CAN YOU DIG IT? DESIGNING TO SUPPORT A ROBUST MAKER CULTURE IN A UNIVERSITY MAKERSPACE

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As makerspaces are increasingly incorporated into mainstream schooling, it has become important to provide educators and administrators with detailed examples of how to support a robust maker culture within those makerspaces so that student participation and learning are maximized. In this design case, we describe our efforts to design for and support a robust maker culture in a university makerspace, the Deason Innovation Gymnasium at Southern Methodist University. Our focus is on designing the space and the learning experiences that happen within the space to promote a maker culture. To do this, we consider three critical elements: (a) encouraging student ownership, (b) fostering a maker mindset, and (c) showcasing student achievements. To illustrate our design decisions and their impact, we present examples of two types of maker-based learning experiences: (a) real-world design challenges and (b) community design and build challenges. We analyze how each type of challenge supported students participating in a maker culture. We conclude with a discussion of the implications of this design case for individuals interested in supporting a robust maker culture in their own makerspaces.

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INTRODUCTION

The maker movement began when a community of enthusiasts, tinkerers, and do-it-yourselfers started creating digital and physical artifacts designed for personal use (Halverson & Sheridan, 2014; Martin, 2015). With the development of outlets to formally and informally share this work (e.g., *Make* magazine, Maker Faire, and the Internet) the maker movement quickly gained momentum and entered the mainstream (Dougherty, 2012). As a result, makerspaces—places where individuals have access to digital and physical tools and materials that facilitate making—have become increasingly popular in libraries, museums, K-12 schools, and on college campuses (Barrett et al., 2015; Brahms & Werner, 2013; Burke, 2014; Gershenfeld, 2012).

Maker-based instruction, an educational perspective grounded in the principles embodied by the maker movement, has emerged as an intriguing and largely untapped approach to promoting student learning and engagement (Halverson & Sheridan, 2014; Honey & Kanter, 2013; Kalil, 2013; Martin, 2015; Peppler & Bender, 2013). From an educational standpoint, makerspaces are places where students can engage in the activities popularized by the maker movement (e.g., tinkering, hacking, designing, and prototyping) as well as places where students can immerse themselves in constructionist learning environments (Martinez & Stager, 2013).

However, building a dedicated makerspace does not guarantee that a vibrant maker culture will spring up to support students learning through making in a way that maximizes the potential of maker-based instruction. Maker culture (i.e., valid and sustained participation in the practices, activities, and mindsets at the core of the maker movement) is an important and often overlooked aspect of successful makerspaces. We believe the power of maker-based instruction lies in the shared vision and practices of the community members, not in the tools and materials that occupy the space. Thus, although there are several detailed manuals describing how to outfit makerspaces (Burke, 2014; Hlubinka et al., 2013; New York Hall of Science, 2013), there is far less information available about how to organize a successful maker culture in such spaces. As a result, school leaders who have access

FIGURE 1. Students working collaboratively on a project in the DIG.

to makerspaces on their campuses may have a good idea of what tools and materials to purchase to put in the space, but are left to puzzle over how to involve teachers and students in meaningful and sustained maker-based activities.

Without intentionally designing to support a maker culture within makerspaces, the potential of maker-based instruction will remain largely untapped. In our work at the Deason Innovation Gymnasium (DIG), a makerspace at Southern Methodist University (SMU), we have taken on the challenge of designing both the space and the learning experiences that happen within the space to support students engaging in a robust maker culture.

CONTEXT

The DIG is a student-centered makerspace, housed within the Lyle School of Engineering at SMU. At the DIG, we are committed to serving engineering students whose formal training may require them to use the tools and materials in the space. However, we also encourage students from across campus to participate in the activities we host (see Figure 1).

