Learning Across Space Instead of Over Time

Redesigning a School-Based STEM Curriculum for OST

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Both employer expectations (National Association of Colleges and Employers, 2011) and education standards, including the Common Core State Standards and Next Generation Science Standards, are shifting the focus of learning from knowledge and discrete skills to the ability to think critically and creatively. STEM educators, both in and out of school, need to be able to translate existing curricula to meet new goals and priorities. Books, curriculum guides, online resources, and social media all provide rich sources of lesson plans and teaching ideas, but many are specifically designed for teacher-led classroom environments. Searching for curriculum materials can be frustrating for out-of-school time (OST) STEM educators who want to promote the self-regulated learning that is at the heart of informal education.

This paper describes the process of translating an existing teacher-led STEM curriculum to fit a learner-

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led, voluntary learning environment. The essence of the process was to be open to insights gained from reflections on the cases at hand, a research strategy known as *naturalistic generalization* (McKenney & Reeves, 2014). After describing the STEM curriculum, we outline our theoretical perspectives and describe the strategies and tools we used to redesign the curriculum for OST education. A key strategy involved using space rather than time to configure scaffolded learning. The outcomes of this summer camp program suggest that our redesign strategy achieved the goal of converting the curriculum from teacher-led to learner-centered instruction.

Existing Curriculum

Save the Seabirds (Schnittka, 2012) is one of several integrative STEM teaching kits based on design principles originally proposed for the Virginia Middle School Engineering Education Initiative (Richards, Hallock, & Schnittka, 2007). With funding from the National Science Foundation program Innovative Technology Experiences for Students and Teachers (ITEST), it was subsequently modified to center around the environmental issue of water pollution for an instructional series called Studio STEM (Evans, Schnittka, Brandt, & Jones, in press). Learning goals are related to students' understanding of force, energy, and motion, as well as the procedures and processes of engineering design.

In the original school-based curriculum, skills are explicitly taught through PowerPoint presentations, demonstrations, and practice. After several such introductory sessions, the learners are presented with a design challenge: An ocean oil spill is affecting seabirds. To prevent spills, learners need to identify an alternative to offshore oil drilling. Since most of the oil pumped from the ground is used for transportation, learners are challenged to design a solar-powered vehicle that can replace trains, trucks, and automobiles. To reinforce the concept that reducing the need for oil drilling will have a positive effect on the environment, the load carried by the students' model vehicles is plaster-filled plastic eggs. Youth are reminded that every vehicle that does not use fossil fuel saves the seabirds. The lecture presentations and skills practice serve as scaffolding to help the learners understand the scientific concepts well enough to complete the capstone design challenge. The physical instructional kit contains Lego blocks, gears, solar panels, wheels, motors, multimeters to measure electrical voltage and current, a cart with weighted eggs, demonstration materials, and the curriculum guide. The original curriculum has been offered to middle school students in traditional school classrooms, summer camps, and afterschool settings (see, for example, Evans, Lopez, Maddox, Drape, & Duke, 2014).

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Although producing a solar-powered Lego car is an inherently motivating goal, teachers and facilitators who implemented the program in one afterschool setting found that parts of the instruction failed to motivate learners (Lundh, Bhanot, Heying, & Stanford, 2013a). External evaluators found extensive evidence that the lectures in the first several sessions of the curriculum did not engage the students. Those lectures "felt like school," and facilitators had a hard time keeping learners' attention (Lundh et al., 2013a). Evaluators also reported that the afterschool facilitators who were not certified to teach middle school science expressed frustration at their own limited understanding of the concepts and vocabulary (Lundh et al., 2013a).

In a recent iteration of the curriculum in an afterschool setting, facilitators reported that having fewer lectures improved student response. Nevertheless, evaluators still recommended providing more time for hands-on experiences (Lundh, Bhanot, Heying, & Stanford, 2013b).

Using the evaluation data and our personal experience with the curriculum, our mission was to create a problem-based curriculum designed specifically for a summer day camp.

Theoretical Perspective

Our redesign was based on two well-established educational practices: social constructivism and problem-based learning. We added a related perspective called design thinking.

