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Closing the knowledge gap between virtual design and product manufacturing : using 3D printing for the ninth grade

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This action research investigates the impact of using 3D printing for a Technology Education course in a ninth grade classroom in general, and the effectiveness of students' ability to connect virtual design and manufacturing concepts in particular. There is a current gap in 3D printing research involving the link between designing products virtually using CADD software and the manufacturing processes necessary to create real life products. This action research attempts to fill the current research gap between computer-aided design and product manufacturing for ninth grade students.

Within the three weeks of this experimental design research, as a teacher who teaches *Introduction to Manufacturing*, I collected both qualitative and quantitative data. I also continually modified the action research project to meet the needs of my students and their instruction. It was found that the use of 3D printers really enhanced student engagement and learning. 3D printers can close students' knowledge gap between virtual design and product manufacturing.

Closing the Knowledge Gap between Virtual Design and Product Manufacturing:

Using 3D printing for the Ninth Grade

A Graduate Action Research Study

Submitted to the

Division of Instructional Technology

Department of Curriculum and Instruction

In Partial Fulfillment

Of the Requirements for the Degree

Master of Arts

UNIVERSITY OF NORTHERN IOWA

by

Jeremiah D. Cooper
May 11, 2015

This Action Research conducted by: Jeremiah D. Cooper

Titled: Closing the Knowledge Gap between Virtual Design and Product Manufacturing:

Using 3D Printing for the Ninth Grade.

has been approved as meeting the research requirement for the

Degree of Master of Arts.

Ping Gao

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Abstract

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Keywords: 3D printing, 3D manufacturing, emerging instructional technologies,

Technology Education classroom, action research study, rapid prototyping, computer-aided

design and drafting, CADD

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Introduction

3D printers and rapid prototyping machines have become increasingly popular in various communities, including hobbyists, designers, and even the classroom. The increased popularity, along with many free and lost cost pieces of 3D printing equipment have made these machines a viable resource that could find their way into every classroom. It is claimed that 3D printers and rapid prototyping will revolutionize the way in which teachers reach and engage all of their students in the 21st Century classroom (Kaur, 2012; Michael, 2013; Tomasiewicz, 2014)

In reality, students are unable to make a clear connection between the virtual designs that they create using computer-aided drafting and design software and how real-world products are manufactured. From my five years of personal teaching experience, I have noticed that my beginning design and manufacturing students' have had a difficult time in my technology education courses when making the connection between these concepts. They face the challenges to make a connection with concepts such as dimensioning, scale, materials, and tolerance, because they are either not involved with the design process or they don't see the physical product in real life that they've designed. The misunderstanding between virtual design and product creation is due to a lack of a connection between the concepts of virtual design, scale, size, materials, and processes necessary to manufacture products.

Recently within the Waukee Community School District, where I currently am employed, there has been an increased push to get 3D printers into Technology Education classrooms by our local Area Education Agency and local libraries. However, there is very little research and evidence to show that 3D printers improve instruction or help students make connections in the design and manufacturing classroom.

The purpose of this action research study is to identify if using 3D printers and rapid prototyping machines in Technology Education classrooms can effectively close the gap between designing products virtually using computer-aided design software and actual product creation using manufacturing processes. This research study will also briefly cover whether or not the high cost for implementing 3D printers in the classroom is justified through increased student knowledge and engagement. Finally, this report will include possible future areas of study and research involving 3D printers that my students helped me identify during the action research process.

The problem that was examined in this action research study involved my both my Drafting and Design and Manufacturing students in the Waukee Community School District. I identified the problem that the students are unable to make a clear connection between the virtual designs that they create using computer-aided drafting and design software and how real-world products are manufactured. The misunderstanding between virtual design and product creation can include concepts of virtual design, scale, size, materials, and processes necessary to manufacture products. The research questions that I set out to answer through both a literature review process and action research study are included below:

- Do 3D printing technologies help increase engagement between virtual design using computer-aided design software and product manufacturing?

- Do 3D printers as classroom instructional technology tools, provide effective and improved results in teaching students about virtual design, scale, size, material properties, and manufacturing processes?

- Does using 3D printing technologies in the classroom result in students displaying an increased level of knowledge and understanding between virtual design and product manufacturing?

Literature Review

I have reviewed 31 peer-reviewed journal articles for conducting this action research. I organized my analysis in two aspects: 1) the general introduction of 3D; and 2) the potential impact in K-12 settings.

My rationale for selecting and analyzing sources was based upon whether or not the source was credible, useful, and relevant. When establishing credibility for the sources, I looked at the credibility of the authors through their background and qualifications within the field of 3D printing. I also established the credibility of the publication by checking dates of publication, whether the information was still relevant to today's technology and manufacturing processes, and if there was a large amount of new data that superseded that of the source I was researching. Another contributing factor when narrowing down sources in my research was the originality of the studies presented by the authors, or if most of the information being presented was from secondary sources. Finally, I analyzed if the source clarified, connected, or contributed to the topic of my literature review. The sources that I referenced needed to fit by identifying key issues, topics, points-of-view, and areas of inquiry that related to the problem statement that I had identified.

Introduction of 3D printing

3D printers are not new technologies and have been in industry for years, however consumer level models that classrooms can utilize have begun to show up on the market lately.

There is a large amount of marketing hype that surrounds these machines, as they claim to be able to create anything that you can design using software, and that it will revolutionize the ways in which people buy and produce goods and products. It's an exciting topic for media to cover as new and previously undiscovered products and items are created and methods of manufacturing at the personal level are developed. However, is all of this media coverage correct and does the excitement level in regards to the potential actually hold up in the classroom? The essential question that I'm hoping to answer in all of this is, do 3D printing technologies help close the knowledge and understanding gap between virtual design using computer-aided design software and product manufacturing?

The big movement now within the 3D printing industry is that it is becoming easier for the average user to understand, and the cost of 3D printers has significantly declined. The average 3D printer, even five years ago was around $12,000. Now it's possible to purchase a 3D printer for a single user or classroom for around $1,200. There have also been several movements within the 3D printing community to create software and printer designs that are free to the public, an example being the RepRap movement. The RepRap movement is all about trying to develop 3D printers that allow for easy self-replication of replacement parts.

In Design and Production 3D printing follows Shane Williams, a member of the Remap community (Spurling, 2013). Remap is an organization and charity that focuses on providing independence to people that have physical disabilities. Williams uses free programs such as Blender and other free CADD software to design parts and products using a 3D Printer. 3D Printing technology has lowered from being several thousands of dollars to just over a thousand dollars for a capable printer. The cost is still somewhat high, but the capabilities and benefits of a 3D printer may outweigh the overall cost. The big difference in the 3D printers that Williams

uses, is that the primary printing material is vinyl as oppose to PLA or MLA plastic. Williams uses the 3D printer to create parts and innovations on existing products, such as his wheelchair, to give it either added improvements or a greater lifespan.

