Teachers' Evolving Conceptions of 3D Scanning and Printing as Authentic STEM Practices

Purpose

The purpose of this study was to explore the evolution of middle and high teachers' conceptions of the role of 3D scanning and printing technology in integrating STEM disciplines (science, technology, engineering, and mathematics) as they engaged in in-service learning involving discussions with scientists and industry experts, and collaborative design of learning activities using 3D scanners, 3D printers, and computational modeling within a paleontology context.

Conceptual Framework

Traditionally, K-12 students have learned STEM disciplines in isolation, which is counter to the common practices in the professional STEM fields today (Roehrig et al., 2011). Recognizing that education within the individual STEM disciplines has great value and efforts to improve discipline-centered learning and teaching should continue, educational researchers and practitioners are working to expand and extend our understanding of integrated STEM learning and explore the potential benefits and challenges associated with it.

Integrating the four STEM domains in K-12 education is a challenging endeavor with important implications for K-12 teachers' and administrators' epistemologies as well as instructional design and assessment practices. A promising approach to STEM integration is the utilization of 3D scanning and printing technologies that are increasingly finding their way into K-12 schools (Bull et al., 2013) in meaningful ways in the classroom. This integration can be achieved in the context of a highly relevant but unexplored educational pathway to STEM in K-12 education – paleontology. Rather than being a specialized field, paleontology is truly a multidisciplinary science that organically integrates concepts and practices from diverse disciplines including biology, environmental science, geology, oceanography, and anthropology. Paleontology in the 21st century also harnesses the resources and tools available from other fields of STEM, including technology (Big Data in the cloud, 3D scanning, Callaway, 2011), complex mathematical modeling and statistical algorithms (Elewa, 2011), and engineering (advanced analytical 3D imaging and 3D printing, Hooper, 2013).

Although schools are thought to be late adopters of emerging technology, observers report that many schools already own 3D printers (Thornburg et al., 2014). Affordable and accessible hardware like the Fab@Home 3D printing kit, Makerbot 3D printers, NextEngine 3D scanners and free software like Tinkercad, Cura and Meshlab make it possible to engage K-12 students in the complex but highly gratifying processes of design, modeling, and manufacturing. The ease of use associated with this new generation of hardware and software promotes access and wide usage without sacrificing the rigor of design and modeling – constructionist practices where scientific and mathematical reasoning, artistic sensibility, and engineering processes come to the fore (Halverson & Sheridan, 2014). The evidence collected by our project team during our recent 3D scanning and printing workshops (Authors, 2015; 2016; Figure 1) suggests that both students and teachers are highly engaged when they scan, print, and analyze fossils (e.g., megalodon teeth) to learn about evolution, biodiversity, and global climate change.

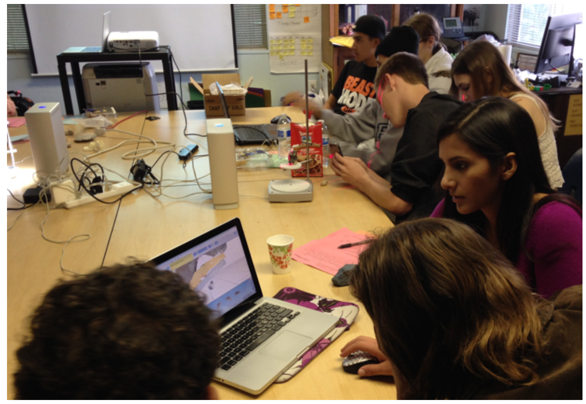

Figure 1: Students are comparing a fossil tooth with the scaled printed version.

Teacher knowledge is the key prerequisite for ensuring effective instruction in general and STEM integration in particular (Honey, Pearson, & Schweingruber, 2014). Teacher knowledge combines knowledge of the subject matter with an understanding of effective approaches for teaching it to students with diverse learning needs as well as the knowledge of appropriate technology use to support effective teaching (i.e., technological pedagogical content knowledge, Mishra & Koehler, 2006). Because integrated STEM education is a recent phenomenon in K-12 contexts, little is known about how to best support the development of teacher expertise in STEM integration.