Social Constructivism

Knowledge is always a human construction. Social constructivism emphasizes both the process of knowledge construction by the social group and the intersubjectivity established through the interactions of the group (Au, 1998). In social constructivism, communities of learners socially construct knowledge rather than having it transmitted to them in a decontextualized way (Doolittle & Camp, 1999; Driscoll, 2005). Learning is socially mediated (Schunk, 2008); it is what happens as learners "become proficient in practices that are valued in specific communities" (National Research Council, 2009, p. 30). Vygotsky (1987) stressed that social interactions are a critical point in learning and that knowledge is often co-constructed between two or more people. Social constructivism encompasses critical and creative thinking; learner-determined goals; social issues; and authentic, relevant learning environments.

Problem-Based Learning

Problem-based learning is, as its name suggests, learning that occurs as a result of solving real-world problems (Combs, 2008). It is inherently meaningful and contextualized. Problem-based learning creates environments where students assume ownership of their learning; it is simply more interesting than memorizing information (Jonassen, Howland, Moore, & Marra, 2003). In this constructivist instructional method (Driscoll, 2005), the problem to be solved has "some social, cultural or intellectual value to someone" (Jonassen et al., 2003, p. 20). Savery (2006) defined problem-based learning in the classroom as having certain critical characteristics:

1. Students have responsibility for their own learning.
2. Problems are ill-structured and allow for free inquiry.
3. Learning is trans-disciplinary.
4. Collaboration is essential.
5. Self-directed learning informs group decisions.
6. Reflection is essential.
7. Self and peer assessment happens regularly.
8. Problems have real-world value.
9. Assessment checks process and product.

(Savery, 2006, pp. 12–14)

Design Thinking

Problem-based learning is similar in many ways to the design process, defined as the process by which people understand, delineate, and solve problems. A design thinking mindset allows people to work together (or "radically collaborate") to find new solutions to problems. As defined by the Stanford d.school (2011), the design process involves stages of empathizing, defining, ideating, prototyping, and testing.

Though design thinking is not an instructional method, its processes are similar to those of problem-based learning. However, the goals differ. In design, the goal is to solve the problem, and the process, though it is valued and documented, is incidental. In problem-based learning, "learning along the way" is the goal of the work. As with problem-based learning, design thinking can be explained from a variety of theoretical perspectives (Feast & Melles, 2010). Design thinking is the foundation on which the Design-Make-Play movement is changing formal and informal education (Honey & Kanter, 2013). It makes sense to integrate design and design thinking into problem-based learning (Schnittka & Bell, 2010).

Tools and Technology

Instructional technology can both facilitate problem-based learning and enable users to document learning for assessment and evaluation. In our ideal informal learning environment, each learner has his or her own iPad or similar device for accessing information, documenting work, taking notes, communicating with other learners, and producing final presentations. Artifacts produced during these processes can then be used for assessment and evaluation. For the redesign process described here, we used iPads to provide access to:

- **Web browsers.** When learners have access to the Internet, teachers no longer need to be subject matter experts in every topic. Google and YouTube are powerful instructional tools.
- **Cameras and note-taking applications.** Photos, videos, and notes can be used to document learners' work.
- **Social media.** We used Edmodo, a Facebook-like social media tool made especially for education. It allows learners to post questions, comments, and photos in a closed group. Posted material is then available to learners and facilitators for portfolios and assessment.
- **Presentation software.** Presentations serve to organize learners' reflections, publicize their work, and document the learning process for evaluation and assessment.

Assessment

How can facilitators and instructional designers determine whether learners meet the objectives we set out for them? Traditional academic measures, such as written or multiple-choice tests, "violate critical assumptions about [informal] settings such as their focus on leisure-based or voluntary experiences" (National Research Council, 2009, p. 3). We used badges and learner interviews to assess the effectiveness of the instruction.

Badges

The concept of using badges as an alternative to standardized testing has recently gained popularity for its ability to motivate learners and allow a greater variety of educational paths (Abramovich, Schunn, & Higashi, 2013; Riconscente, Kamarainen, & Honey, 2013; Young, 2012). A learner's particular combination of badges reveals his or her unique skill set in a way that degrees and grade point averages cannot.