To contrast Williams' point, another article explained that the affordability of 3D printing was clearly underway and that the historical patterns of expansion in 3D printing are showing growth signs close to that of home computing (Michael, 2013). 3D printers are gaining a larger community following and the technology is becoming easier for people and educators to get access. The number of major companies that have 3D printing products for individual designers and classrooms has also increased dramatically in the past few years. This article describes how the growth area for 3D printing includes education, and specifically how it can be used for teaching young children. The article also describes some of the technological hurdles including teacher education over the technology, what materials to use, and at what age does it become appropriate to ask children to be able to create and modify 3D shapes for printing.

Potential Impact of 3D printing in the K-12 Settings

Much of the marketing hype that surrounds the current 3D printers describes them as very user-friendly and easy for everyone to understand (Beato, 2014, Bogue, 2013, Evans, 2013). Is the average student in the Technology Education classroom going to be prepared with the right skill set to be able to effectively use the technology?

As described earlier, 3D printers have been used in industry for the last several decades, however there have been large innovations that have improved the ability for teachers to get them in their classrooms. There is still some significant instruction, maintenance, and planning that must be considered when putting a 3D printer into your technology lineup. There are software and hardware skills that your students will need to understand prior to setting them

loose on any 3D printing machine. The classroom teacher will need to understand that there are going to be issues and hurdles involved with 3D printing and implementing programs in schools (Sangani, 2013).

Like many instructional technologies, there is going to be a learning curve that the teacher must overcome before s/he can effectively teach using the 3D printer effectively (Khaou, 2014). First of all, in order to effectively, the user must have a good understanding of CADD systems and how to edit and manipulate 3D objects using software. CADD software is easily available, however not everyone is going to inherently understand how to use it. CADD software has been proven to be a necessary component of the manufacturing and drafting subject areas, as it expands upon the students' ability to create products designs more efficiently and effectively (Modlin, n.d.). The second barrier is that 3D Printers present issues in regards to how the process works and the materials involved as well. Many different users of 3D printers have experienced various issues, including the printers not working every single time, having to spend large amounts of time fixing their printers, and being limited on the types of materials that they can use to create. Third, many users have also described many issues with the product support after they have purchased their printers, as many companies are not doing everything they can to help their user base (Goldberg, 2014). The average user is also not going to know which 3D printer is necessarily the correct one for them and also how to safeguard against future proofing. As with any state of the art technology, at what point is the product going to become obsolete. Does it makes sense for the average person to become involved with 3D printing now, or should they wait until the products become more mainstream and the issues are worked out? Another large issue is in the idea of being able to create products for free. In the world of

3D Printing and 3D scanning, there is going to be a large amount of product replication and

breaking of patent laws, much like the downloading of music in the early 2000s.

Teachers, administrators, and parents need to understand the need for 3D printers within

their students' classrooms. More and more, the research is pointing to the fact that

manufacturing as an industry is going to go through a large change, equivalent to that of the

previous U.S. industrial revolution (Berman, 2012). Historically, the goal of all manufacturing

was to create large batch quantities of items at very low costs. The shift appears to be that

people are going to start going away from mass-produced products in lieu of small batch, highly

customized objects. There are definitive pros and cons of 3D printing in relation to other

manufacturing methods, as well as, how it will begin to make the average person their own

manufacturer. Traditional manufacturing methods have been expensive, over-complicated for

the average user, and completed in third world countries (Bogue, 2013). 3D Printing has an

advantage that it allows the user to make small batches of products easily or create prototypes

without having to order large quantities. Mass manufacturing is an industry where if you are not

producing millions of a product, you are not making money. 3D Printing takes out the

unnecessary costs associated with small batch manufacturing and puts the control into the hands

of the user. It is now easy for everyone to be their own manufacturer of certain types of

products, made from various materials (Petrick & Simpson, 2013).

The Action Research

Context of the Study

Waukee Prairieview is currently a 9th grade school building designed to help students make the transition between middle school and high school. The building currently serves approximately 600 students and employs over 50 staff members. Students are typically between the ages of 14 and 15 years old, and live in the surrounding communities of Clive, Urbandale, Waukee, and West Des Moines. Waukee is the fastest growing school district in the state of Iowa with more than 900 staff members serving more than 8,000 students in grades preschool through twelfth grade. Waukee also serves open enrollment students from other communities outside the 55 square miles of our district boundaries.

The one hundred and eighteen students who are taking my Technology Education courses this semester, are only required to have one six-week course during their 7th grade year that involves any content with design and manufacturing. The students who I serve in my classroom are not required to take any prerequisites or take both Manufacturing and Drafting and Design in conjunction with each other. My classroom is designed as such to be a collaborative environment where every student has access to a computer, internet, various drafting software, and a 3D printer.

During this action research study, there were several individuals who helped in the process of receiving permission to conduct research, and helping collect data in a way that helped maintain my students anonymity during the participation within the study. Both my building principal and secretary helped administer the surveys and interviews, to help students feel more at ease about giving accurate answers. During the IRB process, I had to make sure to include several methods in which my students' anonymity would remain intact, so that they did not feel that their grade was affected by their answers. Parents and guardians were also notified with a Consent and Assent Letter that had to be signed in order for me to use their child's collected data.

The equipment necessary to conduct the study was already in my classroom, therefore I did not have to seek out budgetary assistance in order to complete this research study. My classroom originally received the funding for the 3D printer that we have from our local Foundation Grant Committee for the Waukee Community School District. My department budget was able to help with the plastic materials necessary to create the final products in the