Method

This qualitative study was designed to address the following research question:

1. What are the evolving conceptions regarding the role of 3D scanning and printing technology in STEM integration within a diverse sample of middle and high school teachers designing integrated STEM learning with 3D scanners and printers in the context of paleontology?

The catalyst for developing teachers' conceptions of technology and integrated STEM in this study is engagement in a three-year project to create opportunities for integrated STEM using 3D scanning and printing, computational modeling, and interpretation of scanned and printed fossils provided by a museum of natural history and local fossil enthusiasts. Core opportunities for in-service learning were designed using the guidelines for effective teacher learning in a blended environment (Dede, 2006; Hoadley, 2012) and include a) a professional learning community in Edmodo, b) a week-long professional development institute in the summer with a focus on project-based learning pedagogy, meaningful use of 3D technologies, and computational modeling in STEM, c) meetings with gender and race matched STEM role models (scientists and industry experts), d) collaborative instructional design of learning experiences, and e) ongoing support from STEM education experts, scientists, and technology personnel.

Study participants were 17 teachers from Florida and California middle (*n* = 11) and high schools (*n* = 6). Nine of the participants were teachers of science, three taught technology, design, and engineering, two were mathematics teachers, two were integrated STEAM teachers (with a focus on art in addition to STEM), and one was a Language Arts teacher. The participants ranged in age from 24 to 61 and identified as female (*n* = 13) or male (*n* = 4).

Data sources included semi-structured focus group interviews facilitated by the authors of this study at the beginning of the project, open-ended interviews before, during, and after the professional development events, and researcher notes based on the observations of participants during project activities. Audit trail and collaborative interpretation were conducted to improve trustworthiness, authenticity, and credibility (Lincoln, Lynham, & Guba, 2011).

Thematic analysis was used to identify and analyze patterns in all qualitative data (Braun & Clarke, 2006; Clarke & Braun, 2013). This approach is a method of examining data for emergent themes, which is a recursive process of thematic coding and analysis. Thematic analysis requires "…searching across a data set…to find repeated patterns of meaning" (Braun & Clarke, 2006, p. 15).

Findings

Baseline Understandings of STEM Integration (prior to professional development activities)

Technology and engineering are more challenging to integrate than science and mathematics. Participants expressed what they identified as a major challenge regarding the difficulty of integrating relevant engineering and technology experiences in instruction. This was a common theme among all teachers in our sample. Early in the project, Integration of technology was discussed primarily from the perspectives of technology tools for formative and summative assessment. "Regarding technology integration, I think of things like Schoology and Quizlet and such… A PowerPoint for the final report or Wikispaces for a team to work on. Engineering… hmm… I don't even know what that might involve… Maybe a building a scale model?" (Jeannae). Four participants indicated that they have access to a 3D printer at their school but they struggle conceptualizing meaningful STEM activities using this technology: "So… I printed a nice phone stand for my iPhone [chuckles]… I know the kids like them. Like a student of mine has printed a Pokémon… But I do NOT [emphasis] see how a science teacher like myself could do this stuff for a lesson. That's not what we are supposed to do in Biology!" (Michelle). Ten other participants implied or stated directly that "… No support is provided at my school to even help me *think* of engineering as something to include in my teaching." Only two participants mentioned the use of technology-based simulation or modeling tools for science or mathematics.

Technology, engineering, and math are tools for enhancing science education. The sample of teachers participating in this study included a majority of science teachers. When prompted to think about the role of each individual discipline in the integration of STEM, our participants overwhelmingly expressed that they view as technology, engineering, and mathematics disciplines in supporting role: "Tech and engineering, and math especially, would be great tools for improving the teaching of environmental science, of life science, I think" (Christine). Even one of the mathematics teachers shared that "Math is great and I love it but it can also be so devoid of real-life applications… Now that I think of it, a lot of the examples I use with my students are actually science examples!" (Madeline).