The DIG houses a number of high-tech tools (e.g., 3D printers, a laser cutter, a vinyl cutter, a computer numerical control [CNC] router, microprocessors, soldering equipment, and power tools) as well as more common tools and materials (e.g., pliers, glue guns, hammers, and cardboard). After attending an initial orientation, students gain 24 hours a day keycard access to the DIG. With some additional training,

FIGURE 2. A neon sign emphasizing the DIG's mission statement.

students can learn to use the tools and materials in the DIG to create objects and complete projects either for personal use or to fulfill the requirements for a class. Crafted collaboratively with students, our mission statement says, "At the DIG, we are not afraid to experiment. No idea is too wild. We enable students of all disciplines to realize their ideas by giving them the tools and space to create beyond the bounds of the classroom. At the DIG, we learn by doing and grow through failure." Figure 2 depicts a sign related to the DIG's mission statement.

During the 2015-2016 school year, 1,037 students had access to the DIG. Seventy-four percent of students with access were from the Lyle School of Engineering. Eighty-nine percent were undergraduates. Over 280 students were trained on the 3D printer, 270 on the laser cutter, 115 on the

FIGURE 3. First Year Design students work on their robotics project in the DIG.

power tools, and 85 on the vinyl cutter. Of these students, 148 requested training via our website (www.theDIG.org). Overall, we have an active community of over 345 regular users (i.e., users who access the DIG several times per week). More than 150 additional students also access the DIG on a semi-regular basis (i.e., several times a month).

Although the DIG is located in the engineering school, the learning experiences we implement are meant to promote students from across the university becoming confident and creative makers. Thus, when we develop and launch challenges, we do so largely independently from the engineering school and its faculty. While students may participate in engineering practices, learn engineering-related procedures, and become proficient with tools that will contribute to them becoming successful engineers, our focus is on building a broad, interdisciplinary culture of making in the space.

Even though we do not typically seek to align the activities we implement in the DIG with engineering curriculum or with faculty interests—unless we are approached specifically by a faculty member—we do support projects carried out in several engineering classes. These classes include: (a) First Year Design; (b) Senior Design; (c) a course offered by the Design and Innovation program called, Form and

Composition; and (d) a course focused on sustainability offered by the Civil Engineering department. Students in First Year Design used the tools and materials in the DIG to design and build components for a robotics project in which they designed robots that used sensors to complete an obstacle course (see Figure 3). Students in Senior Design used the tools and materials in the DIG to build rapid prototypes of solutions to share with their clients. Examples of the types of prototypes students designed include a computer-numeric controlled pipe bender and a wind turbine meant to generate clean energy for a residential home.

DESIGNING THE SPACE TO SUPPORT A MAKER CULTURE

While there are many factors that may contribute to a successful maker culture, we have focused our efforts on three elements we believe to be critical to building a robust maker culture within the space: (a) encouraging student ownership, (b) encouraging a maker mindset, and (c) showcasing achievements. Our rationale for focusing on these three elements is based on our belief that they are foundational for creating a highly engaging and functional makerspace. As such, we believe these elements must be solidly in place before taking on the challenge of designing

mindset. For example, we post inspirational quotes such as, *"This may not work!"* and *"The pursuit of perfection, often impedes improvement"* in various places around the DIG (see Figure 6). These quotes remind students that a maker mindset is a byproduct of sustained curiosity and repeated attempts to overcome failures, rather than an innate set of skills.

A second way we encourage our students to adopt a maker mindset is by employing a team of nine student workers who explicitly model the behaviors we believe contribute to

a maker mindset. These student workers are responsible for facilitating student projects, assisting students with questions, and orienting and training newcomers. While fulfilling these duties, student workers encourage the students they work with to tinker, solve problems, and iteratively design to overcome failure. Our experience has been that when same-age peers model the beliefs and values that contribute to a maker mindset, students more readily adopt their own maker mindsets.

Showcasing Achievements

Some makerspaces are stark and mask all evidence of the activities that have occurred there in the past. In contrast, we intentionally engage students in making objects meant to occupy the physical space in the DIG to showcase student work and past achievements. For example, in a project we describe in more detail later, students designed and built a foosball table. By building a foosball table, students created a functional game to keep in the DIG and demonstrated what was possible to build with the DIG's tools and materials. In addition to students building objects to occupy the space, the DIG manager, himself a master maker, has built several pieces of furniture (e.g., a coffee table and organizing carts to store materials) to improve the beauty and functionality of the DIG (see Figure 7). Like the foosball table, these pieces of furniture serve to inspire future makers and demonstrate what is possible to make with the tools available.