experimental group. The brand of 3D printer that was used throughout the Action Research study was a Makerbot Replicator 2X, which has the unique ability to print multiple colors in the same object.
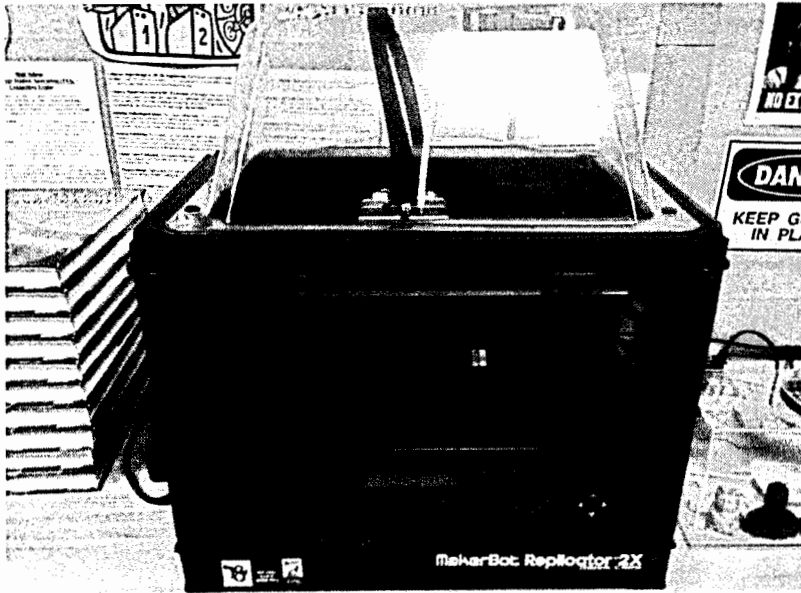
Data Collection Methods

Data collection took place over the course of the three-week study during the second half of the students' semester course, when students would learn about computer-aided design and basic manufacturing principles. The timeline of this action research study included performing a literature review before the study began, and also gaining approval from the Waukee Community School District and University of Northern Iowa to perform research. Students were assigned a number at the beginning of the study to help keep individual students anonymity intact, so that they did not feel pressured to answer a certain way for a grade. After the students were assigned a number, they were broken down into a control group of 58, which did not utilize the 3D printer in any form, and an experimental group of 60 students who did use the 3D printer for their final product. The groups were based upon class sections because it was not a possibility to alter

students' schedules in order for them to attend different sections of the class during the study. The collected quantitative and qualitative data was used to compare the experimental and control groups before and after the research study.

Observational and interview data was collected throughout the entire three week study and was an ongoing process. The observational and interview data was used to help make any necessary changes to the content of the lessons along the way. The students continuously were working towards a final goal of creating a work sample that would either be 3D printed by the experimental group, or described in a presentation by students in the control group. The rubrics used on the final work sample measured the same outcomes in both the control and experimental groups. Both groups of students were required to create a final project during this research project. The control group of students created a product using CAD software and then in a method of their choosing, described the manufacturing process for that product. The experimental group also used CAD software, and then used the 3D printer to create a physical prototype of their product.

Data collection methods for this action research study included both qualitative and quantitative collection methods. Due to the fact that there simply is not that much existing research on the topic of using 3D printers in the classroom, much of the initial data was collected through surveys of my students and then quantifying those reactions as numerical data. Several likert scales were used to establish various baseline sets of data such as their current understanding of 3D printing, the design process, rapid prototyping, and manufacturing processes. The likert scales were distributed via the online surveys to both groups of students.

A coding process was created for students in order to break down their responses into categories, to simplify analyzing the overall results of both my control and experimental groups.

In situations where interviews were conducted with students regarding their work, a fellow teaching colleague with experience in drafting and manufacturing helped with interviewing students as to further protect the student anonymity in the research process.

Timeline of Action Research Project

Steps	Description of Event	Timeline of Event
1	Perform literature review of proposed articles.	December 2014
2	Gain approval for proposed action research project.	January 2015
3	Survey all students regarding their current understanding of 3D Printing Technology	First day of study
4	Collect observational data during content lessons.	Weeks 1,2,3
5	Interview selected students regarding current understanding of 3D Printing.	Week 1
6	Collect Student Work Samples from both the Experimental and Control Groups.	Week 3
7	Conduct an exit survey of the students	Week 3
8	Analyze collected data. Code and categorize collected data. Construct category frameworks.	April 2015
9	Evaluate results of the action research project.	April 2015
10	Create a report of data analysis and observational data.	May 2015
11	Report out findings and analysis through Graduate Research Paper.	May 2015

Data Analysis

In this action research study, the data analysis portion of the process is somewhat ongoing and built into how the study progresses. I chose to do action research because it allowed me to cater the content to my students and classroom without needing to worry whether or not my results could be replicated in other classrooms. This particular study required me to collect both quantitative data and qualitative data which required different methods for organizing the results. As I progressed throughout the study, I was able to change courses slightly in order to meet the changing needs of my students in both groups.

I collected quantitative data through the surveys that were administered to the students. This data helped me establish a baseline of information for both my control and experimental groups of students. The qualitative data was recorded through my interviews, using an approved work sample rubric, and my field notes. All students completed an exit interview with me because I did not know until the study was completed, which students had agreed to allow their results to be used in the study. Only the students who allowed me to use their qualitative data will be mentioned within the findings and conclusion.

The qualitative descriptive data had to be organized into a series of categories that helped establish a picture of how the students were progressing through the study. I used the qualitative data to help validate the findings that were collected during the initial survey that students took to establish a baseline of prior experience and knowledge. The qualitative data was also the most essential in helping me shape the course of the action research study because the research question dealt with students being able to take a product through the entire design process. The design process requires the student to create a model or prototype of their product.

An example of where the follow-up qualitative data helped me validate the quantitative data collected from the survey results, is shown in Figure 3. In this particular question, just under 50% of students rated themselves as having at least an adequate level of knowledge regarding the Design Process, however in the majority of follow-up interviews that occurred after the first survey, the students really couldn't list any of the steps in the Design Process and even less could actually explain what those steps meant. The interview data helped me shape the course of content in the lesson planning regarding the Design Process, and in fact this is where we ended up spending the majority of our time and lesson content. This shows that you cannot always follow self-assessment data without some kind of data validation process.

The Findings

The Action Research performed in my classroom with the control and experimental group of students resulted in a wide gap in student classroom engagement and understanding of the connection between designing a product virtually and creating it physically. The experimental group of students, who had access to the 3D printer, self-assessed themselves as having a higher understanding of physical prototyping in the design process than the control group who did not have access to the 3D printer. The experimental group also scored more proficiently in terms of their final work sample design according to the rubric they were given during the study. The experimental students finally ranked themselves as feeling more engaged with the class content, citing that the content was more personalized to their interests and they were able to actually make a physical prototype of their product during the work sample.

Closing the Gap

When the study began, I was immediately met with a wealth of questions from my students because the 3D printing technology is so new to the core demographic of people. As I found in my research of the current literature, 3D printing is not a new technology, but it is just now becoming cheaper and more accessible to the common consumer. My experimental group of students immediately wanted to know what kinds of things could be created and how they could go about making their own products. There was a sense of engagement in those students because they were so interested in how the technology could allow them to make their own products. I did not see this immediate interest from the control group because they went into learning about computer-aided design with no connection to a real world product. They were not as excited about the content because they weren't necessarily going to get to actually make their product.