As the name suggests, the academic badge concept was inspired by scouting organizations' method for recognizing and documenting achievements. Video game achievements are another inspiration:

> The reasoning is that the strategies that effectively support people to learn new things in game environments might also prove effective in supporting learning of content and skills related to academic subject areas and career readiness. If so, strategic use of badges could help forge effective pathways to STEM engagement. (Riconscente et al., 2013, p. 5)

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Badges serve as a way to organize, document, and recognize student learning. Learners choose a badge they are interested in, complete the requirements, and bring their demonstrations or artifacts to facilitators to "prove" their work. When badge requirements are met, learners can be presented with a virtual or tangible badge. The learner-centeredness of badges makes them ideal for problem-based learning.

Interviews

Another method for assessing student learning is interviews. When learners are asked about their process and product, their recorded responses can give valuable insights into their growth. Although interviewing may not be practical for individual assessment, it can serve as a powerful program evaluation tool.

Context

For this iteration of the curriculum redesign, we ran a 16-hour camp over four days. Participants came to the program from 1:00 to 5:00 p.m., Monday through Thursday, during one week of summer 2013. The 15 participants were rising middle school students recruited from the local community to participate in the research and in the free camp at the Institute for Creativity, Arts, and Technology on the Virginia Tech campus.

The camp was staffed by an experienced educator, who served as camp director, and by four high school facilitators. These older teens were hired based on their prior work with youth, their knowledge of STEM content, and their ability to commit the time necessary for training as well as the summer camp. We worked with coordinators from county school systems to advertise the positions. The students who were hired attended a local magnet school for math, science, and technology.

Instructional Design Guidelines

In the course of redesigning the curriculum from being teacher led and temporally organized to being learner led and spatially organized, we identified seven design strategies:

1. Configure the space instead of the time.
2. Issue the challenge at the beginning of the experience.
3. Include a public presentation.
4. Convert scaffolding material to badge requirements.
5. Strengthen learning goals for process and reflection.
6. Use technology to make information available.
7. Train facilitators.

Configure the Space Instead of the Time

Our camp space was a 4,000-square-foot studio with moveable tables, chairs, and whiteboards. We arranged the tables as badge stations. Each badge station included materials and a list of the badge requirements. Materials lists came directly from the existing curriculum; everything that a teacher would have had for demonstrations was available at the badge tables. Badges for Teamwork and Symposium were situated on collections of sofas rather than tables. As long as they were generally on task and not disruptive, learners were free to move from station to station as they pleased.

An order of events with a tentative schedule served as a guide to divide the time. After orientation, some icebreakers, and the presentation of the challenge, learners' time was generally unstructured. Learners could choose which badge to work on and when. Counselors would periodically bring the group together to share their progress and play a game. Leaving the time unstructured kept space as the organizing factor.

We arranged the tables as badge stations. Each badge station included materials and a list of the badge requirements. Materials lists came directly from the existing curriculum; everything that a teacher would have had for demonstrations was available at the badge tables.

Issue the Challenge at the Beginning

Instead of waiting until all the scaffolding material had been presented, we gave participants the challenge in the first session of the camp. The challenge then served to motivate and guide participants as they determined how best to use their time.

Include a Public Presentation

At the end of the camp, participants put on a symposium in which they presented their process and product to each other and to family members and studio staff. The presentation not only allowed learners to document and reflect on their work but also served as a motivator. If learners became distracted, facilitators gently reminded them of the goals at hand, the time limits, and the need to prepare a final presentation.

Convert Scaffolding Material to Badge Requirements

We knew that most students would not be able to meet the solar car challenge without scaffolding to help them build component skills and acquire requisite knowledge. Our learning goals encompassed the force, motion, and energy objectives of the original curriculum. We articulated additional goals: collaboration, motivation, and problem-solving skills. These skills were translated into observable behaviors and categorized as badges.

We created seven badges: Energy and Fossil Fuels, Solar Circuits, Gears, Friction, Teamwork, Solar Cars, and Symposium. Each badge consisted of three or four requirements that showed how the learning objective was met (see boxes on this page). Some, like the Friction badge, were simply reworked from the original curriculum with little change. Others, like the Symposium badge, were completely new to the curriculum. Solar Cars and Symposium were essentially required badges; both were earned by virtue of fully participating in the camp. In keeping with the free-choice principle, the other five badges were optional. Participants were told that the skills learned for the badges would probably help with building the car. The record of demonstrated skills served as assessment and removed the need for paper-and-pencil tests.