When a project does not involve building a physical object, we still have a system in place to showcase student

FIGURE 6. An example of one of the inspirational quotes adorning the DIG.

FIGURE 7. A coffee table built by the DIG manager meant to inspire future makers.

FIGURE 8. A selection of the 17 iron-on scout-style badges students can earn to showcase their achievements in the DIG.

achievements. For example, when a student demonstrates proficiency using a tool, we award him or her with an iron-on scout-style badge. Students may earn up to 17 badges by demonstrating their proficiency with various tools, such as the vinyl cutter, laser cutter, 3D printer, and CNC router. As students collect various badges, they can attach them to their backpacks to display their achievements (see Figure 8). Additionally, we showcase our achievements digitally by sharing student accomplishments on our website and social media outlets and by posting pictures, tutorials, user guides, and resources to help students get the information they need to make outside of the DIG.

DESIGNING LEARNING EXPERIENCES TO SUPPORT A MAKER CULTURE

In addition to designing the space to support a maker culture, we also design learning experiences that take place within the DIG to support a maker culture. For each design challenge we consider enacting in the DIG, we ask ourselves if the challenge has the potential to connect clearly to the three aspects of maker culture that we value: (a) encouraging student ownership, (b) encouraging a maker mindset, and (c) showcasing achievements. If one of these aspects of

maker culture is noticeably absent, we either consider how we might alter the challenge to include the missing aspect, or we look for another more appropriate challenge.

Encouraging Student Ownership

After deciding on a suitable challenge, we develop an outreach strategy to recruit participants. Because we believe it is essential that participants have eclectic interests and a range of academic training and experiences, we advertise each challenge broadly in the community. For example, we have a list of over 1,900 students, faculty, and staff to whom we send an email announcing the challenge. In addition, we post flyers with a description of the challenge in public spaces near the DIG, around the School of Engineering, and across campus. Finally, we reach out to faculty and staff in different schools and departments to forward word of the challenge to their students.

Next, we ask students who are interested in participating in the challenge to complete an online application. This application gives students the opportunity to share their motivation for participating and describe any specialized skills or abilities they might have. Importantly, this process

also gives us an opportunity to clearly communicate the expectations for participating in the challenge.

Once we assemble a student team, we attempt to inspire students to take ownership of the challenge by engaging them in a novel set of experiences related to the challenge. These experiences are meant to inspire students to learn more and build a personal connection to the challenge. Getting students inspired to work on the challenge is critically important. Without inspiration, students often do not feel connected to the challenge and have little motivation to work through difficult problems when they inevitably arise.

Encouraging A Maker Mindset

When the team is inspired, and students have a sense of ownership over the challenge, we introduce a design brief, which outlines the constraints, deliverables, and deadlines associated with the challenge. After students have examined the brief, we ask them to begin the process of ideation. During ideation, students consider their design aspirations alongside a well-defined problem statement and subsequently generate ideas for how to solve the statement. During this time, we encourage students to be as creative as possible and to participate in divergent and generative thinking. Importantly, we do not evaluate the ideas students come up with until later in the process.

After students have had the chance to ideate, we ask them to select elements of the designed solution that are non-negotiable. We then divide the larger team into sub-teams with a clear deliverable related to those non-negotiable elements. Individual students are encouraged to join a sub-team they find interesting. This division pushes students toward using new tools and learning new skills. When technical problems arise while students are working in their sub-teams, we direct them to a variety of resources to help them solve those problems (e.g., the Internet, student staff, mentors from industry, and the DIG director). Importantly, we do not attempt to predict the variety of problems that students may encounter when working in their sub-teams. We have found that students who feel a sense of ownership over the project have a high capacity for troubleshooting complex issues related to technical and non-technical problems.

Periodically, we ask the sub-teams to meet together as a larger team to report their progress, discuss problems, and to solicit feedback from their peers. As a result, students have opportunities to clarify benchmarks and ensure that they are making progress towards building an initial low-resolution prototype of their designed solution. Scaffolding this process helps promote students balancing the work of creating a product while at the same time developing an appreciation for the process.