Evolving Perspectives (during and after professional development activities)

Professional development and collaborative instructional design that our teacher participants engaged in required them to learn from experts and from each other about effective conditions for project-based activities integrating STEM disciplines, and to experience the application of 3D scanning and printing technologies to scan, manufacture and analyze fossils of charismatic animals (e.g., Megalodon, Titanoboa) as a way to situate learning in the big ideas of climate change, biodiversity, deep time, and STEM practices such as computational modeling, data visualization, and scientific argumentation. These opportunities appear to have brought about important changes in participants' conceptions of integrated STEM. Through modeling, vicarious and direct experiences with 3D scanners and printers in the context of paleontology and conversations with scientists and industry experts using these tools, participants began to identify appropriate applications for these technologies in the science and mathematics classroom.

3D scanning and printing technologies can provide a useful gateway for STEM integration. One participant described technology as the "… glue that holds the STEM disciplines together because it is such an essential part of doing STEM these days" (Mark). Teachers working in STEM groups to generate ideas for integrating 3D scanning and printing technologies in their insturction produced many creative insights ranging from "Students could scan and analyze apex predator teeth, analyze the serrations etc. and then design the ultimate predator tooth!" (Randy, middle school design/engineering teacher) to "We could scan in and print several fossil snail shells for our classroom collection, discuss shapes and designs and why they evolved to be what they are and compare the shells from different periods to talk about adaptation by natural selection, biodiversity, and climate change" (Michelle, high school biology teacher).

Technology should be used to support modeling and engagement in other authentic STEM practices. As the project unfolded and participants became more comfortable with 3D scanning and printing technologies and developed the technological pedagogical content knowledge of authentic STEM practices in paleontology that these technologies support, they expanded their repertoire of appropriate uses of technology in integrated STEM activities. The main difference between their initial conceptions and the developing knowledge relative to technology use appeared to be a shift away from using technology as a tool to externalize knowledge as part of formative or summative assessment and towards using technology to support the *process* of learning rather than measure its outcomes. Specifically, participants noted that "… Modeling is so pervasive across the STEM disciplines, it makes sense that it's a core practice in NGSS and Common Core… It seems that 3D technologies we have been using are really useful for supporting this particular aspect although I can see how the 3D scans and prints can be used as evidence to support scientific explanation and argumentation as well" (Christine).

[A more in-depth treatment of the themes such as STEM Integration Is Not Always Useful will be provided in the full paper due to the proposal word limit requirement.]

Significance

This study addresses the recent calls for more *in-situ* research on STEM integration in K-12 education, and contributes to a research agenda for examining effective conditions for integrating STEM disciplines in K-12 contexts. Our findings support the recommendations of the National Research Council Committee on Integrated STEM Education (Honey, Pearson, & Schweingruber, 2014) and demonstrate that it is important to provide opportunities for teachers to engage in focused conversations with STEM experts regarding authentic practices in the STEM workforce and integrating appropriate technologies to support such STEM practices. Once teachers develop understandings of the interactions between STEM practices, disciplinary core ideas, and crosscutting concepts, it is important to afford opportunities for them to share and explore activity ideas in collaborative design teams with representatives of each STEM discipline and feedback and support from STEM education researchers and STEM experts. These findings contribute to our knowledge of effective strategies for adult learning (e.g., Knowles, 1984) in general and teacher learning in particular (e.g., Dede, 2006). Future research should focus on examining the dynamics of teachers' conceptions of STEM integration during and after feasibility and usability testing of the technology, lesson implementation, and reflection on the learning processes and outcomes that integrated STEM experiences support and sometimes limit.

Acknowledgements

This study was supported by the National Science Foundation (project #XXXXXXXXX).

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