I organized the collected descriptive data through the use of Google Spreadsheets which

allowed me to easily analyze the numerical data into charts and graphs.

On a scale of 1 - 5, how would you rate your knowledge of 3D Printing?

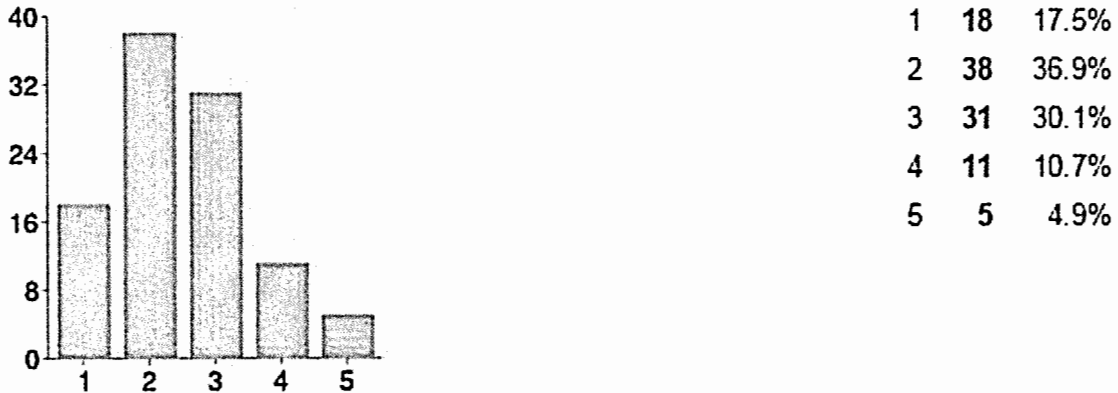|		
1	18	17.5%
2	38	36.9%
3	31	30.1%
4	11	10.7%
5	5	4.9%

Figure 1 Current level of knowledge regarding 3D printing. The figure suggests that the students have a varying range of prior knowledge of 3D printing. The overall majority of the students elaborated in a follow-up question that they had heard about 3D printers in the media.

Please rate your current level of knowledge and experience using computer aided design and drafting (CADD) software.

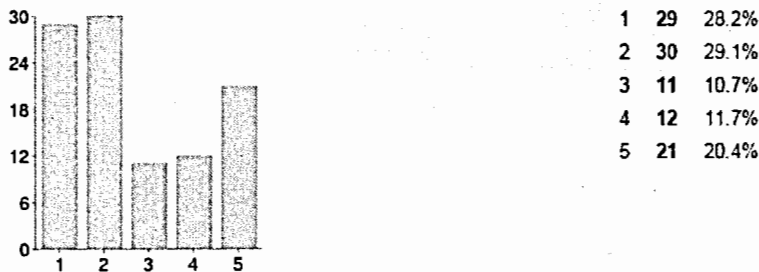|		
1	29	28.2%
2	30	29.1%
3	11	10.7%
4	12	11.7%
5	21	20.4%

Figure 2 CADD software knowledge. The result suggests that the majority of the students who participated in this study, did not have prior CADD experience. The students who rated themselves higher said that they had either taken Drafting and Design the prior semester, Gateway to Engineering in 8th grade, or both.

Please rate your current level of knowledge and experience using a "design process" to develop and manufacture a product.

1	28	27.2%
2	25	24.3%
3	23	22.3%
4	17	16.5%
5	10	9.7%

Figure 3 Current knowledge of the design process at the beginning of the study. The above chart Figure 4 – Current knowledge of the design process at the beginning of the study. Figure 3 displays data from this question that suggests many of the students had at least a basic level knowledge of the Design Process. However, in follow-up interviews students had great difficulty in actually describing the steps within the process. This is an example of quantitative data that was somewhat misleading when helping me shape the lesson content of the Design Process.

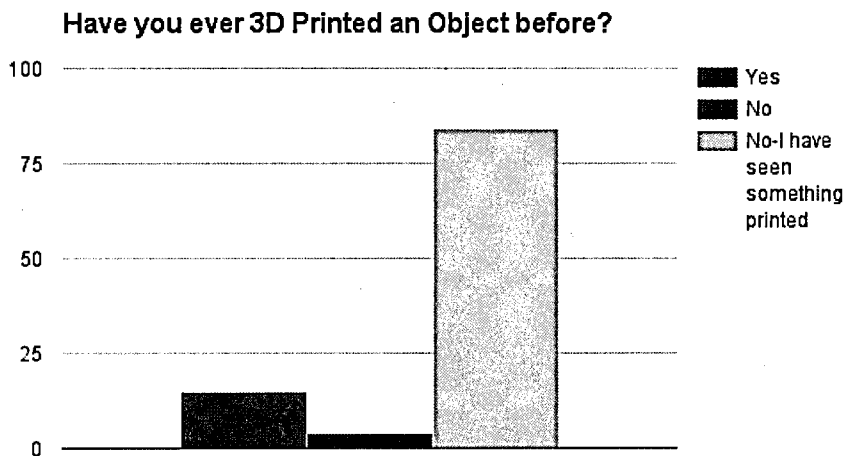**Have you ever 3D Printed an Object before?**

Figure 4 – Have you ever 3D Printed an Object before? Figure 4 shows quantitative data that the majority of students did not have prior experience using a 3D printer, however many of them had seen something printed before. This could be because of all the media attention surrounding 3D printers and how more and more Waukee classrooms are getting and using 3D printers.

Student Engagement

The most unforeseen descriptive and observed outcome of my study dealt with the students' level of engagement throughout the process. The experimental group of students rated their level of interest in the topic much more highly at the end of the 3D printing final project

and cited the primary reasoning for this occurrence for being due to the physical model of their

product that they created, as shown in Figure 6.