Showcasing Achievements

Once students have built low-resolution prototypes—usually made from cardboard and tape—they can test them by subjecting them to a physical stress or by going into the world to find out what others think about their designed solution. Importantly, the process of testing a prototype motivates students to iterate and improve their designed solution and introduces them to the idea that they do not need to produce a perfect final-form solution early on.

After several rounds of testing and refinement, we push students to build the final version of their designed solution. During this process, we bring the participants together and make sure everyone understands the group's shared vision. In the event that there are sub-teams working on different aspects of the project, we begin the process of asking the sub-teams to integrate their work. At the end of this process, the team always produces a range of physical and digital products that serve to illustrate the achievements of the participants.

IMPLEMENTING DESIGN CHALLENGES THAT SUPPORT A MAKER CULTURE

We have developed two types of maker-based learning experiences intentionally designed to introduce students to the three aspects of maker culture we consider important. These learning experiences include (a) real-world design challenges and (b) community design and build challenges. We define each of these types of challenges, present an example of a challenge, and then analyze how participating in the challenge supported students participating in a maker culture.

Real-World Design Challenges

Real-world design challenges are open-ended projects derived from actual student needs. During these projects, students design and build a physical artifact meant to solve the challenge. Real-world design challenges promote students using a range of technologies, tools, and materials; working independently or in small groups; and creatively solving student-driven problems.

Transportable boat design challenge

In the spring of 2016, 12 students came together over the course of eight days to solve a real-world design challenge. The problem statement motivating the design challenge was posed by one of the participating students. Her statement was, "I enjoy kayaking but I do not have a car to transport my kayak to the water." By putting several simple constraints around this problem statement, we devised a challenge: Can you design and build a functional human-powered boat for less than \$100 that can be transported by bicycle to a nearby lake?

FIGURE 9. Students explore the nature of boats in the SMU pool.

The students solved this challenge in four parts. First, they gathered data to better understand the challenge. To do this, students borrowed several kayaks and a canoe from SMU's outdoor recreation program and took them to an indoor pool to learn about (a) the properties of the materials making up the boats, (b) how human-powered boats handle in water, and (c) what elements of a boat are most necessary (see Figure 9). Additionally, while at the pool, several students worked hard to sink a kayak to learn more about displacement and buoyancy.

Second, students researched materials used to build boats, eventually deciding to build their own boats by folding large sheets of corrugated plastic and attaching the different parts together using zip ties. Students reasoned that corrugated plastic and zip ties would make good boat-building materials because they were lightweight, easily manipulated, and watertight. Additionally, each 4 foot by 8 foot sheet of corrugated plastic costs \$30, which was well under the \$100 budget.

Third, students began sketching boat designs and building models from paper and cardboard. Students iterated on these models and eventually moved from building paper and cardboard models to building scale models made from small pieces of corrugated plastic. Once students had

FIGURE 10. Students tested their scale models in a nearby fountain.

constructed these models, they tested them in a nearby fountain by placing metal ingots into the models to see how well they would float when under a load (see Figure 10).

Fourth, after troubleshooting issues (e.g., leaks) associated with their small-scale corrugated plastic models, students built their own foldable boats from larger sheets of corrugated plastic. As each boat took shape, students made their way to the fountain to test their boats with human passengers. All of the students who participated in the challenge

FIGURE 11. A student testing her transportable boat in a nearby fountain.

FIGURE 12. A student paddling his transportable boat in a nearby fountain.

achieved the goal of building a functional transportable human-powered boat (see Figures 11 and 12).

Supporting a maker culture

When we launched the transportable boat design challenge, we reasoned that few of the participants would arrive with prior boating experience or with a strong interest in boating. To encourage ownership of the challenge, we arranged for students to use kayaks and canoes in SMU's indoor pool. It was through this experience—rather than by reading about boating or by researching boating online—that students learned how boats worked, how they handled in water, and how much fun they could be. The interest and engagement this activity created carried through the challenge and motivated students to want to understand the nature of boats and boating. Additionally, the activity gave students an experience to connect to when they tested the physical properties of the boats they designed.

