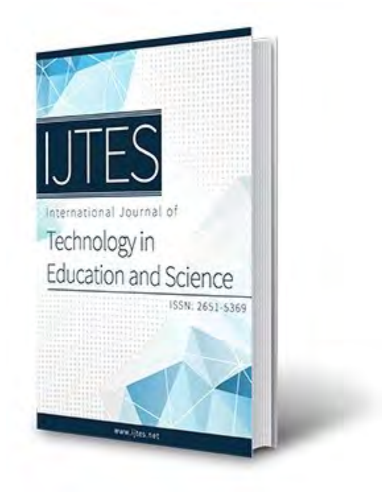

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Impact of 3D Printing on Occupational Therapy Student Technology Efficacy

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Abstract

This study examines a mixed methods experiment, evaluating the impact of 3D printing on Occupational Therapy student's self-reported technology efficacy levels, before and after an educational module focused on 3D printing technology. Utilizing free and online software and university owned 3D printers, students were challenged to create client centered assistive devices. Software included free computer aided drafting software, slicing software, and an online design repository. Copyright and attribution licensing concepts were also addressed for design modification considerations and use in clinical settings. Participants explored adaptations of 3D designs to meet individualized client needs and integration of rehabilitative theories. Project-based implementation of 3D printing with 'real world' clients created increased student 'buy-in' and engagement. Participants were recruited from private, rural, higher education, occupational therapy students in pre-clinical lab courses. Comparisons between student groups exposed to 3D printing and a control group without exposure are assessed using quantitative and qualitative data. The control group expressed interest in further technology education in their field. Students show significant increases in technology focused self-efficacy between participant groups.

Introduction

Healthcare professionals are faced with a wide variety of patients who can benefit from assistive devices and the number and selection of technology created solutions is significant. Undergraduate students progress through rigorous healthcare related courses, which do not always include cutting-edge technology implementation. Knowledge of technology options in developing patient treatment plans can assist clinicians in providing more efficient and effective interventions.

Lent et al. (1994) asserts that high self-efficacy influences an individual's interest in a certain field. This belief is founded in social cognitive career theory where self–efficacy, outcome expectations and personal goals drive career development (Aslan, 2021; Lent, Brown, Hackett, 1994; Lent, Brown, Hackett, 2002; Simsar & Jones, 2021). As part of this theory, Wang defines self-efficacy as "an individual's judgment of his or her own ability to complete an action required of a certain type of performance" (Wang, 2013, p. 666). Clarke-Midura et al. (2019) found significant gains using an informal learning environment to increase interest in computer science professions and an individual's beliefs about ability to program. However, according to Google Inc. and Gallup Inc., only 40% of K-12 schools report offering at least one computer science course (Google Inc. and Gallup Inc., 2016). So, many college students come with some knowledge of computer use, but few have experience with more than being able to use the computer for schoolwork.

Tsai et al. (2019) found the impact of computer self-efficacy in the healthcare profession, directly influences the adoption of and perceived ease of use. There are three self-efficacy factors in healthcare technology:

- General Self-Efficacy (GSE),
- Computer Self-Efficacy (CSE), and
- Healthcare Technology Self-Efficacy (HTSE).

Research in technology self-efficacy has matured in the area of information systems, yet is just becoming established in healthcare (Rahman, Warren, Carpenter, 2016). These authors found self-efficacy was a significant predictor in the adoption of technology and technological solutions specifically in healthcare settings. Therefore, understanding the impacting factors related to technology acceptance and self-efficacy, can assist healthcare educators in promoting innovative and adaptive technology to support students in the skill development needed to consider technology for future practice.

Three-dimensional (3D) printing allows the user the ability to design and create almost any object. It is relatively new to the field of occupational therapy (Ganesan, Al-Jumaily, & Luximon, 2016). These authors identify a number of advantages for using 3D printed devices when compared to conventional methods including ease of adaptability and cost. Customized devices in healthcare include braces, orthotics, prosthetics, customized padding for burn patients, even tissue and organ fabrication (Bolus, Ganti, & Inan, 2018; Ahmad, Salleh, & Ismail, 2019; Lee, Kim, Cha, Kim, Kim, & Kim, 2018; Salinas, 2018; Ventola, 2014).

The use of 3D printing is growing in the field of occupational therapy and is seen extensively with printed orthoses and prostheses (Lee, Kim, Cha, Kim, Kim, & Kim, 2018; Zuniga, Katsavelis, Peck, Stollberg, Petrykowski, Carson, & Fernandez, 2015). Ribeiro et al. (2019) found that printed prosthetic devices have significant benefits including high levels of customization and lower production costs. Others have found that printed designs are aesthetically more pleasing, fit better and weigh less than traditional devices (Portnoy, Barmin, Elimelech, Assaly, Oren, Shanan, & Levanon, 2020).