Student Engagement Survey (Experimental vs. Control Groups)
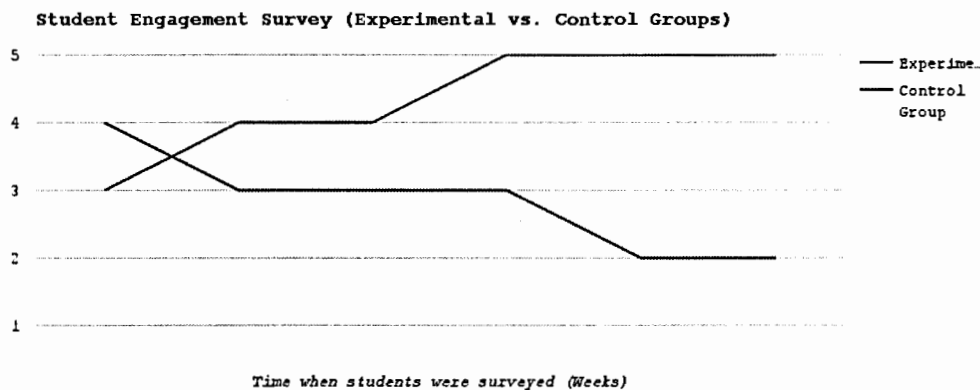

Time when students were surveyed (Weeks)

Figure 5 – Weekly survey data of experimental and control group engagement during the Action Research study. The line chart above shows that the students in the two groups felt moderately engaged at the beginning of the study, but the gap increased between the two groups by the end of the three week study. During the last week of the study, students in the control group rated themselves overall as only slightly interested (2), while the experimental group rated themselves as extremely engaged (5).

The control group rated their final project as being only mildly interesting and that they

couldn't always tell what each other's project would really look or feel like because they didn't

create an actual object. Technology Education courses within the Waukee Community School

District have experienced drops in student enrollment for various courses in the past, and the

inclusion of 3D printing technology could be the answer to increasing enrollment across our

various curricula.

Please rate your feelings towards whether or not you feel that 3D Printers are a helpful and necessary tool for classrooms.

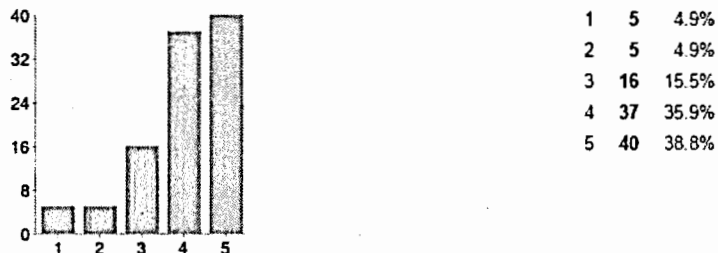|		
1	5	4.9%
2	5	4.9%
3	16	15.5%
4	37	35.9%
5	40	38.8%

Figure 6 – Are 3D printers a helpful and necessary tool? Figure 5 displays student exit interview responses showed that 90% of students surveyed, rated 3D printers as being moderately (3) to extremely (5) necessary as an instructional tool for classrooms.

Many of those students expanded upon this question by saying that they should be a standardized tool in all classrooms as an alternative method of showing proficiency on course content.

A Connection between Visual Design and Prototypes of Products

Examples of some of the students' work samples are shown below. There are various levels of success in terms of the usability of certain products, but all students within the experimental group were able to and completed a physical 3D printed model. Students in the experimental group were allowed to incorporate other technologies, such as 3D scanning, and using multiple materials as long as the majority of their product was 3D printed. Figure 8, shows a successful use of multiple materials used in a 3D printed prototype. The prototype was a small marble maze that the student developed used CADD software. The maze portion of the project was 3D printed and the student incorporate a piece of acrylic as a cover that would hold the marble inside the maze. The student made the realization that the marble falling out of the maze was a possible problem with her idea, and she developed the idea of a circular cover to keep the marble inside the maze. This particular situation required that the student learn how to cut acrylic material into a circle, and also how to join the two materials together. Originally this study was only going to allow students in the experimental group to utilize the 3D printer, but what I found is that some of the students' ideas required that they gain additional skills or knowledge of other areas of manufacturing. This was an excellent example of how the use of 3D printing in the experimental group led to students having to seek out additional information, or gain additional skills in order to make their prototype successfully, which had to be modified from the original design of the action research study.

Figure 7 - Multiple Use of Materials in 3D Printing. Figure 6 shows a student created marble maze that features multiple materials (plastic, acrylic, aluminum) and advanced manufacturing techniques for the ninth grade course level.
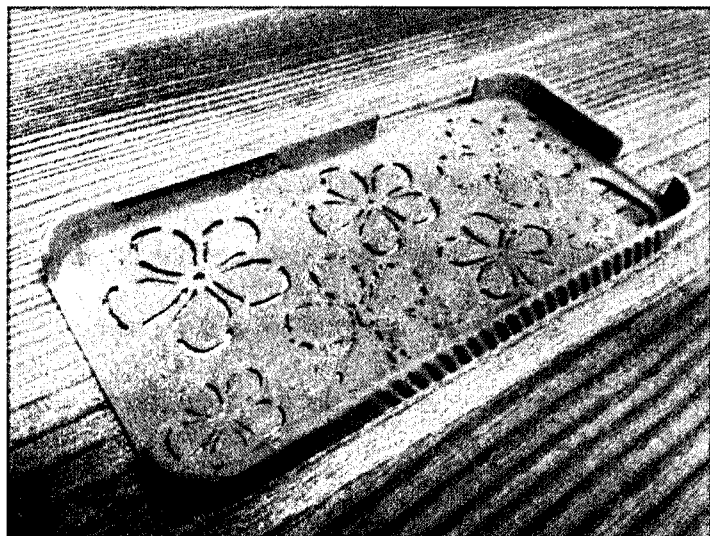

Figure 8 – Student work sample #1 with dial caliper measurement. Figure 7 shows a cell phone case that a student innovated upon by including a texture grip feature and decorative elements on back. The student used a dial caliper to measure their cell phone in order to develop a sketch with dimensions of their product.
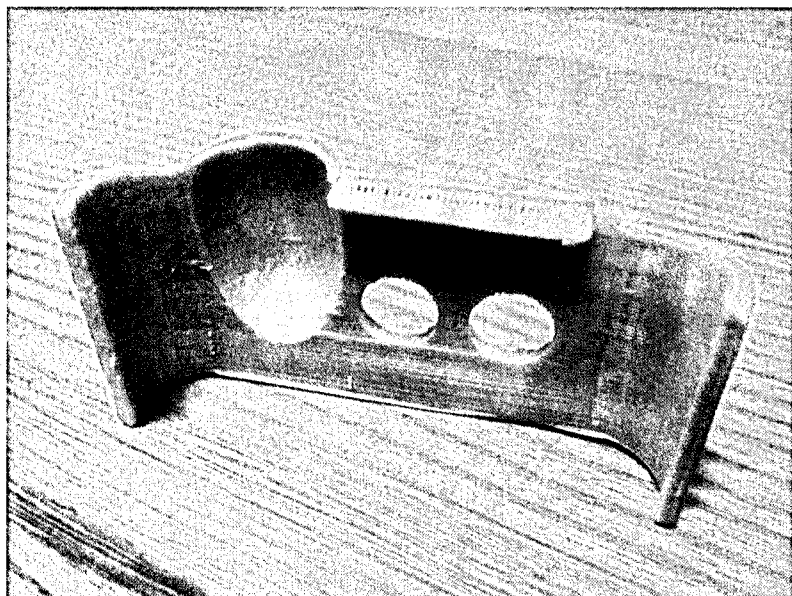
Figure 9 – Student work sample #2 with product innovation. Figure 8 shows a student's innovation attempt at creating a wrap-around speaker that would send the sound from the speaker on the back towards the phone user. Incorporated holes for the two cameras on the back of the phone.

