

Effects of 3D Printing and Design Software on Students' Overall Performance

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Abstract

Researchers found that student-centered, technology-integrated learning environments help to produce students who are better able to think critically, solve problems, collaborate with others, and engage deeply in the learning process. Understanding the impact of technology and finding the best ways to integrate technology into the classroom is critical. Because of this, an investigation was conducted to determine whether the use of technology, specifically 3D printers and 3D design software, in a summer camp setting had a positive effect on students' motivation, interests, and mathematical and technical skills. Five-point Likert scale pre- and post- surveys were administered to the participants in two summer camps. A paired-sample t-test and one sample t-test were run to see the effect of 3D printers and 3D design software. In addition, Cohen's *d* effect sizes were calculated to see practical importance. The results revealed a statistically significant increase in some mathematical skills, motivation, and technical skills. The implication of such results will be discussed in detail.

Our world is constantly changing, and it is important to embrace it and grow with change. Technology is changing how we interact and learn in amazing ways. Because technology is prevalent in our society, students will be using technology in their careers. Students' out-of-school lives are richer in information and communication technology than their in-school lives (Ching, Basham, & Planfetti, 2005). The decrease in the cost of technology allows many schools to implement technology into curriculums and makes it more accessible to more students (Hollenbeck & Fey, 2009). Students now have access to Excel®, software programs, and other more sophisticated technologies that help their learning process. Thus, using these sophisticated technologies in instructional methods is important.

As technology advances and is increasingly incorporated into classrooms, it is important for researchers to understand the implications of using technology to achieve educational goals. Researchers have demonstrated that implementing technology properly enhances not only learning experiences, but also academic performance (Dix 1999; Lavin, Korte & Davis, 2010). All information cannot

be presented using paper and pencil. For example, engineering, science, and mathematics require visualization and critical thinking which are limited in paper and pencil classrooms. Healy and Hoyles (1999) stated that the appropriate use of technology could enhance teaching and conceptual development and enrich visualization. Designing through 3D software has shown to allow students to think visually in three dimensions, which improves students' spatial visualization (Martin-Dorta, Saorin, & Contero, 2008; Ziden, Zakaria, & Othman, 2012). Therefore, understanding the impact of technology and finding the best ways to integrate technology into the classroom is critical for improving students' performance.

Introducing concepts and teaching through technology can get students excited. Using technology in classrooms is a fun way for students to get involved in the lessons because they are able to understand the subject. (Jones, 2000; Hollenbeck & Fey, 2009). Software such as graphing calculators, Geometer's Sketchpad, e-transformation, and Geogebra can be used as effective technological tools in teaching and learning, especially in mathematics classrooms. Seeing real world applications through the use of technology also motivates students to learn (Ching, Basham, & Planfetti, 2005). Thus, adding technology to any discipline can be an effective approach to teaching by enhancing students' technical skills and allowing them to apply their skills to real-life.

Although much research has shown that there are many benefits of technology, some researchers do not agree. A study by Erkoç, Erkoç, and Gecü, (2013) showed that drawing through Google SketchUp did not enhance students' mental rotation skills any more than drawing by hand. Moreover, educators have concerns that students rely too much on technology and, thus, will not experience true learning (Dror, 2008). For example, calculators are often thought of as an easy route to mathematics, and, because of them, students no longer know how to do simple multiplication or division; but this is not always the case. A calculator can be used as an initial step in developing a conjecture before solving the problem (Hollenbeck & Fey, 2009). Using a calculator can help reduce errors in calculation, making the calculations less tedious and stressful for the student, and drawing his or her focus to more

complex mathematics (Goldenberg, 2000; Hollenbeck & Fey, 2009). Such an effective approach to teaching should not be taken away from the classroom when it is enhancing the knowledge of our students like never before.

This introduction is followed by a literature review, which examines previous literatures about the impact of technology on students' mathematical skills, technical skills, and motivation and interest. Next, the author describes how the study is applied by a quantitative approach to examine the ways students engaged in a summer STEM camp with using 3D printing and 3D design software and how that impacted students' mathematical skills, technical skills, motivation and interest. The author argues that the findings indicate how technology, especially 3D printing and 3D design software, positively affect students' overall performance during the summer STEM camp. As previous researchers claimed, this study showed how using technology in classrooms affected students in positive ways.