Several studies support an interprofessional model of practice when it comes to the design and manufacturing of 3D devices. Wagner et al. (2018) reported that their group needed engineering support with writing the specific files required for their occupational therapy student proposed projects. Gherandini et al. (2018) found that using a co-design method including an occupational therapist, design engineer and client, allows for improved customization of devices. While Ludwig et al. (2017) indicated many professionals in healthcare lack emerging technologies training, which limits the implementation of the newer solutions.

Based on individual attitudes regarding self-efficacy and technology, students in healthcare do not feel confident exploring newer technologies to assist patients. Early exposure in the educational setting to improve technology self-confidence increases awareness of technology enabled interventions. Combining confidence and awareness, increases an individual's likelihood to use multiple customized problem solving approaches. The American Management Association (2019), listed problem-solving skills as a priority for healthcare employers. Expanding technology confidence contributes to increased innovation and adaptive solutions within healthcare settings. Introducing undergraduate occupational therapy students to emerging technologies, specifically 3D printing in healthcare settings, creates exposure to innovative thinking, increased confidence in use of technology and creative problem-solving skills.

Faculty at Husson University began looking at how to provide a learning opportunity for students around 3D printing and improve a student's willingness to engage in the technology in the field. Since the program's inception, only one student has reported that they have engaged in a 3D printing project prior to entering the School of Occupational Therapy. With the cost, customizability and speed in which devices can be printed, this technology is an invaluable skill for new therapists. Providing students with a multi-modal interprofessional module will improve their self-efficacy with this technology and enable them to use it in the clinic.

Purpose

The purpose of this study was to examine the change in occupational therapy student self-reported technology efficacy levels before and after an educational module focused on 3D printing.

Method

Design

Implementing a mixed method, experimental design, the experimental group completed pre-test and post-test surveys regarding their self-reported assessment of their ability with technology, opinions about 3D printing, and self-confidence in implementing 3D printing. The control group completed a post-test survey, however, did not participate in the educational module. This study assessed the change in self-efficacy perceptions after the one month long 3D printing technology module. Results were paired and then compared to the results of the control group.

Subject Recruitment and Selection

All participants were recruited from the School of Occupational Therapy, at a rural, private university. Participants were occupational therapy students enrolled in either an occupational therapy lab course in the Fall 2019 semester or their final year of the program. There were a total of 68 participants for this research project. Forty two students joined the experimental group and 26 in the control group. We did not collect age and gender as this program often enrolls traditional students so any student over the age of 23 would be identifying and the same for gender where there are typically only between 3 and 5 males in any cohort. No student wishing to participate was excluded.

Procedure

The lab course was coordinated by a member of the occupational therapy faculty and includes a 3D printing module taught by a member of the integrated technology faculty. All participants filled out a survey hosted as a Google form, in a password protected account that the grading professor did not have access to until after the course was completed. The survey was adapted from Wagner et al. (2018) and is a validated self-report measure.

Following the belief that self-efficacy in technology is increased through familiarity with technology, the educational module was created to introduce 3D printing in the least intimidating manner the researchers could envision (see Figure 1). The experimental participants' interest was further engaged through the use of problem-based learning, specifically using real-world 'clients' as the motivation for the 3D printed adaptive design developed. Participants were encouraged to design their own adaptive solution for a person known to them, who might benefit from an assistive device. Once the experimental participants completed the pre-survey questionnaire, they were introduced to the learning process of 3D printing using the technology described below, see Resources Used. All elements, except the printing filament and printer, were non-operating system/platform specific, free software with easy to use interfaces.

Figure 1. Educational Model

Experimental group participants identified a 'client', someone they knew who could benefit from an adaptive device. Using their knowledge of occupational therapy as third year students, they were to identify the client needs and assess the technology fit in creating a device. Introducing 3D printing and example adaptive devices, the experimental group was introduced to digital resources to assist in creating digital 3D printing designs. The creation of adaptive devices and printing allowed for a physical implementation of their occupational therapy knowledge and newly acquired technology skills. Participants were then able to assess and reflect on the process as a whole and the device that was created.

During the reflection, the experimental group presented their adaptive device designs and printed objects to the students enrolled in the class and discussed the design, intentions, and challenges of the project. This self-reflection included improvements for future projects. This ongoing cycle was believed to increase familiarity with the technology and contribute to a mindset of future technology usage, through the review and future improvement reflections. Further research into the impact of technology reflection contributing to self-perceived technology self-efficacy based on ‘envisioning’ future implementations is warranted.