The qualitative data suggests that students' who used the 3D printer were also more easily able to understand the design process and why some products must go through several iterations in order to achieve their final design. While it was a time-consuming process to create multiple 3D printed models for students, they ultimately achieved the look, feel, and scale of the product that they originally set out to make. One example shows a student's train model that they created using a 3D CAD program. The original scale of one component of the final product did not match that of the rest of the project, and the student was able to make a real world connection on why the scale of all parts must be uniform in a multi-component design. This was not an uncommon issue when students tried to create products that incorporated multiple parts. However, once the students realized that their pieces would not fit together because of the scale or texture pattern that they had created, it did force the student to analyze their model and figure out why the scale was so integral to the success of the project.

In my observations of the experimental and control group, there was a much better connection for the students who were making the physical model of their products using the 3D printer. There was no sense of urgency in fixing the 3D models on the computer when the control group students weren't actually making a physical model. While not particularly measureable from a researcher's point of view, the projects were much more simplistic from the control group and they weren't attempting to create products that were more personalized to themselves. It was also difficult to motivate the control group to go back and rework their virtual designs when design flaws were discovered during the final assessment. There simply was no real world connection for the control group to make during the design process. This is why the prototyping stage is necessary when designing a new product or innovation. However, the students in the experimental group attempted to re-modify their design after some of their initial prototypes did not meet their expectations or the expectations of the final work sample rubric.
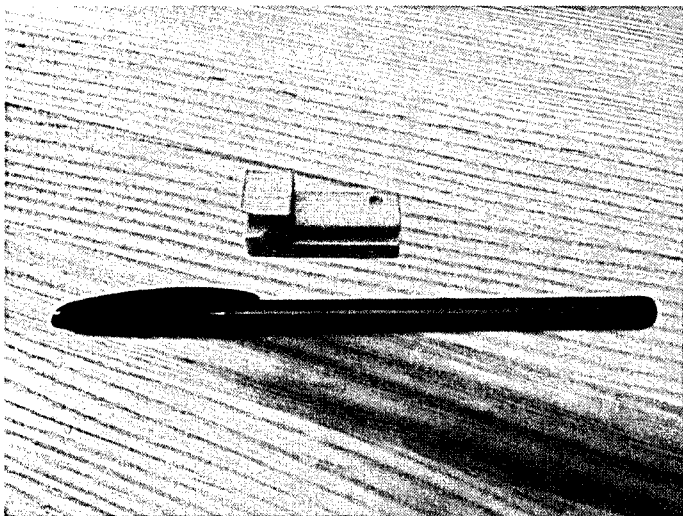

Figure 10 – Example of student rework due to scale discrepancy. Figure 9 shows that a student's object scale was too small for other components.
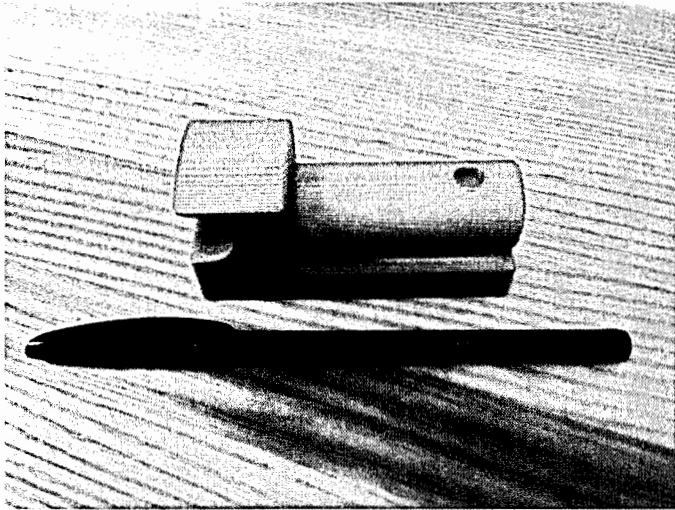
*Figure 11 – Reworked project with uniform scale between pieces. Figure 10 shows that the student created uniform (increased)
scale to fit additional components.*

An unforeseen action on the part of the students was their interest in seeking out other

design problems within the world outside of the realm of our classroom. One particular student

in my experimental group took apart a candy machine in his home and decided to build a better

gear component on the inside that would allow the mechanism to turn more easily and dispense

the candy in a more efficient manner. This was a student who normally had difficulty being

motivated to participate in other activities, and here he was spending hours a night according to

their parents, creating this 3D model. The 3D printing curriculum related to the student and they

became incredibly vested in the outcome of this physical model. During class, we printed the

first prototype and the student took it home for testing. The prototype failed because the gear

teeth did not mesh with the other gears inside the mechanism causing it to not function. The

student revised his CAD model and brought in a newer version the next day to be printed. After

the second prototype was created, the student experienced success with his product. I

interviewed the student at the end of the study and in their exit interview, I was really interested

in what caused the increased interest in this project. I wanted to know why this particular

student, who has a history of behavior issues and turning in assignments and project, was

suddenly interested. Specific quotes that came out of the interview included, "I wanted to make

the dispenser actually work because we've never been able to get any candy out of it." Other

quotes included, "It was something that actually affected me personally and was fun to be able to

see my parents and sister use the candy machine," and "I actually found the software to be easier

to use once I knew what I wanted to make. It made it more real life for me." The majority of the

conversation was focused on how the connection between something that was important to the

student now created a sense of engagement with the concepts that we were covering in the

classroom. Certainly this is nothing new within the education world, but it shows that 3D

printers can help add to the list of classroom technologies that can be used to help connect

