University Makerspaces as Workplaces for K-12 STEM Educators

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INTRODUCTION

The maker movement is comprised of a growing community of enthusiasts and do-it-yourselfers who design, create, and share a variety of digital and physical products to solve problems or satisfy personal needs. Over the past several years, the tools and tenets of the maker movement have been increasingly incorporated into K-12 settings [1]. In fact, makerspaces—spaces equipped with technologies that facilitate students learning through making—have become fixtures in many public and private K-12 schools [2]. However, the rapid speed at which makerspaces have spread throughout K-12 schools is presently outpacing the development and dissemination of pedagogical supports designed to help teachers effectively use makerspaces to connect to traditional subject area content [3]. The result is that although many K-12 schools have incorporated makerspaces into their buildings, teachers at these schools often continue to struggle to implement high-quality maker-based instruction.

In order to realize the full potential of the maker movement in K-12 schools, we must introduce formal supports to assist teachers incorporating maker-based instruction into their regular classroom teaching practice. These formal supports could come in the form of professional development opportunities in which teachers learn about techniques helpful for implementing maker-based instruction; hands-on experiences during which teachers learn to work with tools and equipment found in their school makerspaces; events during which teachers come into contact with knowledgeable makers who model practices, mindsets, and cultural values related to the maker movement; or opportunities for teachers to become makers by designing and building their own artifacts.

An explicit goal of the Deason Innovation Gym (DIG)—the collegiate makerspace located in the Lyle School of Engineering at Southern Methodist University (SMU) in Dallas, Texas—is to promote a campus-wide maker culture by increasing the number and diversity of students who regularly use the space. With this goal in mind, staff at the DIG and faculty at SMU’s School of Education partnered to bring graduate students enrolled in education classes into the makerspace. A second goal of the collaboration was to promote and support these graduate students—many of whom are also in-service K-12 teachers—using the DIG to learn new skills, operate new tools, and prototype classroom activities grounded in science, technology, engineering, and mathematics (STEM) standards.

RESEARCH QUESTIONS

We tasked SMU graduate students to develop a design challenge rooted in K-12 STEM standards that they could pose to their own K-12 students. Then, using the tools in the DIG, we asked graduate students to build one possible solution to their design challenge. We asked the following questions:

1. What types of design challenges will graduate students develop?
2. What tools and materials will graduate students use to complete the design challenge?
3. How will graduate students connect their design challenges to STEM standards?

In answering the second question, we made a distinction between tools and materials. Tools included any high-tech or low-tech hardware or software in the DIG that could be reused while materials included any consumables graduate students used to solve the challenge.

CONTEXT

A. ENGINEERING SCHOOL: UNIVERSITY MAKERSPACE

The DIG is a student-centered makerspace equipped with a range of high-tech and low-tech tools, such as: 3D printers, power tools, a laser cutter, a vinyl cutter, a computer numerical control (CNC) router, pliers, glue guns, hammers, scissors, and tape measures. Although one of the primary goals of the DIG staff is to support undergraduate engineering students completing assignments related to their classes (e.g., First Year Design, Senior Design), an additional and broader goal is to promote students from across campus participating in a range of creative programming. For example, an interdisciplinary team of students recently redesigned and built the inside of SMU’s new mobile makerspace, the MakerTruck. By participating in these types of projects, a wide range of SMU students have opportunities to learn to operate the tools in the DIG, work in teams to finish complex projects, build creative confidence, and experience the joy of making. Thus, while the DIG staff contributes to turning out proficient engineers, they also value building a robust maker culture within the DIG and try to spread that culture across campus.

B. EDUCATION SCHOOL: STEM SPECIALIZATION

Students who enroll in the M.Ed. program in the School of Education are required to take four core courses. After completing their core courses, these graduate students may elect to earn specializations in two areas (e.g., STEM, English as a second language [ESL], special education, gifted and talented). The STEM specialization consists of a four-course sequence emphasizing designing innovative STEM learning environments and teaching STEM content in an integrated way. This approach to teaching STEM aligns with recent calls from the National Research Council (NRC) advocating that STEM instruction lead K-12 students to build knowledge in
individual STEM subjects and make connections between them [4]. The four courses comprising the STEM specialization are: STEM and the Learning Sciences, Coding for Teachers, Designing and Making, and Community-Centered STEM Integration. The project described in this paper was the final assignment for the third class in the sequence, Designing and Making.