Literature Review

Because technology is prevalent in our society, students will be using technology in their careers. Therefore, they need experience with using it before entering the workforce. The digital age workforce requires some degree of technical competency, and students can acquire these skills by using technology in education. Various technologies such as learning platforms, interactive videos, complex gaming, innovative technologies, and electronic presentation tools are incorporated into classrooms (Dror, 2008; Lacey, 2010). With emerging technologies, especially 3D printers, students are able to get more engaged in science and mathematics. The 3D printers show how educators can bring up-to-date hands-on learning to classrooms that ensure high-quality education for tomorrow's professionals (Craig, 2000; Lacey, 2010; Segerman, 2012). Thus, teachers should use 21st century instructional methods in classrooms.

Students enjoy learning using technology. Introducing students to mathematics through technology can get students excited because they are able to understand the subject, and it is a fun way for them to get involved

and to be active in the lesson (Craig, 2000; Dix, 1999; Segerman, 2012). Because students become engaged in the technology-rich lessons, students use their cognitive ability to observe and reflect on the relationships among the representations provided by the dynamic software. 3D printing and 3D design software give students freedom to learn while exploring different pedagogical approaches. Students are able to succeed at creating 3D objects because they learn with their particular learning style (Lacey, 2010; Vanscofer, 2014). Students who use technology are able to explore mathematical ideas, which allows them to touch, verbalize, and build representations. In addition, student-centered lessons and technology-integrated lessons help students to think critically, solve problems, and engage in the learning process (Lacey, 2010).

New and powerful technological tools are available to support changing roles for schools (Bakar et al, 2002; Craig, 2000; Dede, 1996). By providing a student with a visual image alongside a concept or skill, the likelihood of the student's ability to understand and remember increases (Bakar, Ayub & Tarnizi, 2002; Hollenbeck & Fey, 2009). 3D printing aids visualization through the creation of tangible representations, and 3D designing allows for the visualization of information, incorporation of feedback, and experimentation that may be limited in paper and pencil classrooms (Lacey, 2010; Vanscofer, 2014). Thus, 3D printer and 3D design software allows students to better understand and grasp complex or abstract concepts.

As the visual image is a pedagogical tool for helping students understand, technology is another learning tool for enhancing recall and discovery, which can greatly affect a student's performance (Dror, 2008; Goldenberg, 2000; Healy & Hoyles, 2009). For example, when dividing 30 by 7, the answer on a calculator reads 4.28571428571429. This number is rounded, but a pattern is evident in this number. If the goal of this lesson is to find the pattern, then the student can do the problem by hand to understand the reasoning behind the pattern. Having the calculator's result in the beginning can allow students to visualize the patterns and draw their focus to the more important mathematical ideas.

Despite various technologies being implemented in secondary schools, some researchers argue that there is limited evidence of positive effects on student achievement. Falck, Mang, & Woessmann (2015) found that there were only positive effects of using computers to look up information and there was little to no effect of classroom computers on student achievement. Students did not gain any of the potential learning benefits and showed negative effects from using computers to practice skills. In addition, some researchers argue that if using technology is not carefully planned in relation to curriculum target goals or if teachers do not connect the use of technology with learning goals, then its use is not warranted (Dede, 1996; Dror, 2008). Thus, it is important to establish which tech-

nologies and under what conditions technology positively affects the teaching and learning.

The emergence of technology-rich mathematics classrooms helps diverse student populations to learn mathematical ideas, reason mathematically, and apply their mathematical thinking to real-life (Ching, Basham, & Planfetti, 2005; Dede, 1996; Suh, 2010). Suh (2010) showed that scaffolding, a progression of meaningful experiences of cognitive technology tools, not only encouraged students to make conjectures through interactive activities by trying what-if scenarios, but also promoted mathematical talk and critical thinking. "When teachers know how to effectively use the unique features of computer applications, they can address the varying cognitive strengths and needs of different students" (Suh, 2010, p. 440). Thus, teachers need to use the 21st century teaching methods to provide meaningful learning to diverse students.

