RTP: Developing rural students' mathematics self-efficacy through Makerspace experience

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Abstract

This study investigated the use of 3D printing to support rural high school students' mathematics self-efficacy in algebra. Rural students often face persistent achievement gap in algebra, which in turn may negatively influence their engagement in mathematics. Research has shown the potential of integrating 3D printing technology in K-12 education for enhancing student understanding of abstract concepts. By embedding 3D printing into a high school algebra class, this study sought to make abstract mathematical concepts more tangible through hands-on learning experiences and thereby improve students' mathematic self-efficacy. The study was conducted at a rural public high school in the southeastern United States. A series of guided algebra activities integrated 3D modeling and printing into classroom instruction. Students used 3D modeling software to design representations of algebraic concepts which were then fabricated as physical models using 3D printers. Following a mixed methods research design, this study collected data including pre- and post-test of a mathematics self-efficacy survey and semi-structured individual interviews with students. Findings indicated an increase in students' algebra self-efficacy in understanding algebra concepts following their participation in the 3D printing activities. The results suggested that 3D printing had the potential of supporting mathematics learning in rural schools, especially in fostering students' confidence in algebra and improving their understanding of abstract concepts.

Introduction

Algebra has been a foundational component of secondary mathematics education that directly determines how students are prepared for advanced coursework in future STEM education [1], [2]. Despite its importance, many high school students struggle with algebra due to its abstract nature and heavy reliance on symbolic reasoning [3], [4]. These challenges can be particularly pronounced for students in rural schools, where limited instructional capacity and resources may constrain students' meaningful engagement with mathematics [5], [6]. As a result, rural students may experience lower confidence in their mathematical expertise, which can negatively influence their academic performance and intention of pursuing future educational pathways.

Self-efficacy, defined as individuals' beliefs in their ability to successfully perform specific tasks [7], has been a predictor of students' engagement and achievement in mathematics [8], [9]. Students with higher mathematics self-efficacy are more likely to persist through challenging problems, employ effective learning strategies, and view mathematics as relevant and attainable [10], [11], [12]. Consequently, instructional approaches that build students' confidence in algebra are especially important in rural contexts characterized by persistent mathematics achievement gaps.

Recent advances in educational technology have created new possibilities for addressing these challenges. Among these, 3D printing has emerged as a promising tool that enables students to design, create, and manipulate physical representations of abstract concepts [13], [14], [15]. Research has documented the benefits of 3D printing in engineering and science education, but little is known about its potential to support algebra learning, especially fostering students' mathematics self-efficacy of rural high school students. As an exploratory effort, this study examined whether and how the integration of 3D printing into algebra instruction influences rural students' mathematics self-efficacy.

Literature Review

Mathematics Self-Efficacy

Algebra is often identified as a "gatekeeper" subject that significantly impacts students' long-term academic trajectories, especially for their future STEM education pathways [2], [16]. Students' struggles with algebra often result in their decreased confidence in mathematics and thereby avoid taking advanced mathematics courses. However, rural schools face additional challenges for engaging their students in algebra, including their geographic isolation, a shortage of funding, and limited access to technologies and infrastructures [5], [6]. These challenges can further restrict students' access to effective STEM learning experiences and place them at a disadvantage compared to their urban peers in STEM academic achievement.

Mathematics self-efficacy has been consistently linked to students' performance and persistence in algebra [8], [9], with students who believe in their mathematical capabilities demonstrating greater resilience when faced with complex problems. Instructional strategies that emphasize transforming abstract concepts into tangible understanding have been shown to support the development of mathematics self-efficacy [12], [14]. Integrating accessible technologies, such as 3D printing and makerspace, may help bridge these gaps by offering rural students with opportunities for hands-on learning. Those activities may improve rural students' conceptual understanding of abstract concepts and gradually build their confidence in the domain.

3D Printing in Mathematics Education

The use of 3D printing in mathematics education has garnered increasing attention as an intervention for supporting students' spatial reasoning [17], [18], visualization [14], [17], and conceptual understanding [19], [20]. By transforming abstract mathematical representations into tangible objects, 3D printing allows students to physically manipulate and explore mathematical relationships [14], [15]. Prior studies have reported positive outcomes related to student engagement and conceptual learning; however, empirical research examining the impact of 3D printing on mathematics self-efficacy remains limited. This study thus sought to contribute to the existing literature by exploring the impact of students' makerspace experience on their mathematics self-efficacy in algebra classrooms at a rural high school.