Throughout the design challenge, students engaged in prototyping, iterative design, and cycles of building and testing. Once students were ready to begin building, they started by folding an 8.5 inch by 11 inch sheet of paper into a boat design. Next, they moved to constructing their boat designs from cardboard. From there, students built scale models of their boats using small pieces of corrugated plastic. After students tested their scale models and improved them based on the test results, we issued them an 8 foot by 4 foot sheet of corrugated plastic to build their full-sized boat. Participating in this process encouraged students to focus on making incremental progress rather than building a perfect boat from scratch the first time. Instances of failure became opportunities for iteration and improvement, and these failures ultimately supported students developing their maker mindsets.

All students who participated in this design challenge finished with a functional transportable boat. While most students took their boats with them at the end of the project, one of the boats remains hanging from the ceiling in the DIG as a way of showcasing student achievement. One element of this challenge we would change in the future is that we were never able to test the boats in a natural body of water. Because of scheduling difficulties and inclement weather,

FIGURE 13. Students build a cardboard prototype of the foosball tabletop.

FIGURE 14. Cutting wood to assemble the foosball table.

we were forced to cancel a trip to a nearby lake to test the boats in the real world. We believe that having the opportunity to take the boats out into open water would have enhanced the challenge.

Community Design and Build Challenges

Community design and build challenges are complex collaborative projects. During these projects, students build a tangible artifact either for the DIG or the SMU community. Community design and build challenges introduce students to a diverse set of tools, promote students building technical skills with those tools, and foster collaboration and project management skills.

High-tech foosball design challenge

In the fall of 2015, a team of 16 students, 4 student coaches, and 3 faculty and staff worked together every Tuesday night for two months to design, prototype, and build a functional regulation-size foosball table meant to become a permanent addition to the DIG. When recruiting participants for this community design and build challenge, we purposefully sought to include students who regularly used the tools and materials in the DIG as well as students who were brand new to the DIG. Our reasoning for this decision was that students with experience using the tools and materials would be able to help the less experienced students build the skills they needed to make a contribution to solving the design challenge.

When the team first assembled to start working on the challenge, they began by identifying each of the major categories of work necessary to complete the challenge (e.g., woodworking, electronics and coding, and 3D modeling and printing). After identifying these categories of work, the team brainstormed opportunities for innovating the elements of a traditional foosball table (e.g., adding speakers, personalizing the handles, and personalizing the foosmen [the miniature players]).

Next, the larger team divided into sub-teams to tackle the different categories of work. Each of the sub-teams then set out to create full-scale cardboard prototypes of different elements of the foosball table (see Figure 13). For example, the 3D modeling and printing sub-team built prototypes of the handles and foosmen.

After evaluating each sub-team's prototypes, the whole team met and compiled a list of tasks to complete to build the

FIGURE 15. Assembling the foosball table.

FIGURE 16. Students and faculty bask in the glow of the finished foosball table.

FIGURE 17. Video documenting the design process and the table in use.

final table. This list of tasks included enhancing the design of the foosmen (they were too large and banged into the table-top when mounted on the rod), cutting the correct lengths of wood needed to assemble the table, and troubleshooting certain electronic components, such as the scoring system (see Figure 14). Students completed these tasks during the week (e.g., the 3D modeling and printing team revised their CAD models, the woodworking team drew schematics and cut the necessary lengths of wood, and the electronics and coding team wrote and rewrote code to control the scoring system) so that they could finalize their sub-team's contribution to the overall project.

The whole team eventually came together to integrate all of the discrete elements of the foosball table (see Figure 15). However, participating in this process surfaced a number of additional issues. For example, one team member identified a weakness in the design of the foosmen (they were too flimsy at the point where they connected to the rod). The 3D modeling and printing team agreed to improve the foosmen by building up the thickness and strength of the collar (i.e., the part connecting the foosman to the rod). Also, after being declared “buggy,” the electronics and coding team agreed to rewrite the code controlling the scoring system so that the electronic sensor would correctly register and count each scored ball.

