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Three-Dimensional (3D) Printing in STEM Education: Recommendations for Qualitative Research

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Abstract

Three-dimensional (3D) printing is an additive manufacturing technique that generates real objects from digital 3D computer models. Seven primary additive manufacturing procedures have a significant impact on the education, business, and government domains. 3D printing is a hands-on learning activity that complements flipped learning and other active learning strategies, designed to stimulate creativity and critical thinking skills. 3D printing is frequently employed as a learning technique in medical education to enhance comprehension of anatomical and physiological principles. Medical students have reported higher knowledge gains following interactions with 3D printed models. Other disciplines, such as biology, chemistry, and botany, utilize 3D printing to reinforce fundamental topics. Several important undergraduate outcomes, including engagement, information transmission, satisfaction, and concept comprehension, are enhanced in science, technology, engineering, and math (STEM) courses that incorporate 3D printing as part of their teaching approach. While the costs of 3D printing technology are more affordable, the costs of 3D printing remain a significant factor in underutilization on campuses with limited resources. More social science qualitative research is required to understand the impact of 3D printing on STEM undergraduate perceptions and outcomes. Furthermore, additional 3D printing teaching and learning materials are necessary to broaden usage across STEM fields. The article presents ten 3D printing qualitative open-ended survey questions to investigate STEM undergraduate viewpoints.

Keywords: 3D Printing; Career Training; Qualitative Research; STEM Education; Flipped Learning

1. Introduction

Hands-on learning strategies have shown great promise in terms of creating highly engaging traditional and online STEM courses at the college level [1-3]. STEM courses embedded with hands-on opportunities that duplicate real-world workforce obligations may enhance academic retention and undergraduate STEM career readiness [4]. From an anecdotal perspective, students demonstrate elevated concentration during course activities when tasked with the physical or virtual manipulation of materials and models. Moreover, student engagement in mental manipulation exercises enhances problem-solving skills and the exploration of ethical issues relevant to course topics and societal concerns. The use of physical models and virtual models potentiate the conversion of abstract concepts to perceptible knowledge. Medical, engineering, and science courses are most likely to benefit from the use of physical models in the short term to enhance undergraduate comprehension.

Flipped learning falls under the umbrella of active learning because it promotes active student participation and collaboration during the instructional period. In flipped learning, the typical process of content dissemination, problem-solving, and application of concepts is reversed [5]. Students are required to study course content at home through readings and online resources before class and complete basic knowledge assessments before the instructor intervenes.

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Quality comprehension assessments for flipped methods include virtual quizzes at home or pre-activity quizzes in class. Flipped learning has experienced a surge in applications over the years, facilitating career development outcomes among undergraduates [6-7]. Given the operational definition and reported outcomes of flipped learning, integrating flipped principles with in-class 3D model printing to enhance the meaningful retention of course material may be academically rewarding for STEM majors.

Three-dimensional printing technology enables STEM faculty to create physical instructional models that supplement content exploration and enhance learning. Three-dimensional printing refers to the use of specialized reproduction equipment to create a solid entity. The occupational fields impacted by 3D printing are extensive and constantly expanding. Various sectors utilize 3D printing, including dental, medical, automotive, education, aerospace, architecture, and engineering. Additionally, 3D bioprinting enables scientists to fabricate human cells and other biological structures, paving the way for advances in medical applications and biomedical research, with a particular focus on drug design and delivery [8-9]. In today's marketplace, 3D printers range from basic to highly sophisticated, utilizing artificial intelligence technology to produce elaborate reproductions, such as patient-specific organ systems [10]. Additive manufacturing (e.g., 3D printing) involves the layer-by-layer production of objects and utilizes various types of printing materials (e.g., thermoplastics, resins, metals, ceramics). The seven most popular additive manufacturing procedures are Material Extrusion, Vat Photopolymerization, Powder Bed Fusion, Material Jetting, Binder Jetting, Directed Energy Deposition, and Sheet Lamination. Each additive manufacturing process has its own set of advantages, disadvantages, and limitations. Course needs and the availability of resources affect the incorporation of 3D printing concepts and applications. Science courses often use 3D printing to create custom models, enhancing comprehension. Technology and mathematics courses frequently focus on understanding 3D printing hardware, modeling software, and precise algorithms necessary to produce complex structures. Engineering courses utilize 3D printing to create products that solve problems across various industries.

Qualitative research techniques seek to gather in-depth, non-numerical data, as opposed to quantitative data. Qualitative studies enable researchers to gain a deeper understanding of critical issues by probing perceptions, real-world experiences, attitudes, and viewpoints through the collection of broad data from traditional in-person interviews or questionnaires consisting of open-ended questions [11]. The use of meticulously crafted open-ended ontological or epistemological questions encourages reflection, critical thinking, and thorough exploration of feelings and perspectives [12]. Following the qualitative survey analysis, the themes identified among respondents shed light on vital issues. The research participant sample size is smaller for qualitative research, making it particularly useful for colleges and universities with low-enrollment courses. The purpose of this article is to review literature that purports the beneficial undergraduate outcomes of employing 3D printing in STEM courses and to present qualitative survey questions that may improve understanding of how 3D printing impacts college student development. Advancing department goals through evidence-based practices is crucial to producing competent graduates with the skills necessary to thrive in challenging technical fields.

