A music teacher teaches engineering and uses CAD: A case study

Kenneth Reid
Virginia Polytechnic Institute
United States
kenreid@vt.edu

Medha Dalal
Arizona State University
United States
medha.dalal@asu.edu

Cheryl Beauchamp
Virginia Polytechnic Institute
United States
cherbea@vt.edu

Abstract: The K-12 engineering education is currently challenged to have willing and qualified teachers to teach high school level engineering classes. Using multiple data sources that include interviews, classroom observations, and weekly reflections this single case study details how a music teacher with a non-engineering background embraces computer-assisted design. Results suggest that appropriate professional development and encouragement from administrators combined with personal drive can empower teachers from non-STEM disciplines to teach design and provide collaborative learning experiences relating to student fields of interest. The study has implications for engineering professional development programs for teachers and the sustainability of such efforts.

Introduction

An increasing need for engineering professionals has resulted in a sharp rise in engineering education programs at the K-12 level across the nation (Purzer, Strobel, & Cardella, 2014). One of the challenges for K-12 engineering education is the teacher readiness and willingness to teach content they do not understand well (Brophy, Klein, Portsmore, & Rogers, 2008; National Research Council, 2010). Since college-level engineering education programs are not standardized (Reid, Reeping, & Spingola, 2018), there is also an issue of providing equivalent undergraduate credit toward student admissions for higher education. To help address the need, the National Science Foundation in 2018 launched Engineering for US All (E4USA), a national pilot program for a high school engineering course (Engineering For Us All, 2019). The program was established as a partnership among five universities to 'demystify' engineering for high school students and teachers with the involvement of deans of engineering. Two primary objectives of the program include development of: 1) curricula and assessments for engineering design thinking principles and processes for high school students, and 2) professional development (PD) models to empower teachers to gain the self-efficacy, confidence, and skills to teach and assess students' engineering-based competencies. With an overarching goal of standardizing high school engineering curricula in the future, it was also necessary to align the E4USA curriculum to state and national standards. The intent was to support schools who chose to use the course but still needed to address their state requirements for student learning in science and technology.

Thus the first E4USA course is specifically designed “for us all”, not just students who may be predisposed to pursue engineering. The curriculum is developed around threads of discover engineering, engineering design, engineering professional skills and exploring the intersection of engineering solutions and society. Using project-based modules, the course offers students opportunities to think ‘like an engineer’ to develop and practice skills, such as problem-solving, design thinking, creativity, innovation, collaboration, and inter-disciplinary thinking. Students are expected to follow an engineering design process multiple times in the course to design a solution to an identified problem. As mentioned, the E4USA course is also designed to address multiple standards to include the Next Generation of Science Standards for Engineering, Technology, and Application of Science (NGSS Lead States, 2013). In addition, online and fact-to-face PD modules were developed concurrently to prepare teachers to teach the course.

During the first year of the E4USA pilot, nine high school teachers were recruited. The teachers participated in the online PD during spring of 2019 and then attended one of two five-day workshops at one of the partner universities during the summer of 2019. The first workshop was attended by four teachers. Two of these teachers had studied undergraduate engineering and were currently teaching Physics and Robotics classes in high schools. The remaining two teachers did not have prior engineering background. One was a history teacher and another was teaching music. This meant that the goal of demystifying engineering for all was tested from the onset. Post-PD, as the teachers started teaching the introductory E4USA course, the research team set out to explore the implementation of the curricula. The current case study focused on one teacher in particular, to address the following research question:

> How did a high school teacher with a non-STEM background embrace computer-assisted design (CAD) to teach an introductory level engineering course?

Methodology

Research design

A single case research design was selected to generate data rich in detail and embedded in the context (Stake, 1994). The study focused on a single case by purposive sampling because of the unique qualities of the selected classroom that can promote understanding of the phenomenon under research and inform practice for similar situations (Creswell, 2013). Yin (2014) specifies that contextual conditions are important to understand the phenomenon under study. The next section describes the setting for this study in detail.

Setting

This study focused on one E4USA classroom in a public high school located in the southwestern United States. The teacher, Mr. Melvin Rogers (pseudonym) is an experienced teacher, although he has no experience in any STEM area. He has been teaching music for the past 22 years with extensive background in the Symphony Orchestra world. He runs a Creative Musical Arts & Sciences (CMAS) program at the high school – a fully open creative platform and record label run by students, creating and producing music. His students’ music is often endorsed by industry professionals. Melvin is anything but a typical teacher. He often talks about his desire to push the limits of how technology and the creative process can be linked.

Melvin teaches at one of five high schools in his district. Four of the high schools have an existing engineering program, however, Melvin’s school did not at this point. Mounting parental pressure led to the administration seeking a typical engineering course and Melvin was signed up for PD for a nationally well-known program. However, his application was rejected due to a lack of experience in teaching in any area of STEM. The PD administrator for that program recommended Melvin to investigate the E4USA program, that she had learned about at a national engineering conference. Consequently, Melvin approached the E4USA team and was signed up for the first PD.