Research Questions

This study was guided by the following research questions:

RQ1: To what extent does integrating makerspace into algebra instruction impact rural high school students' mathematics self-efficacy?

RQ2: How do rural high school students describe their learning experiences with makerspace integrated into algebra instruction?

Methodology

Research Design

A convergent mixed methods research design [21] was employed to examine the impact of a makerspace-integrated algebra intervention on students' mathematics self-efficacy. Quantitative data were collected to assess changes in self-efficacy, while qualitative data provided insight into students' perceptions and experiences.

Participants and Context

The study was conducted in an Algebra II course at a rural public high school in the southeastern United States. The instructional activities were implemented during regular class periods by the classroom teacher with support from the research team. Participation in the study was voluntary, and parental consent and student assent were obtained prior to data collection. A total of 36 students voluntarily participated in the study but only 28 of them completed both pre- and post-tests due to logistic challenges. Participants' age ranged from 16 to 18 years old and included 16 male and 12 female students. In addition, 13 of them were African American, 12 were white/Caucasian, two were Asian and one was American Indian or Alaska Native.

Intervention

The intervention consisted of a series of algebra lessons that integrated 3D modeling and printing activities. Students used 3D modeling applications on a laptop, AutoCAD and TinkerCAD, to design 3D models to design physical representations of algebraic concepts, including linear equations, slope, intercepts, and systems of equations. Once designs were completed, models were fabricated using MonoPrice Select Mini 3D Printers. Students were encouraged to revise and iterate on their designs.

Data Collection

Quantitative data were collected using a validated mathematics self-efficacy survey [8] administered before and after the intervention. Qualitative data were gathered through semi-structured interviews [22] conducted at the conclusion of the instructional unit. Interview questions focused on students' perceptions of algebra, their confidence in learning mathematics, and their experiences with the 3D printing activities.

Data Analysis

Descriptive statistics were examined to describe the central tandem of participants' mathematics self-efficacy. Shapiro Wilk tests were performed and confirmed the assumption of normal distribution was met. Paired-sample t-tests were conducted to examine changes in students' mathematics self-efficacy from pre- to post-intervention.

For qualitative data, interview transcripts were analyzed using an inductive coding [23] approach, with two cycles of coding [24] used to identify recurring themes related to student learning and self-efficacy.

Results

Quantitative Findings

Descriptive statistics showed that participants' mathematics self-efficacy increased from pre-test (M = 1.28, SD = 0.61) to post-test (M = 3.42, SD = 0.46). Paired sample t-test result indicated that the change was statistically significant, $t(27) = 4.51$, $p = .04$, with a medium effect size (Cohen's d= 0.62). The result indicated an increase in students' mathematics self-efficacy following participation in the 3D printing integrated algebra lessons.

Qualitative Findings

Qualitative findings revealed three themes, including increased conceptual clarity, enhanced engagement, and improved confidence in algebra. Students frequently described the physical models as helpful tools for visualizing relationships among variables and equations. A majority of the participants noted that the hands-on nature of the activities made algebra feel more accessible and less intimidating.

Discussion

The findings suggest that integrating 3D printing into algebra instruction can positively influence rural high school students' mathematics self-efficacy. By providing tangible representations of abstract concepts, 3D printing supported students' conceptual understanding and fostered a sense of competence in algebra.

For educators in rural settings, 3D printing offers a feasible and impactful instructional strategy for enhancing mathematics instruction. Incorporating design-based, hands-on activities into algebra lessons may help increase student engagement and confidence while addressing resource constraints common in rural schools.

This study was limited by its small sample size and single-site design. Future research should examine the long-term impact of 3D printing on mathematics achievement and self-efficacy across diverse rural contexts. Additional studies could also explore how 3D printing influences other areas of mathematics learning.

Conclusion

This study highlights the potential of 3D printing as an innovative pedagogical tool for supporting algebra learning and mathematics self-efficacy among rural high school students. By making abstract mathematical concepts tangible, 3D printing can help bridge instructional gaps and promote more equitable mathematics education for students in underserved communities.

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