**METHOD**

**A. PARTICIPANTS AND SETTING**
Participants included 16 graduate students (4 male, 12 female) enrolled in the Designing and Making course in the spring of 2017. The majority of these graduate students (n = 12) were in-service teachers who taught a variety of grades (ranging from 3rd to 12th) and a variety of subjects (ranging from art to algebra). All in-service teachers were within their first five years of teaching and many (n = 8) were finishing their two-year commitment as Teach for America teachers in difficult-to-staff schools in Dallas Independent School District (DISD), Fort Worth Independent School District (FWISD), and local charter schools. The first author was the course instructor. All project-related work took place in the DIG using the available tools and materials.

**B. INSTRUCTIONAL DESIGN**
Designing and Making is a semester-long course that met for three hours every week for 15 weeks. Throughout the semester, graduate students enrolled in the course participated in a number of hands-on activities and discussed how to connect those activities to STEM content appropriate for their own K-12 students. The final assignment required graduate students to complete two parts: (a) plan a design challenge they could enact with their K-12 students using one or more of the tools found in the DIG (e.g., laser cutter, vinyl cutter, 3D printer) and (b) build a prototype to illustrate one way in which their K-12 students might solve the challenge.

Graduate students in the course were free to invent their own design challenges as long as they identified a setting, characters, and a compelling problem. Additionally, graduate students were allowed to pick their own groups. Groups ranged in size from 2-5 graduate students. Most groups included teachers or former teachers who taught different grade levels and subjects. The course instructor guided graduate students to the DIG by asking them to complete a new student orientation run by the DIG staff. After attending the orientation, graduate students worked on the design challenge in their groups without formal instruction for the next two weeks.

**C. DATA COLLECTION**
The deliverable for the final assignment was a poster displaying: (a) the design challenge prompt, (b) a list of materials, (c) photos documenting the design process, (d) explicit links to STEM standards, (e) a list of problems encountered during the process and the solutions to those problems, and (f) photos of the final product. In addition to creating a poster, graduate students also presented their poster and their prototypes to their peers in an open-format presentation in which professors in the school of education and graduate students enrolled in other classes came to see their work. During the presentation, the instructor interacted with the students by asking them questions about their projects and took pictures of their groups and their finished prototypes. After the presentations, the instructor collected the posters for analysis.

**D. ANALYSIS**
To answer our research questions, we looked across the graduate students’ posters and recorded three pieces of information: (a) the design challenges they came up with in their groups, (b) the tools and technologies they used to solve the design challenge, and (c) the STEM standards to which they connected their design challenges.

**RESULTS**

**A. RQ1: WHAT TYPES OF DESIGN CHALLENGES DID GRADUATE STUDENTS DEVELOP?**
Six groups of graduate students developed design challenges. (See Table 1 for a complete list of challenges.) The six challenges covered a variety of settings. For example, some groups situated their challenges in K-12 schools and other groups situated their challenges outside of school (e.g., the city). In addition to covering a range of settings, the different challenges covered an array of potential problems. For example, one group posed a challenge rooted in a timely and somewhat controversial cultural problem—designing spaces in their school to be more equitable for transgender students—while another group posed a less controversial challenge by asking K-12 students to develop something useful for the classroom and marketable to students and schools.

**Table 1 Design Challenges Developed by Graduate Students**

<table>
<thead>
<tr>
<th>Group</th>
<th>Design Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design equitable spaces for transgender students</td>
</tr>
<tr>
<td>2</td>
<td>Use technology to improve bicycle safety</td>
</tr>
<tr>
<td>3</td>
<td>Create a visual and tactile representation of Escalante Creek in the Grand Canyon</td>
</tr>
<tr>
<td>4</td>
<td>Make something useful for the classroom that is marketable to students and schools</td>
</tr>
<tr>
<td>5</td>
<td>Develop an adaptive visual representation of a city skyline</td>
</tr>
<tr>
<td>6</td>
<td>Design a space that you or your classmates could use to increase focus while in class</td>
</tr>
</tbody>
</table>