As technology can be beneficial for students, it can also be helpful for educators. Technology changed the way educators assess learning and the design of their curriculum's content (Herrington & Kervin, 2007; Jones, 2000; 2001). Using the National Library of Virtual Manipulatives can be a useful tool to teach the area of a triangle. Web applets are very handy when demonstrating lessons involving rotation, growth, or movement. The combination of visuals and numerical calculation with analytic reasoning on the mathematical subject allowed students to develop a solid understanding (Hollenbeck & Fey, 2009; Karner & Bell, 2013; Sinclair, 2009). Students could improve their mathematic abilities using technology, including having visual and spatial representations, and instant feedback for them (Kilic, 2013; Knuth & Hartmann, 2005; Segerman, 2012;).

Technology can also be used in classrooms to provide meaningful information for teachers. Student Response Systems (SRS) can be handed out to students for them to post answers anonymously to the teacher. This allows teachers to see what areas of the content students are struggling with, thus improving test scores by clearing up any confusion (Jones, 2000; Jones 2001; Karner & Bell, 2013). It provides instant feedback, where teachers can adjust their teaching accordingly (Herrington & Kervin, 2007; Hollenbeck & Fey, 2009; Sinclair, 2009). Therefore, technology can improve teachers' competency and utilization of technology when properly utilized.

Statement of Purpose

The purpose of the study was to evaluate whether the use of 3D printing and designing had a positive influence on students' motivation, interests, mathematics skills, and technical skills. Through analysis of pre- and post-surveys from the students in the summer STEM camp, the researcher examined how 3D printing and designing class influenced students' motivation, interests, mathematics

skills, and technical/real-life skills.

Methodology

Participants

The research was conducted with secondary school students at a summer STEM Camp which took place in the southern part of Texas during the summer of 2015. The camp consisted of students who were entering grades 7 through 12. There were 67 students who took 3D printing and design class, but only 47 students were able to finish both pre- and post-surveys. Among those students who took 3D printing and design class, 3 students were from Italy, and the rest of the students were from several different states in the United States such as Texas, Alaska, New York, and Tennessee. Their ethnic backgrounds consisted of Hispanic (26.8%), White (56.3%), Asian (8.5%), Black (1.4%), and Indian (2.8%) with the remainder giving no specific ethnicity by either refusing to check a specific one or checking other (4.2%). Before the camp started, informed consent was collected from all of the students and their parents.

Intervention

Participants spent each day engaged in a 3D printing and design class during the two-week summer Camp. On the first day of camp, students filled out a survey about their knowledge and confidence on mathematics and real-life skills like technical skills. All of the students participated in designing and printing a 3D object. Students used Google SketchUp and XYZware software to design and print their own object. The learning objective and outcome was to print students' own unique 3D object. Students had their own laptop to work on in every class. The teacher used video clips and software tutorials to introduce 3D designing and printing. Students started exploring the vectors and geometric shapes on the SketchUp software program before they started drawing their own objects. Students not only received help from the teacher and classmates, but also learned by themselves by watching the software tutorials again. The teacher checked if students were working on it correctly and addressed any misconceptions to the class. During the last week of the Summer Camp, students who finished their design presented what objects they designed, what the purpose was, why their object was unique or special, and what they liked about their project. On the last day of the camp, students filled out the same survey they took on the first day, which consisted of their knowledge and confidence in mathematics and real-life skills.

Instruments

Pre- and post-surveys were administered to the participants in two summer camps through Qualtrics. The survey questions consisted of Likert-scale, open-ended, and short response types (1 = "strongly disagree," 2 =

“disagree,” 3 = “neutral,” 4 = “agree,” 5 = “strongly agree”). Participants took a pre-survey before the camp started and took the post-survey after the camp was done. There were some identical questions on pre- and post-surveys to measure the difference of their level in confidence and knowledge regarding the following topics: project management tasks, problem solving skills, SketchUp software, XYZware software, spatial visualization skills, visualization skills, 3D Printing, 3D design, transformation skills, 2- and 3-dimensional vectors, proportions, angles and measurements, and technical skills. A software package, SPSS 23, was used for statistical analysis.