students to real world applications within the curriculum.
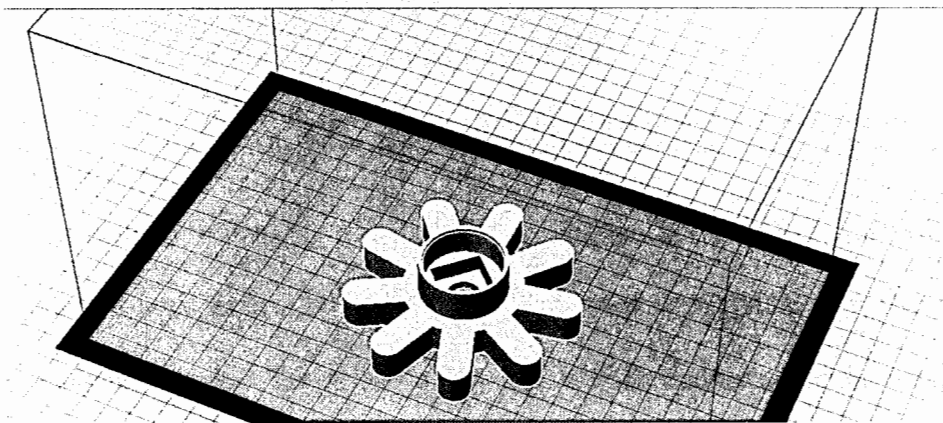

Figure 12 – Example of CADD modeled custom work piece. Figure 11 shows a student's innovation for improving a candy machine in their home. This particular student struggled at being motivated in both my classes, as well as others. The student said that because they saw an actual use for this knowledge and could create something physical, that they became interested in 3D printing.

Figure 13 - 3D print of a 3D Scanned Student. Figure 12 shows a collaborative effort between one of my students and another classroom within our district. The student used a 3D scanner to scan their upper body and then used the file to print himself out on the 3D printer.

Another interesting work sample to consider is shown in Figure 12, which features a

student's work piece that involved the use of another 3D technology that a Waukee School

already had access. The student made use of a 3D scanner which involved a couple of handheld

scanning devices, and the student rotated themselves in a chair in order to get a complete model

of their upper body. The student was then able to take that 3D model generated from the 3D

scanner and then was able to print themselves out using the 3D printer. This was an excellent

example of multiple technologies and people working together to achieve a common goal of

creating a successful 3D printed model of a person. The student gave a couple copies of the 3D

printed model to the middle school classroom that had the scanner and they are now using it as

an example in their curriculum.

The Plan of Future Action

After conducting my action research study and seeing the results of the data collected

from my students, I am convinced that the investment in 3D printing technology within my

classroom is necessary and justified. The results of my action research show that within my

classroom, the use of the 3D printing technology not only helps my students make a clearer

connection between product design and manufacturing principles, but that it also raises their

level of engagement. The groups of students who were able to use the 3D printer to actually

create the object that they created on the design software, ranked themselves much more highly

than the students who were only able to draw it on the computer and then describe all of the
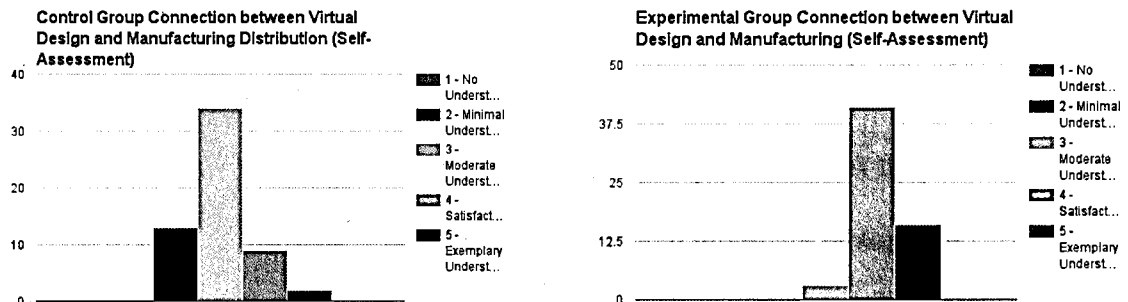
features about it.

Figure 14 - Control and Experimental Group Self-Assessment Data for Connection between Virtual Design and Manufacturing. The two graphs show the comparison data for how students assessed their own learning regarding the connection between virtual design and manufacturing.

The students also ranked themselves much more highly in their level of interest in both 3D

printers and design and manufacturing, this data is shown in Figure 6.

Personally for me, as the teacher of this particular classroom, these results show that I need to do more to make 3D printing even more accessible within my classroom. It also says that as a district, we should perhaps be incorporating this technology into our lower grade levels in the Technology Education department, and possibly other STEM (science, technology, engineering, and math) classrooms. I plan to speak with my building principal, school board, and Foundation Grant Committee to see if we can expand upon our current level of 3D printing technology in the Waukee Community School District.

Conclusions

Outcomes

The outcomes of my study showed that using 3D printers within my classroom created an overall clearer connection between product design and rapid prototyping, and also increased the engagement of my classroom. The experimental group, which utilized the 3D printer during their final project rated themselves as having a better understanding of the design process and could explain why prototyping was a necessary component to product manufacturing. The control group showed results that were similar to other groups of students that I've had in the past in terms of trying to explain how drafting and manufacturing are related and while the design process is so important to the development of a product. Student responses suggest that the use of the 3D printer also helped raise their level of engagement with the course content. From my own observations, the control group of students was somewhat disappointed that they did not get to use the 3D printer for their final project, and it showed when it came to assessing their work samples. The students in the control group cited responses such as wanting to actually be able to create their products and see how they looked and felt in real life, that only writing about them or describing them was not a sufficient way to prototype a product. In Figure

15, you will see the distribution data from both the control and experimental groups for their

final work sample projects. The grading system was built on a 1-5 scale, which mimicked the

students' normal standards-referenced grading system. I kept the grading system similar to how

all the other classes in Prairieview School score their assessments, so that students would not be
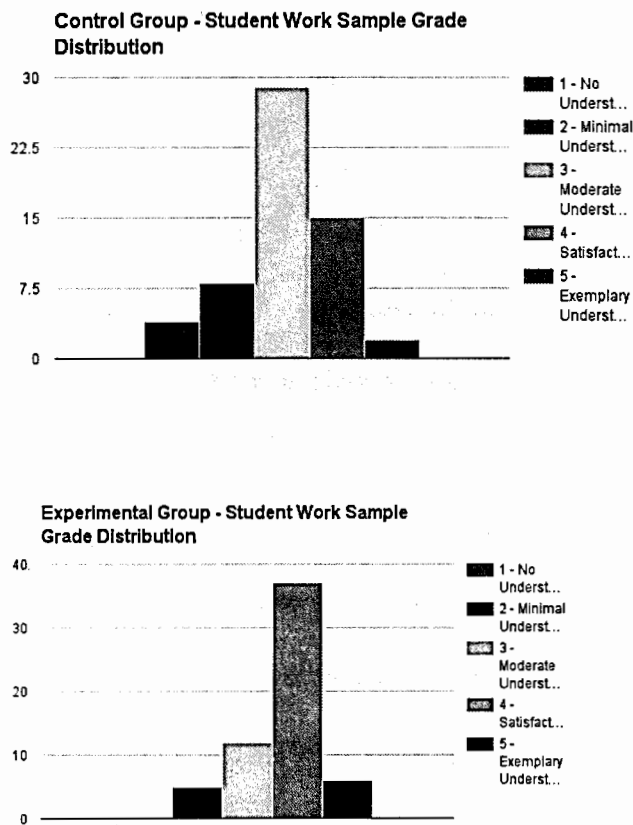
confused by a new grading system.

