary content plays out in a range of ways across fields and contexts—in much richer ways that most conventional bounded subject-matter learning suggests (Root-Bernstein & Root-Bernstein, 1999). Both design and STEAM can work together in ways that respect the messy, interdisciplinary, creative, real-world project-based nature of such teaching.

Without the framework of design, STEAM is sometimes conceived of as a basic integration of arts to STEM—which may have its own advantages and which we do not detract from. But which also does not completely address the full potential of a marriage of multidisciplinary ideas or the blurring of disciplinary lines that practitioners of the arts, STEM disciplines, and all other fields tend to experience in practice.

Design can help us to broaden our view of STEAM as an area of disciplinary intersection. It can also help teachers by offering a framework of design thinking skills that may guide them in the revaluation and redesign of STEM or other curriculum, toward more STEAM. The three cases we have discussed here provide just a small set of examples of the possibilities for ways teachers might consider using design skills in their own processes to support STEAM curricular efforts. When teachers are involved in weaving together STEAM ideas using design thinking, the important themes that emerge and connect these paradigms include several things: a focus on creativity, connections to real-world examples or applications, the use of problem- or project-based teaching and learning, and potential for authentic human-centered experiences. These themes are nothing unheard of or entirely new. They have also emerged often through much of the history of recent work around constructivism and current educational psychology (Sawyer, 2011), in what is known about effective teaching. However, what we are introducing in the consideration of all of these themes taken together is that they provide a connective tissue between the domain of design and STEAM. In this connection, there is much for both research and practice to explore, as we seek to broaden the landscape of STEAM work and the capacity of teachers to infuse it into learning experiences.

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