When finished, the team had created a functional regulation-size foosball table (see Figure 16). Innovative elements

of the table included 3D-printed horsetail-shaped handles and foosmen modeled after SMU's mascot, Peruna the Mustang. In addition, LED lights illuminated the field, an Arduino-based electronic system kept score digitally, and built-in speakers allowed students to connect a smartphone to the table to provide a game-time soundtrack (see Figure 17). Also, Caroline Gurley, a student member of the team wrote this commentary on the experience: <http://blog.smu.edu/hilltopambassadors/2016/02/25/peruna-foosball-in-the-innovation-gym/>.

Supporting a maker culture

Most participants connected with this design challenge from early on because they had played foosball in the past. Unlike the transportable boat challenge, we did not need to provide a unique experience to motivate students to take ownership of the challenge. Students knew that the finished foosball table would be on display in the DIG and they looked forward to playing it in the future. The upshot of intentionally selecting a design challenge based on a popular college pastime was a decrease in the up-front work we had to do to motivate students to complete the challenge.

Throughout the design challenge, participants had the chance to build up their maker mindsets. For example, students with a background in engineering had the opportunity to share their expertise around tools such as the 3D printer and to teach their peers how to design 3D models using computer-aided design software. These opportunities

to teach and learn helped some students to develop 3D modeling skills and others to develop more confidence in their 3D modeling skills.

Students also developed their maker mindsets by engaging in prototyping and iterative design. For example, when building their cardboard prototype, the students working on the sub-team responsible for building the tabletop repeatedly rounded up as they measured and cut pieces of cardboard. By doing this, they inadvertently introduced rounding error. As a result, when this sub-team assembled their prototype tabletop, several parts were too large to fit together. Upon realizing their error, students had to rebuild the prototype.

Once the foosball table was complete, students had a substantial artifact in the DIG showcasing their achievement. One caveat of displaying the foosball table in the DIG is that although it stands as a significant student accomplishment, it also masks a time-consuming and messy process. We see this as problematic for two reasons. First, future design challenge participants may be intimidated by the table and decide too early that they cannot build something as significant. Second, future design challenge participants may assume the opposite, that the table was easy to build, giving them a false sense of the difficulty of a design challenge.

DISCUSSION AND REFLECTION

In this design case, we examined a university makerspace to illustrate one approach to designing the space and the learning experiences that happen within the space to support students participating in a robust maker culture. There are three key takeaways from this design case for individuals interested in supporting a robust maker culture in their own makerspaces. First, it is possible and productive to design for a maker culture, which is perhaps the most important but least recognized aspect of a successful makerspace. Implementing structures and procedures that encourage student ownership, foster a maker mindset, and allow students to build and showcase artifacts, contributes to supporting a vibrant maker culture and motivates students becoming invested in the space and in the act of making.

Second, it is useful to design high-quality learning experiences for makerspaces in which students become immersed in a maker culture. In the two types of learning experiences we presented here (i.e., real-world design challenges and community design and build challenges), students had many opportunities to design, prototype, test, iterate, and implement their ideas. Also, the nature of the challenges we developed allowed students to draw on their personal experiences and generate a sense of pride in their work. Additionally, students had opportunities to build new skills, such as learn to operate complex tools, communicate with peers, and collaborate between groups.

Third, developing a maker culture is a process that must be carefully scaffolded. Students do not participate in all the aspects of a maker culture at the same time and certainly should not participate in these aspects alone. Working in carefully structured environments with ample community support is what allows students to become creative, collaborative, and to demonstrate their resilience.

It is worth noting that when seeking to promote a culture of making, it is important to include a diverse group of participants in any design challenge. With a diverse group of students participating in making, there will inevitably be significant variability in the ways students approach and solve design challenges. Additionally, with a diverse group of students comes a range of knowledge and experience that instructors can leverage in different ways and at different times. Restricting the diversity of participants by recruiting from a subset of individuals (e.g., students with experience making or students who enjoy engineering) could make for a more fragile maker culture by unintentionally diminishing the interests, experiences, and knowledge of participants.

Although we have offered suggestions here for designing the space and the learning experiences happening within the space to support a maker culture, we understand that many educators may not be able to implement these suggestions immediately or at all. It takes time and resources to build a maker culture and to plan innovative and interesting maker-based learning experiences. Therefore, to further facilitate supporting a robust maker culture in makerspaces we must continue to remind ourselves that making slow and incremental progress is always a move in the right direction.

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