2. 3D Printing and STEM Education

Since its emergence in STEM education, 3D printing has offered many advantages with several notable challenges to curricular implementation on college campuses (e.g., equipment and supply costs). Most of the scholarly literature on 3D printing and instruction originates from studies conducted with medical students [13-15]. The research findings from these studies provide resounding support for the use of 3D printing in education. Lampert et al. [16] developed an interactive 3D printing activity in which students printed 3D models of the structural components of flowers to gain a better understanding of how different reproductive structures in flowers impact insect pollination and plant diversity. Results from a post-activity qualitative interview indicate that the 3D printing activity was sufficient to foster student engagement and knowledge acquisition. Munir et al. [17] examined the functionality of 3D printing in biomedical robotics education. The researchers compared the viewpoints and grade performance of engineering students who completed learning modules involving 3D printing activities with engineering students who learned similar robotic engineering principles using traditional pedagogical methods. Results from the Mann-Whitney U test revealed statistically significant differences between the groups, demonstrating that the 3D printing group had greater satisfaction and better grades compared to the non-3D printing group.

Kilic et al. [18] presented exciting evidence from a workshop designed for medical students to explore the impact of 3D printing activities. In the workshop, students participated in designing and printing relevant anatomical models. Findings suggest that student-centered 3D modeling activities produced a positive impact on motivation and professional development, as well as a significant reduction in stress and anxiety during instruction. Engaging students as both creators and learners is a crucial pedagogical goal that may enhance their interest in STEM careers. Similarly, a team of faculty members and other professionals developed and implemented 3D printing workshops designed to enhance the creativity of engineering student researchers and postdoctoral fellows. Workshop participants designed and printed small research laboratory equipment [19]. The sample qualitative research questions presented in this article will serve as a springboard for developing qualitative questions to extract students' perceptions about the infusion of 3D printing activities in STEM courses (Figure 1).

Qualitative Research Study Questions

1. How do 3D printing activities affect your motivation to attend class?

2. How did the 3D printing activity affect your understanding of the course material?

3. How do hands-on activities such as 3D printing affect your views about the course?

4. Describe the skills you developed based on your interaction with the 3D printing activity.

5. How is your experience with a course that uses 3D printing technology compared to a course where lecture is the dominant teaching method?

6. How do 3D printing activities influence your desire to work with other equipment in class?

7. In what ways do 3D printing activities affect your desire to become an entrepreneur?

8. In what ways did the 3D printing activity modify the way you study for exams?

9. In what ways will the skills you learned from the 3D printing activity help you in your career?

10. Describe the modifications to the 3D printing activity that may improve student learning outcomes.

Figure 1 Sample 3D printing qualitative research questions

3. Conclusion

Hands-on learning activities are superior to passive learning activities. STEM educators have barely scratched the surface regarding the benefits of integrating 3D printing to elevate student engagement, training, satisfaction, and comprehension. Medical educators have been enhancing medical student knowledge and career readiness for many years, suggesting that the large-scale interdisciplinary utilization of 3D printing learning activities may help alleviate misunderstandings in science concepts and theories. Develop on-campus 3D symposia to showcase undergraduate 3D printing projects. These types of dissemination events promote students' creativity and entrepreneurship. In addition to incorporating 3D printing in STEM classes, establish a 3D printing center for all STEM majors on campus, thereby enabling greater 3D printer usage, technical workshops, and one-on-one training to promote democratization aims [20]. Livestreaming 3D printing projects may provide a mechanism for disseminating ideas and potential applications to larger audiences. It may encourage other institutions to consider using additive manufacturing devices when they observe how 3D printing technology can be effectively employed.

Moreover, educational research that focuses explicitly on student-centered 3D printing activities in which students design and print unique models that support individualized learning goals would be helpful. 3D printing research projects create prospects for interdepartmental collaborations. Increased on-campus faculty partnerships foster collegiality, thereby creating a stronger educational community. STEM departments should identify and pursue funding opportunities that provide funding to purchase 3D printers and supplementary printing materials necessary to adopt these novel approaches, which energize educational environments.

Qualitative research findings offer a more in-depth description of student phenomena. Qualitative research questions help characterize, explore, compare, understand, or evaluate. The selection of a unique qualitative research design (e.g., narrative design, grounded theory, phenomenological design, and ethnographic design) depends on the research goals and context. The sample 3D printing qualitative research questions serve as a starting point for future studies designed to help students comprehensively express their opinions about using 3D printing and the perceived benefits to their education and future careers. There is a limited understanding of the use of 3D printing to promote students' scientific product development skills and entrepreneurial skills. Thus, in addition to gathering student viewpoints on traditional academic outcomes, educational research findings are needed to explore STEM students' perceptions of the use of 3D printing technology to improve entrepreneurial acumen.

Compliance with ethical standards

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