Exploring Fossils with 3D Technologies:
A Study of Teachers' Perspectives of Integrated STEM

Problem

Traditionally, K-12 students have learned STEM disciplines in isolation, an approach that 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). This research project argues that integration of STEM 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 content 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).

While many schools already own 3D printers (Thornburg et al., 2014), meaningful uses of this desktop manufacturing technology in K-12 education are rare. Affordable and accessible 3D scanning and printing hardware and software like Tinkercad 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 the recent 3D scanning and printing institutes (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 explore and internalize the big ideas of evolution, biodiversity, extinction, global climate change, among others.

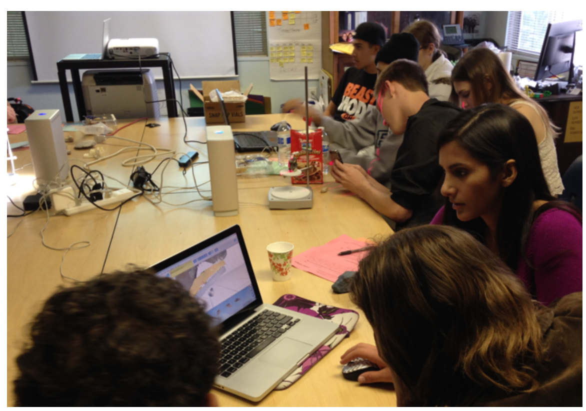

Figure 1: Students are comparing a fossil tooth with the scaled printed version.

Teacher knowledge is the key prerequisite for ensuring effective instruction in general (National Research Council, 2014) and STEM integration using 3D scanning and printing technologies in particular. 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 best to support the development of educator expertise in STEM integration.

The purpose of this study was to explore the evolution of middle and high teachers' conceptions of integrating STEM disciplines in grades 6-12 as they engaged in in-service learning, discussions with STEM researchers and industry experts, and collaborative design of learning activities aligned with the three dimensions of science learning and supported with 3D scanning and 3D printing technologies within the paleontology content.

Research Design

This study was designed to address the following research question:

What are the evolving conceptions regarding the nature, scope, and outcomes of STEM integration within a sample of middle and high school science, mathematics, design/ engineering, and technology teachers designing integrated STEM experiences using 3D scanning and 3D printing technologies in the context of paleontology?

The catalyst for developing teachers' conceptions of integrated STEM is engagement in a three-year design-based research 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. Key opportunities for in-service learning were designed using 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 three dimensional science learning, project-based learning pedagogy, meaningful use of 3D technologies, and computational modeling in science, 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 staff.

Study participants were 17 teachers from Florida and California middle (n = 11) and high schools (n = 6). Nine of the participants are teachers of science, three teach technology, design, and engineering, two are mathematics teachers, two are integrated STEAM teachers (with a focus on art in addition to STEM), and one is 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 teacher observations during project activities. Audit trail and collaborative interpretation were conducted to improve trustworthiness, authenticity, and credibility.

Thematic analysis was used to identify and analyze patterns in all qualitative data. 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 and Analysis

Initial Conceptions

There cannot be too much STEM integration. Study participants are leaders in the K-12 community who follow the national conversation on curricular reform and engage in professional development to keep their knowledge and skills updated. A key theme that emerged early during data analysis and was pervasive across our data sources early in the project was that STEM integration is a highly positive trend in K-12 and all teachers should consider integrating STEM as well as literacy and arts domains in their instruction. As Daphne eloquently put it, "There cannot be too much STEM integration. Our life is STEM… Our life is STEAM… So, it's extremely important that we teach and our students learn in integrated ways." Others reinforced this point by indicating that "… Real-life problems are complex and if we are to prepare our students for the workforce, life, the flat world society… we gotta integrate complexity in our instruction" (Michael). Two teachers discussed the integrated nature of middle school science curriculum they are using and how this curriculum "… transformed how I think and how I act. I totally see and support integration of STEM although the technology and engineering pieces are not that easy to include…" (Natercia).

Technology and engineering are more challenging to integrate than science and mathematics. As the previous quote indicates, concerns were expressed regarding the challenge of integrating relevant engineering and technology experiences in instruction. This was a common theme among all science and mathematics teachers in our sample. 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… Maybe a PowerPoint for the final report or Wikispaces for a team to work on. Engineering… hmm… I don't even know what might involve… Maybe a building a scale model?" (Jeannae). Four participants indicated that they have access to a 3D printer in their school but they struggle conceptualizing meaningful science, mathematics, or engineering 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 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 tools or science or mathematics related uses of a 3D printer. One of these individuals is a STEAM teacher and the other is an art and technology teacher with background in science education.

Technology, engineering, and math are means for improving science learning. The sample of teachers participating in this study was biased heavily towards science. 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

3D scanning and printing contribute the "T" and the "E" to help integrate STEM. In-service learning and collaborative instructional design that our teacher participants experienced during the project required them to learn from experts and from each other about effective conditions for project-based learning 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. Exposure to 3D scanning and printing technologies in particular appears to result in important changes in the teachers' 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.

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 worked in STEM groups to generate ideas for integrating 3D scanning and printing technologies in science, mathematics, and engineering design classes, and 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) 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).

STEM disciplines can be integrated around the authentic practice of modeling. As the project unfolded and participants became more comfortable with the 3D scanning and printing technologies and developed the technological pedagogical content knowledge of authentic STEM practices in paleontology that these technologies support, they expanded the repertoire of the appropriate uses of technology in integrated STEM activities. The main difference between their initial conceptions and the developing knowledge relative to technology use was the shift away from using technology 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).

STEM integration is not always useful. This theme focused on the appropriate integration of STEM disciplines relative to the instructional objectives driven by the Next Generation Science Standards. The theme will be discussed during the presentation (due to space NARST abstract page constraints).

Contribution

This study contributes to the research agenda on examining effective conditions for integrating STEM disciplines in K-12 contexts. Our findings support the recommendations provided by the National Research Council Committee on Integrated STEM Education (NRC, 2014) and demonstrate that it is important to provide opportunities for teachers and STEM experts to engage in focused conversations about strategic integration of STEM disciplines, authentic practices in the STEM workforce and integrating technologies to support such STEM practices. Once teachers develop the technological pedagogical content knowledge to understand 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. Future research should focus on examining the dynamics of teachers' conceptions of STEM as a result of feasibility and usability testing, lesson implementation, and reflection on the learning processes and outcomes that integrated STEM experiences support and limit.

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