During the face-to-face PD session over the summer of 2019, a few design tools were discussed such as TinkerCAD and Google SketchUp. Since Melvin had no prior experience with CAD software, he was understandably apprehensive about his ability to teach students how to use the software. The PD leaders clarified that using CAD software was an option for communicating and iterating design solutions, it was not required for implementing the curriculum. If teachers were interested in using CAD software, recommendations included having students walk through the CAD software provided tutorials. Melvin later shared that this was a great suggestion because as he went through the TinkerCAD tutorials, he realized that although it would take some initial effort, the software was easy to use.

As the new school year started in August, 38 students (21% females) signed up for Melvin's introductory engineering class. It is a highly diverse student group with 16 Hispanic students, 14 Caucasians, three African-Americans, two Asians, two mixed-race students and one student from the Middle East. Since engineering course is an elective, it is also a mixed group of 20 freshmen, seven sophomores, eight juniors and three seniors.

Melvin's classroom is equipped with 13 computers for student use. Students and the teacher also have their own laptops and they can access the Internet anytime from the school premises. Technology is used extensively by Melvin and his students to collaborate, share presentations, submit assignments over Google Forms, write reflective journals, and send parental newsletters. The class meets five days a week for 55 minutes during the school year. Each class features a similar schedule: the instructor introduces the lesson for 10 to 12 minutes followed by 6 to 8 minutes of discussion time with students, and then the students use the remainder of the class time (roughly 30–35 minutes) to perform a structured hands-on design activity.

Melvin had a conflict and was scheduled to miss a few days of teaching during the beginning of the school year. Having gone through the TinkerCAD tutorials, he felt this was something his substitute could manage. So he had the the substitute introduce CAD and facilitate tutorials in his absence.

In the process of interviewing the teacher on his experience and progress in the course, the discussion often focused on his implementing CAD in the class.

Data Collection and Analysis

Qualitative data was gathered by two primary methods: 1) Multiple interviews with the high school teacher during the fall term, and 2) classroom observations regarding the students' use of the design tools and resulting models. In addition, the teacher shared his weekly reflections with the researchers.

Data was analyzed using a combination of open coding, narrative analysis, and observation protocols. Open coding (Corbin & Strauss, 2015) was used to capture the concepts underscored by the teacher in interviews and weekly reflections. Interpretive narrative analysis (Clandinin & Connelly, 2000) was used to first identify narratives or sub-stories from the interview transcripts and then construct a chronological account of Melvin's experience and progress. Observations were used to further interpret data and triangulate the results. In the following section we present the results in a narrative chronology with embedded participant quotations.

Results

Results describe: 1) how a teacher with a non-STEM background teaching an engineering course successfully integrates computer-aided design software for modeling, and 2) the development of an engineering mindset and the collaborative and cognitive aspects of learning for engineering design.

While implementing CAD is not a requirement within the E4USA course, it can be used as a design communication and collaboration tool to digitally create models that enable students to examine real-world, complex systems. For schools with computer access, CAD is a cost-effective means to create, innovate, and share ideas for solving problems. Use of CAD also meets technology, science, and Career and Technical Education (CTE) learning standards. TinkerCAD was recommended during PD due to its easy learning curve, accessible tutorials, and free educational version for schools.

Melvin was introduced to CAD during PD, weeks prior to the start of his school year. He was initially apprehensive about using CAD in the classroom for two reasons. He did not have a STEM background and his classroom lacked a 3-D printer. However, Melvin decided to investigate TinkerCAD on his own with the help of online tutorials. He found that he was able to reach a proficiency quickly enough that it was suitable to schedule during the time the substitute would lead the class.

> *I looked at TinkerCAD, which was a great suggestion; it's easy to use. I went through a couple of their tutorials, and thought that it's going to take a little bit of time for them to get used to it. But we'll build it into the projects and things of you know, find some time.*
>
> *<On missing a few days of class> I'm going to be gone for a few days. I don't need to be there; this is a thing the sub can do: go through the TinkerCAD tutorials. Maybe they don't apply it until later in the semester, but at least they will have seen it; they will understand some of the concepts.*

Melvin had planned a project early in the course where students would design a shelter; the design was constrained by a given set of materials. Students were tasked with developing a design, creating a drawing, and building a prototype. Students were given free range on how to create their drawings: Google Sketchup, hand-drawing, or TinkerCAD. Of the eight groups, three chose to use TinkerCAD while the other five used paper and pencil.