Strengthen Learning Goals for Process and Reflection

The badges that were new to the curriculum, Teamwork and Symposium, legitimized the learners' efforts to collaborate, reflect on their work, and document their work—all of which are critical skills in the design process. In addition, participants were encouraged to use the Edmodo social network to document their work and collaborate.

Participants worked through the camp curriculum in four teams of three and one team of two. Working in teams encouraged learners to think critically about their process as they defended or questioned decisions made by team members.

Use Technology to Make Information Available

In previous uses of the curriculum, teachers reported feeling uncomfortable with their own understanding of the engineering concepts (Lundh et al., 2013a). The high school students who facilitated the camp had taken advanced classes in STEM subjects, but none was a particular expert in the badge topics. Instead of living subject matter experts, learners had iPads, which they used to do research on the web, take notes on the design process, post on Edmodo, and develop their final presentations. The facilitators were not responsible for having all the knowledge.

FRICTION BADGE REQUIREMENTS

1. Experiment with objects of various weights and compare their weight, static friction, and sliding friction force. Make a conclusion about the relationships among them. Document your work.
2. Use pull-back toy cars with various materials (wax paper, sandpaper, rubber) on the back wheels to determine which material has the most sliding friction. Document your work.
3. Use a spring scale to measure the sliding friction of three different tires. Document your work.

SYMPOSIUM BADGE REQUIREMENTS

1. Create a timeline of your process to present at the symposium.
2. Share the story of your process and products with the public.
3. Show how your design saves the seabirds.
4. Make your presentation in about five minutes.

Train Facilitators

As with previous iterations of the curriculum, training facilitators was key to the program's success. The veteran educator who served as the camp director was experienced with the curriculum. She trained the four high school facilitators to manage the learning environment. These older teens gave learners their challenges, monitored their progress, assisted at badge stations, and served as role models.

Before the training, the teen facilitators were given the curriculum so they could familiarize themselves with the content. At the full-day training session, the camp director helped the teens understand the task of facilitating as opposed to teaching, using *Quantum Teaching: Orchestrating Student Success* by DePorter, Reardon, and Singer-Nourie (1999). Role-playing was used to model facilitation behaviors, showing the teens how to use age-appropriate language to explain the necessary science concepts.

The teen facilitators took an active role in getting the camp ready. They helped to decide how to set up the space, taking into account the potential learning styles of the youth and anticipating what might work for all of the campers. They then worked through each badge station, making modifications and suggestions as they anticipated the students' needs. The camp director modeled good questioning techniques, offered suggestions, and helped the teens learn to combine content facilitation with group leadership. Facilitators were encouraged to use higher-order thinking when crafting questions.

In some ways, this facilitator training was like the training for previous uses of the curriculum: Facilitators learned about the curriculum and acquired leadership strategies. However, this training was different in that it prepared facilitators for the flexibility required for a program organized around space rather than time. With an attitude of "absolute rigid flexibility," teen facilitators prepared icebreakers and collaborative games to help redirect the learners as needed. Since the facilitators were themselves high school students, their own STEM learning was being reinforced. The camp director, the only professional educator on staff, was freed up to manage the instruction.

Training continued throughout the camp. At the end of each camp session, the teen facilitators wrote in journals, using guiding questions developed specifically for this curriculum. They also participated in a debriefing session to highlight what was going well and what needed to be addressed for the next day. Their questions and suggestions helped them refine their methods of guiding students through the engineering design process and the badge stations.

How It Worked

Of the camp's 15 participants, 14 came all four days; one camper did not return after the first day. The remaining participants engaged fully in the camp. Each team of two or three learners built a working solar car and presented at the final symposium.

To assess how well our redesign accomplished its goals, we collected data in several ways, with institutional review board approval. Undergraduate researchers interviewed two of the camp's 15 participants in order to construct case studies. We used a badge notebook to track which badges were earned by whom and when. We observed the camp and kept notes on these observations. Artifacts generated during the design of the camp, including curriculum materials, schedules, and maps, contributed to our understanding. Artifacts generated by the participants, including symposium presentations, photos, drawings, and Edmodo posts, were also used in this analysis. Finally, the camp facilitators' journal reflections provided additional data.