**B. RQ2: WHAT TOOLS AND MATERIALS DID GRADUATE STUDENTS USE TO COMPLETE DESIGN CHALLENGES?**
Graduate students used a wide variety of tools and materials to build their solutions to the design challenges they posed. (See Table 2 for a complete list of tools and materials.) For example, one group used the vinyl cutter and sewing machine to create custom t-shirts with embedded electronics and another group used CAD software and the laser cutter to build a topographic map of one section of the Grand Canyon. Additionally, students in several groups used digital technologies associated with the different tools but not freely available in the DIG (e.g., some groups used Adobe Illustrator to design digital files for use with the laser cutter and vinyl cutter).
education can plan engaging and provocative design chal-
gles to enact with their own K-12 students. This is an im-
portant finding because it demonstrates one way to support
K-12 teachers implementing maker-based instruction in their
own schools. In addition, we also found that graduate stu-
dents in the class—many of whom had never used the tools in the
DIG—learned to operate a diverse set of tools in service of
solving the design challenge they developed. We find this
promising because it demonstrates that K-12 teachers are
capable of using and become proficient in the types of tools
found in many makerspaces. Finally, graduate students also
connected to an array of grade-level specific content stan-
dards (e.g., NGSS, ISTE, TEKS) when developing their design
challenges. Thus, asking graduate students to develop design
challenges appears to support them developing integrated
STEM learning objectives. One possible cause for concern is
that although some graduate students in the class were ele-
mentary teachers, they did not explicitly connect to elemen-
tary standards. It would be problematic if elementary teachers
believe it is too difficult or impossible to connect to elemen-
tary standards through makerspace design challenges.

DISCUSSION
The results of this descriptive study indicate that with clear
goals, adequate time, and ready access to a makerspace with a
suite of high-tech and low-tech tools, graduate students in
education can plan engaging and provocative design chal-

Table 2 Tools and Materials Used by Graduate Students

<table>
<thead>
<tr>
<th>Group</th>
<th>Tools</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laser cutter, Adobe Illustrator</td>
<td>3mm oak plywood</td>
</tr>
<tr>
<td>2</td>
<td>Vinyl cutter, t-shirt press, sewing machine</td>
<td>LEDs, batteries, wires, t-shirts, heat transfer vinyl, thread</td>
</tr>
<tr>
<td>3</td>
<td>Laser cutter, circular saw, tape measure, SolidWorks, AutoDesk 123D</td>
<td>MDF*, wood glue, thin metal pins</td>
</tr>
<tr>
<td>4</td>
<td>Vinyl cutter, Adobe Illustrator</td>
<td>Vinyl</td>
</tr>
<tr>
<td>5</td>
<td>Laser cutter, clamps, Adobe Illustrator</td>
<td>3mm oak plywood, Styrofoam, Plexiglas, wood glue, tape, LED strips, solder, wires, batteries</td>
</tr>
<tr>
<td>6</td>
<td>3D printer, hand saw, electric drill, clamps, tape measure, scissors</td>
<td>Wood glue, hinges, tape, 3D printer filament, plywood, acoustic paneling, premium liner</td>
</tr>
</tbody>
</table>

* MDF—Medium density fiberboard

C. RQ3: HOW DID GRADUATE STUDENTS CONNECT DESIGN CHALLENGES TO STEM STANDARDS?
Graduate students connected their design challenges to sev-
eral families of STEM standards. (See Table 3 for a complete list.) For example, groups connected to: the TEKS (Texas Essential Knowledge and Skills), the NGSS (Next Generation Science Standards), and the ISTE (International Society for Technology in Education) standards. Some groups connected their challenges to many different families of standards, while other groups connected their challenges to a single family of standards. Finally, although there were elementary teachers present in several of the groups, no groups connected to el-
lementary-level standards.

Table 3 Connections to STEM Standards

<table>
<thead>
<tr>
<th>Group</th>
<th>Family of Standards</th>
<th>Target Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STEM TEKS</td>
<td>High school</td>
</tr>
<tr>
<td>2</td>
<td>NGSS, Physics TEKS</td>
<td>High school</td>
</tr>
<tr>
<td>3</td>
<td>8th grade science TEKS, ISTE, Middle school NGSS, 8th grade math TEKS</td>
<td>Middle school</td>
</tr>
<tr>
<td>4</td>
<td>NGSS, ISTE</td>
<td>Middle school</td>
</tr>
<tr>
<td>5</td>
<td>ISTE</td>
<td>Not stated</td>
</tr>
<tr>
<td>6</td>
<td>NGSS, 8th grade math TEKS</td>
<td>Middle school</td>
</tr>
</tbody>
</table>

REFERENCES