Procedure

All students were pre- and post-tested to measure their motivation, interests, mathematic skills, and real-life skills. To see if there was a positive influence on student performance on the identical questions, the researcher used SPSS 23 to run a paired-sample *t*-test comparing pre- and post-survey mean scores for all participants. Cohen’s *d* effect sizes were reported for the entire set of participants. In addition, one-sample *t*-tests were performed for the remaining post-survey questions about students’ overall performance. Independent-sample *t*-tests were run with regard to the students’ motivation, real-life skills, and mathematics skills. Because multiple univariate tests were calculated, a Bonferroni correction was used. There were 22 paired-sample *t*-tests, so the Bonferroni correction was calculated by dividing .05 by 22 to get the new alpha value, .002.

Results

To determine if the intervention was helpful, descriptive analysis was used. The mean score for all of the participants on the posttest was higher than that for the same participants on the pretest except for confidence in proportions and angles/measurements. The mean differences between the pre- and post survey results are shown in Table 1 ranging from -.085 to 2.128 and standard deviation differing from .960 to 1.698. The greatest mean difference was the knowledge in XYZware Software, and the smallest mean difference was the confidence in proportions.

t-tests

To answer the question of relationships between 3D printing and design class and student performance, paired samples *t*-tests were used.

Knowledge. Students’ pre- and post survey scores revealed a statistically significant increase in students’ knowledge of SketchUp software, XYZ software, spatial visualization, 3D printing, 3D design, transformation, 2- and 3-dimensional vectors, and technical skills ($p < .002$). However, knowledge of visualization, proportions, and angles/measurements were not statistically significant.

Pre and Post test pairs	N	Mean Difference	SD Difference	p
Knowledge in SketchUp Software	47	1.830	1.698	< .001*
Knowledge in XYZware Software	47	2.128	1.610	< .001*
Knowledge in Spatial Visualization	47	.681	1.218	< .001*
Knowledge in Visualization Skills	47	.255	1.031	.096
Knowledge in 3D Printing	47	1.170	1.551	< .001*
Knowledge in 3D Design	47	1.085	1.558	< .001*
Knowledge in Transformation	47	.723	1.246	< .001*
Knowledge in 2- and 3- Dimensional Vectors	47	.809	1.362	< .001*
Knowledge in Proportions	47	.106	.961	.452
Knowledge in Angles/Measurements	47	.234	.960	.102
Knowledge in Technical Skills	47	.532	1.060	.001*
Confidence in SketchUp Software	47	1.255	1.519	< .001*
Confidence in XYZware Software	47	1.787	1.654	< .001*
Confidence in Spatial Visualization	47	.213	1.062	.176
Confidence in Visualization Skills	47	1.170	1.110	.298
Confidence in 3D Printing	47	.915	1.586	< .001*
Confidence in 3D Design	47	.660	1.464	.003
Confidence in Transformation	47	.362	1.358	.074
Confidence in 2- and 3- Dimensional Vectors	47	.617	1.208	.001*
Confidence in Proportions	47	-.085	1.039	.577
Confidence in Angles/Measurements	47	-.064	1.051	.679
Confidence in Technical Skills	47	.489	1.101	.004

* Significant at $p < .002$

Table 1. Paired Samples t-tests

Confidence. Students’ pre- and post-survey scores revealed a statistically significant increase in students’ confidence using SketchUp Software, XYZware software, 3D printing, and 2- and 3-dimensional vectors ($p < .002$). However, confidence with spatial visualization, visualization, 3D design, transformation, proportions, angles/measurements, and technical skills was not statistically significant.

One sample *t*-test for students’ only post survey scores revealed a statistically significant increase in all items. The student’s mean score was 4.190 on how motivated they were to learn new materials during the program. After the intervention, students’ mean scores were high for interest in 3D printing ($\bar{X}=4.320$) and design ($\bar{X}=4.280$). Students also felt confident enough with 3D printing to teach it to someone else ($\bar{X}=3.980$). Lastly, not only were

students more motivated to learn ($\bar{X}=4.130$), but also accomplished real-life skills ($\bar{X}=3.910$).