The camp was generally a success. (For specific analysis of the data collected, see Evans et al., 2014.) This section discusses how each of the seven recommended design strategies contributed to participants' learning.

Configuring the Space Instead of the Time

In previous iterations of the curriculum, learners had appeared bored during lectures (Lundh et al., 2013a). In this summer camp, learners remained engaged. Though the unstructured time and access to technology meant they were occasionally distracted by the ability to modify self-portraits or find new material on YouTube, they did not stay off task for long. The symposium deadline and friendly competition among groups kept motivation high.

Issuing the Challenge at the Beginning

The participants were clear from the beginning that their goal was to build a solar car that could pull a set of eggs. In the first few days, we heard them discussing which badge requirements would help them reach this goal. In their reflective presentations at the end of the camp, they said that they came to appreciate the value of the engineering design process. Conducting research, prototyping the car, and experiencing iterative failures and incremental success was a motivating process. Having the challenge from the beginning helped to focus the learners' efforts and provide a cohesive experience.

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Including a Public Presentation

All the camp participants had a role in the final symposium. Some groups made videos or slide shows set to music. Some demonstrated their cars. Some said they wished they had spent more time on their presentation and less on their car. The symposium not only provided a culminating event but also added an element of peer accountability. Participants were responsible for speaking to the audience and communicating their part in the process. Parents commented that they enjoyed seeing their children's work.

Converting Scaffolding Material to Badge Requirements

All 14 participants completed the Solar Car and Symposium badges by virtue of fully participating in the camp. Different groups of participants approached badges in different ways. One group completed most of one badge the first day and a full badge the second day; then the group did no more badge work. Two groups completed a badge the first day only. Another completed one badge on the first day and started but did not complete two more. These groups did not seek to earn badges after they began working in earnest on the design challenge. However, the final group earned all five optional badges, though group members were ambivalent when asked about the value of the badges.

The experiences of these groups show that badges can motivate learners who might not know where to begin to solve a larger problem. We used Edmodo to publish badge achievements but did not offer an award ceremony or other recognition. Badges might be more motivating with a more formal public recognition of achievement.

Strengthening Learning Goals for Process and Reflection

Several elements of the camp, including Edmodo, the Teamwork and Symposium badges, and the final symposium itself, were designed to gather learners' reflections on and data about the process. Edmodo was heavily used: Participants posted often and responded to each other throughout the week. Their conversations provided a small window into the learners' process.

The Teamwork and Symposium badges were designed to recognize the work of process and reflection, but they were not particularly motivating to students. The only team that completed the Teamwork badge is the one that earned all of the badges. Meanwhile, all participants earned the Symposium badge by virtue of participating in the symposium, but the peer pressure and public audience, rather than the badge, seemed to be what motivated the students. The symposium itself provided an important outlet for participant reflections. Students' public presentation of their process also gave researchers insights into the participants' experience.

Using Technology to Make Information Available

The iPads were helpful for both accessing and sharing information. Students stated in interviews that they used the iPads to access YouTube and Wikipedia to help them understand such topics as gears and solar cells and to look up information on designing and building solar cars. Learners used an app to sketch out car designs and collaborate with their group; they took pictures and videos to document their progress. They shared on Edmodo the information they found and the designs they generated. Finally, they used their iPads to design their symposium presentations, incorporating the media they had generated throughout the week.

Training Facilitators

Training helped the teen facilitators become comfortable with the curriculum, including its flexible schedule. Working through the curriculum at the badge tables, just as the learners would later do, gave them a feel for what participants would experience, what questions they might have, and what challenges they might encounter. The training also gave the facilitators time to become comfortable with the camp's lack of temporal structure.

Stimulating STEM Interest

The camp, redesigned from being a teacher-led, temporally organized experience to a learner-led, spatially organized learning experience, was a success. Our seven strategies for redesigning instruction put learners in control of their learning so that they remained motivated throughout the experience.

OST educators can use our seven design-based strategies to adapt school-based curriculum to their needs. These strategies can help to spur participants' interest in problem-based learning projects that integrate several learning modalities. The emphasis in our summer camp on problem solving, new media, and peer interaction stimulated participants' interest in deeper STEM learning (Evans et al., 2014). Future research will explore how well the model can be applied to other formal curricula.

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