> *You're going to design a shelter: I gave them some limitations on what materials they could use. It was going to be a mini prototype; it would be built to scale and you needed to be able to house five people in it. You have to create the schematic drawing either by hand or TinkerCAD just as you could have described it verbally. I gave them a day to do that.*
>
> *<After the designs were completed,> I'm going to give you a different group's design randomly to build the prototype. You may not interact with the other group. You may not ask them any questions; you may only have their design.*

Some of the advantages of using CAD were immediately apparent: designs could be easily compared: "You know what makes it different from someone else's design." Students were able to more accurately describe advantages to their designs. Student teams were then tasked to construct the prototype designed by a different team: again, CAD drawings offered an opportunity to approach this building effort more step-by-step:

> *You know there are written instructions on it; step by step. It was, it was pretty cool to see. And it was kind of interesting for me that the TinkerCAD versions were very detailed like you can see another one here, but the kids had it figured out how to put in instructions.*

Melvin also noticed an increased spirit of collaboration. First-year students were actively 'tutoring' third and fourth-year students on TinkerCAD. This interaction led to an increase in collaboration within design and became one of the means to reduce intimidation toward engineering. Implementation of TinkerCAD within projects led to more effective teamwork among students. In other words, Melvin felt that because he integrated CAD, his student teams are more collaborative. He was impressed with the initiative the students took when they figured out specific enhancements and functionality of the software that went beyond the given assignment (AZ Unit 1 transcript 173 at 00:21:00.060).

Melvin was able to explore one of the tenets of the course early: engineering in society as opposed to engineering as an isolated profession. Through the design of the shelters and the presentation and analysis of student designs, the conversation turned to the concept of using the projects in the course to actually solve problems: taking a step beyond prototyping to building final products. Indeed, this represents an engineering thought process, a main goal of the project:

> *We could actually not just have them design it, we could have them implement the solutions. I would be able to get hold of <funding> every year. For this part of a program; for kids to actually implement their designs; obviously a big part of it would be design, reflect, iterate, and improve that in prototype, all those things. Looking at the Arizona state standards for high school engineering, we'd be hitting every engineering design criteria.*
>
> *This is no longer a theoretical thing and it wouldn't even be superficially connected. This would be real world. We've got clients. We've got stakeholders. We got real problems that need real solutions. None of this is theoretical. I'm looking at going to where a kid walks out of here literally with a resume of I designed this thing and actually built it. We implemented it and you can actually go and look at the thing being used now.*

Melvin describes engineering and its relation to music: "The idea of what I call the creative process, that's the same thing as the engineering design process. It's identical. It's not even like related kind of identical, it is identical."

Discussion

According to the Education Counts Research Center, all 50 states included technology standards of learning for students to some degree (Education Counts Research Center, 2019). Integrating engineering design in technology education curriculum addresses several of these technology standards. Arizona's technology standards (Arizona Department of Education, 2019) include using models, simulations, and digital tools to create, innovate, and communicate solution ideas. Additionally, the use of CAD software and the engineering design process supports the International Society for Technology in Education (ISTE) standards, the International Technology Education Association's Standards for Technological Literacy, and the Next Generation of Science Standards. In fact, several studies have also supported the integration of engineering in technology education to increase students' problem solving skills and technology literacy (DeLuca, 1991; Ernst, 2009; Wicklein, Smith, & Kim, 2009). Not only does integrating engineering design increase student problem solving skills and technology literacy, but using CAD to communicate design ideas engages students in active learning where students are creating and collaborating with each other and the teacher can support where needed. For example, Melvin even noted that the students in his class who were more comfortable with CAD assisted those who were not. He felt this interaction strengthened the relationship and collaboration amongst the different grade level students in his class.

During the PD, Melvin and other teachers like him who did not have prior engineering background or experience using CAD software were concerned and anxious about teaching their students how to use software they themselves were unfamiliar with. However, after Melvin watched the recommended tutorials for TinkerCAD, worked with the software, and compared the models his students made using CAD software to those that didn't, he reflected that students should learn how to use CAD software and he looks forward to including the more advanced CAD program SolidWorks in his future course. His desire to integrate the more advanced software and recognition of the value of having his students learn how to use CAD software is a positive change from the initial position shared during the PD in which he and the other teachers preferred letting their students use other, non-digital means to create and communicate their design solutions. The initial perspective that the software would be a challenging hurdle for the teachers to master in a short time in order to assist students in their learning was replaced once Melvin worked through the tutorials himself and observed not only the positive student collaboration when learning TinkerCAD, but the detail in the designs the students provided when using the software.

The remainder of the course involves further designs of larger scope and with more clients and/or stakeholders, and some projects will be more ready for CAD. While we don't know what will happen as the projects become more elaborate, there is a reason to be encouraged with the adoption and level of implementation of CAD within designs appearing early in the course.

Limitations and Future Work

There are some limitations that must be acknowledged regarding the validity and reliability of this study. Single case research design leads to the limitation of generalization. However, as Flick (2014) explains, the selected single case is "a typical or particularly instructive example of a more general problem" (p. 122). Moreover, the observation time was limited and the researcher did not observe all classroom periods when TinkerCAD was used. Altogether six observations were conducted during the fall term. Future work includes further investigation of the integration of CAD in more elaborate design projects and expanding the interviews and reflection analysis to include larger number of teachers within the program.

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