Effect Size

To determine the magnitude of the differences between pre and posttest, Cohen’s *d* effect sizes were calculated for all the variables, and they ranged from -0.082 to 1.322. Many variables showed practical importance, which indicated using 3D printing and designing software had a positive effect on overall student’s performance regarding mathematical skills and technical skills.

Knowledge. Eight variables had practically important Cohen’s *d* coefficients, and the variables were knowledge in SketchUp, XYZware, spatial visualization, 3D printing, 3D design, transformation, 2- and 3-dimensional vectors, and technical skills. The greatest Cohen’s

Post Test Questions	Mean (SD)	Sig. (2-tailed)
During this 3D printing and design project, I was motivated to learn new materials.	4.191 (1.056)	< .001*
After finishing this 3D printing and design project, I have interests in 3D printing.	4.319 (0.980)	< .001*
After finishing this 3D printing and design project, I have interests in 3D design.	4.277 (0.994)	< .001*
After finishing this 3D printing and design project, I feel comfortable enough with the topic of 3D printing to teach it to someone else.	3.979 (1.170)	< .001*
After finishing this 3D printing and design project, I have more enthusiasm toward learning.	4.128 (0.924)	< .001*
After finishing this 3D printing and design project, I learned real-life skills.	3.915 (1.139)	< .001*

* Significant at $p < .002$

Table 2. One-Sample t-tests on Only Post Survey Questions

d was 1.322 for knowledge in XYZware software. These variables showed a large span of practical significance.

Confidence. Seven variables had practically important Cohen's d coefficients, and the variables were confidence in using SketchUp, XYZware, 3D printing, 3D design, transformation, 2- and 3-dimensional vector, and technical skills. The greatest Cohen's d was 0.577 for confidence in XYZware, which shows a very high practical importance. These variables had a range from -0.082 to 1.080 with seven variables greater than .443.

Discussion

The 3D printing and design class allowed students to become more interested in learning the material. Previous research states that teaching concepts through technology can motivate students to become excited because they are able to understand the subject, and it is a fun way for them to engage in STEM lessons (Jones, 2000; Hollenbeck & Fey, 2009). The t -test results reveal statistically significant results for students' motivation and interests. The mean for all the variables on the post-survey only questions were higher than 3.900, showing that the intervention allowed students to gain enthusiasm toward learning. Students were also motivated to learn and gained interest towards 3D printing and design. As previous research shows, emerging technologies engage student in the learning process. Thus, using appropriate technologies will allow students to gain enthusiasm toward learning.

As students were motivated to learn, students' mathematics skills increased. In both the pre- and post-surveys, students' mean score for overall mathematical skills increased. Variables such as knowledge of spatial visualization, transformation, and 2- and 3-dimensional vectors were statistically significant. Thompson (2006) notes that having a statistically significant result "does not mean that the results are important or valuable" (p. 147); thus, it is important to report effect sizes. To see the magnitude of the differences between the pre- and post surveys, Cohen's d was reported. Variables such as knowledge of spatial visualization, transformation, and 2- and 3-dimensional vectors also had large effect sizes ranging from .580 to 0.599. The variable, confidence in 2- and 3-dimensional vectors, was also statistically significant, and the effect size was 0.511. This not only shows practical importance, but also tells one that students have acquired mathematical skills and greatly increased their mathematical ability through the intervention program, and researchers have demonstrated that implementing technology properly enhances not only learning experiences, but also the academic performance (Dix 1999; Lavin et al., 2010). Moreover, Students did not only gain mathematical knowledge, but also were confident in their mathematical skills.

Although some mathematical skills improved statistically significantly, students' confidence in many math-

ematical skills were not statistically significant. However, students did not receive any lessons on mathematics during the intervention, thus students might not have felt confident enough to teach it to other people. However, the increase in the mean scores for the mathematical skills shows that students were able to verbalize, touch, and build representations as shown in previous researches. If students even had mini lessons on mathematical concepts, the intervention would have been more effective for increasing students' knowledge and confidence in mathematical skills.