Figure 15 - Work Sample Grade Comparison. The two bar charts show the work sample assessment grades for students in both the control and experimental groups. The grading system used was standards-referenced in nature.

I felt that I experienced several successes throughout this study because it ultimately

showed that I had not wasted time or the district's grant funding to purchase this technology in

past school years. Also, since I am not the only teacher within the district who has access to this

technology, the conclusion of this study can be used in the curriculum writing process for future classrooms in the district that want to utilize this technology. There's been a lot of interest from our business and entrepreneurship courses in beginning to use this technology to setup a 3D Printing Store within the district for students to operate.

I truly felt that this research was needed within my district because of how many teachers, libraries, and local education agencies in my community were beginning to ask questions and even purchase these products. The financial investment to start and maintain a 3D printing station is still fairly expensive and there is very little existing research that shows whether or not these technologies help improve student learning.

I also felt that I experienced several difficulties when trying to implement this study within my classroom. Time is always a factor for teachers and I had to very strategically place this study into a timeframe where it would be most effective for my research and my students' learning, without disrupting the other necessary curriculum that must be taught as a part of these courses. Due to the timeframe in which I had to include this study in my course, we had a very quick turnaround in regards to the analysis and findings of the study itself. It was difficult to compare my results with any other existing action research studies involving 3D printers because there are so few and the topics in which they researched were completely different from what I was doing in my classroom.

My goal as the primary researcher was to establish a simple but insightful action research study that could potentially be replicated in another Technology Education classroom with minimal time and low budgetary restrictions in order to help boost the amount of research being conducted about 3D printing technologies in the classroom.

Implications

The question that was ultimately researched throughout this study was whether or not the use of 3D printers helped students make a stronger and clearer connection between computer-aided design software and manufacturing within my own classroom. My goal was to find out whether or not the financial investment and time necessary to implement the 3D printing technology was justified, and whether or not my school district should continue to invest in these technologies for students. Throughout the process of this study, I established several possible extensions and branches off of what my research was able to show. The biggest twist in what I was observing with my students was their focus on the materials that are able to be 3D printed. Most of my students understood that products could be made from plastic, however they had some difficulty with understanding that plastic is not the only printable material. Since our classroom 3D printer could only print plastic, this was an equipment limitation that I experienced during my study. Students were very interested in learning about concrete, wood, and food-based 3D printing. These topics could serve as future action research projects within another classroom.

An unforeseen limitation that I didn't think about prior to the study was that students would talk to each other about what was going on in their classes. Many of the students knew that certain classes were getting to use the 3D printer and others were not. So it was difficult to keep the control group motivated and on task during the work sample portion of the study. There were a lot of questions and complaining from the control group's perspective because they felt like they were getting the lesser experience and wanted to use the machine. Ultimately, I had to modify my plan and told the control group that they would get to print their objects after the conclusion of the study, and that they needed to do their best to give me their thoughts, feelings,

and knowledge without using the 3D printer during this time. They found this to be an acceptable change and it didn't require any sacrifice on my behalf other than the time to print the objects out.

Another limitation that I had to work around in regards to my study was making sure that I had enough time to complete all the required tasks of this study and still also cover all the required elements of our course. While 3D printing, computer-aided design, and manufacturing are all built into our course curriculum, we also have other topics that must be learned and assessed. I had to make sure that I was not going over on the amount of time spent on my study, at the expense of the other course topics that needed to be covered in my classes.

The third limitation was the short span of time in which to collect data from my students without disrupting their regular classroom instruction. Therefore, the results of my action research cannot necessarily be applied to all Technology Education classrooms without possible modification of curriculum. 3D printing and computer-aided design are both concepts that are included in our current curriculum guide, but the amount of time dedicated to those topics is very minimal. With the current timespan of our Technology Education courses only being sixteen weeks of instruction, other content area topics will have to be shortened in order to accommodate the time necessary to cover 3D printing and virtual design topics. Again, the implications of this limitation point towards the need for a new course to be added to the curriculum that would cover 3D printing and computer-aided design in more depth.

A final limitation that did cause a lot of planning in terms of the design of the study was that I was the students' teacher and the primary researcher. Several different methods of coding had to be implemented in order to ensure that students' anonymity was maintained and that

students did not feel that they grade depended on their answers in order to ensure accurate research.

In order to expand upon my current study within my own classroom, I would like to expand upon the materials used in the 3D printing and whether or not that would help introduce students to even more advanced manufacturing techniques. In the exit interview data, students suggested that they wanted to know about several topics that they had heard in the media such as 3D printing food, 3D printing medical technologies, and structural engineering through the use of 3D printers. These are all topics that could be expanded upon in the appropriate classroom. There is a need for other Technology Education teachers to replicate my study within their classrooms in an effort to help validate or negate the analysis of my students' data, my findings and analysis, and implications within the classroom.

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Appendix

Sample Interview Questions

Task Questions

1. Can you create a virtual object and describe to me the purpose it's going to function once a physical model is created?

2. Can you operate a rapid prototyping technology, such as the 3D printer, to create a physical product?

3. What kinds of materials can you use in a 3D printer and other rapid prototyping technologies?

    a. Follow-up: Are you able to use different materials in a 3D printer to create various types of physical products?

Specific Questions

1. How many (if any) years of computer-aided drafting and design experience do you have prior to taking this course?

    a. Follow-up: What computer-aided drafting and design software have you used prior to this course?

2. What does the term "virtual design" mean to you?

3. What is "product creation" and have you ever had to manufacture a physical product? Follow-up: What kinds of products have you had experience creating?

4. Have you had any prior experience with rapid prototyping technologies, such as 3D printing.