Moreover, this may be due to the complication of intervention. First, students had to learn about the computer itself and other new software programs such as Google SketchUp software and XYZware in three to five days. They also had to make individual objects in 2D on the software and connect it to 3D software. To be able to print this, they had to visualize what the 3D object would look like on a plate because this could not be seen on Google SketchUp. Moreover, they had to scale arbitrary objects. Students had to accomplish all of these skills in eight days, which is a great amount of cognitive load for these secondary students. Thus, if the cognitive load was reduced for the students, they may have acquired more mathematical skills. Even though students had a great amount of cognitive load, the results do not diverge far from statistical significance.

While student's overall performance increased, real-life skills highly increased after the camp. As students are living in a technology rich world and there are many available technologies in schools now, educators should use those technological tools for teaching (Dix 1999; Lavin et al., 2010). Both knowledge of and confidence in 3D printing, SketchUp software, and XYZware software and knowledge of technical skills significantly increased effect sizes and showed practical importance. Although the change in knowledge of 3D design was statistically significant, the change in confidence in 3D design was not. However, the confidence in 3D design is very close to being statistically significant and its effect size shows a practical importance. This shows that if the intervention were longer, the effect size would be more than 1 standard deviation, which is a great change in students' performance. Therefore, the effectiveness of 3D printing and design software on student performance demonstrated here matches previous research.

In conclusion, the incorporation of technology into curriculum can enhance students' learning experiences and overall performance. However, factors that increase or decrease the effectiveness of technology should be taken into consideration. Factors that can lessen the effectiveness of technology in classrooms may be background knowledge of students, teacher competency levels with the technology, and students' social class (Falck, Mang, & Woessmann, 2015). Because every student had their own laptop to access the software system, the socioeconomic

factor did not affect students to improve in certain skills. Some students may have had a more difficult time in designing the 3D object because they may not have been exposed to SketchUp software or even the computers itself. However, every student was able to successfully create and print their 3D object, which met the learning outcome. Thus, teachers need to consider these factors and properly utilize them in their classrooms.

Conclusion

The intervention, 3D printing and design class in a summer camp program, had a positive influence on student's motivation, interests, mathematic skills, and real-life skills. The results showed not only statistical significance, but also practical importance of student performance. If the intervention was longer, reducing the cognitive load for students, it would have potential of being even more successful. This overall positive result suggests taking 3D printing and designing class to formal learning environments. Implementing 3D printing and designing in classrooms and having specific learning outcomes matching it will enhance students' learning experiences. Thus, using technology to reach each of the students in 21st century classrooms must be flexible in meeting the unique needs of learners.

Moreover, the decrease in the cost of technology allows many schools to implement technology into curriculums, making it more accessible to a larger number of students. As technology advances and is increasingly incorporated into classrooms, it will allow students other opportunities for learning because they are engaged in activities that are relevant, interesting, and authentic. However, teacher training, consideration of student technology proficiency, and clearly defined objectives of every technology-integrated lesson is necessary for successful student performance. Therefore, teachers should introduce technology and use technology integrated lessons in order to prepare the 21st century students for practical problem solving and technological applications to guide them to the road of success.

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Appendix A

Pre-/ Post Survey Questions

Please rate your knowledge and confidence regarding the following topics. 1 represents the lowest level, while 5 represents the highest.

	Knowledge					Confidence				
	1	2	3	4	5	1	2	3	4	5
SketchUp Software										
XYZware Software										
Spatial Visualization										
Visualization Skills										
3D Printing										
3D Design										
Transformation										
2- and 3- Dimensional Vectors										
Proportions										
Angles/Measurements										
Technical Skills										

Appendix B

Only Post Survey Questions

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
During this 3D printing and design project, I was motivated to learn new materials.					
After finishing this 3D printing and design project, I have interests in 3D printing.					
After finishing this 3D printing and design project, I have interests in 3D design.					
After finishing this 3D printing and design project, I feel comfortable enough with the topic of 3D printing to teach it to someone else.					
After finishing this 3D printing and design project, I have more enthusiasm toward learning.					
After finishing this 3D printing and design project, I learned real-life skills.					