The control group did not participate in the educational module or create an adaptive device using 3D technology. The control group completed all other course work including field placements as scheduled. Collaboration between the occupational therapy and integrated technology departments, represented an interdepartmental collaboration to improve and expand student skills.

Resources Utilized

During the educational module, participants were introduced to easy to use, free software. The goal was to allow the experimental group to experience technology and 3D printing at an entry level. Further exploration of 3D printing and technology usage was encouraged, but left to the participants, due to time constraints in the educational setting.

To facilitate self-confidence and limit interface impedance, the experimental group was introduced to the concept of using Attribution Licensed 3D print models from Thingiverse.com. Attribution licensing is the most permissive of the Creative Commons license and allows for use, modification, adaptation, and selling of works as long as credit is attributed to the original creator (Creative Commons, 2017). Designs on Thingiverse.com are commonly listed with attribution licenses. Participants were introduced to the concept of licensing and given an overview of the different types available.

MakerBot, a manufacturer of 3D printers, offers Thingiverse.com as a repository of 3D designs. Creators share designs, comments, and remixed designs with those who are interested in using 3D printing (MakerBot, n.d.). This is the source for 3D printing designs the participants in this study modified for their clients in the problem-based learning module. Thingiverse.com has over 1,951,130 3D printing designs focusing on a broad range of applications, adaptive devices included.

Participants were tasked with editing an existing design or creating a 3D design of their own, using Tinkercad.com. Tinkercad is a computer aided design tool available free online. The Tinkercad environment is an entry level, online version of a professional editing software from Autodesk (an engineering, construction, and drawing software) using a 3D drafting environment (Autodesk, n.d.). This software allows users to learn more about the 3D creation process and edit designs in a website (Autodesk Tinkercad, n.d.). Files compatible with 3D printing (.stl) were exported for review in the Cura slicing software. The ease-of-use presented in Tinkercad and its platform independence were aspects of why it was chosen for this project. As a web based tool, the complications of different operating systems were mitigated.

During the educational module, participants were introduced to the import tools present in Tinkercad, allowing designs from Thingiverse.com to be uploaded, edited and modified, then exported for review in Cura software.

Applying the concepts and training from occupational therapy courses, the participants, who were preclinical students, were tasked with applying the occupational therapy concepts to design/modify an assistive device using technology. This modality was not introduced in the occupational therapy program prior to this educational model.

Ultimaker's Cura slicing software was introduced to participants, allowing them to examine the final .stl files (3D printing file type) and identify issues prior to printing. The software is a 'slicing' program that renders the layers for a 3D object to be printed (Ultimaker, n.d.). Models were assessed by the control group for obvious issues that might impact print quality, using Cura, to visualize each layer and determine overhangs (which need support when printing), hollows and solid areas as appropriate, and length of print duration. Each print, in this educational module, was limited to 2 hours total print time, unless otherwise specified. The concept of visualizing the print, layer-by-layer, prior to printing, generated anecdotal responses indicating significantly more clarity in understanding the print design and how it would be "built".

An Ultimaker S5 3D printer, using Tough PLA (polylactic acid), was used for project printing. The choice of Tough PLA in the printing process, as discussed with the participants, was chosen to limit potential fumes in an enclosed environment and for the increased strength of the PLA material (Ultimaker, n.d.). Tough PLA has an approximate strength to other commonly used printing filaments, but is non-toxic and was determined to be the better choice in an educational environment. The Ultimaker S5 3D printer is a dual nozzle printer, with automated leveling, reducing the complexity of use from other 3D printer models. This model is within the predicted budget of a clinic or organization that the participants are projected to be employed by post-graduation.

Data Collection and Analysis

The surveys were downloaded from the site at after completion of the semester. Quantitative data was analyzed using Kruskal Wallis, also known as a one-way ANOVA for ranks. It is a nonparametric assessment for determining statistically significant differences between two or more independent groups. It is considered to be an alternative to the one-way ANOVA and an extension of the Mann-Whitney U test, allowing for two or more independent groups to be compared. If the Kruskal Wallis test is significant, then the Mann-Whitney test or a Dunn-Bonferroni post hoc method was used to find out which of the groups was significantly different. Qualitative data was analyzed using Voyant Tools (Sinclair, Rockwell, 2020; Voyant, n.d.).

Results

The experimental group was given a pre- and post-survey regarding their self-reported responses to questions measuring their self-efficacy and perceptions of technology, specifically 3D printing, in healthcare. The control group received the same survey a single time. The dominant trend between student responses prior to the 3D printing technology module and afterwards demonstrates a shift in mean response ranking (see Figures 2 and 3).

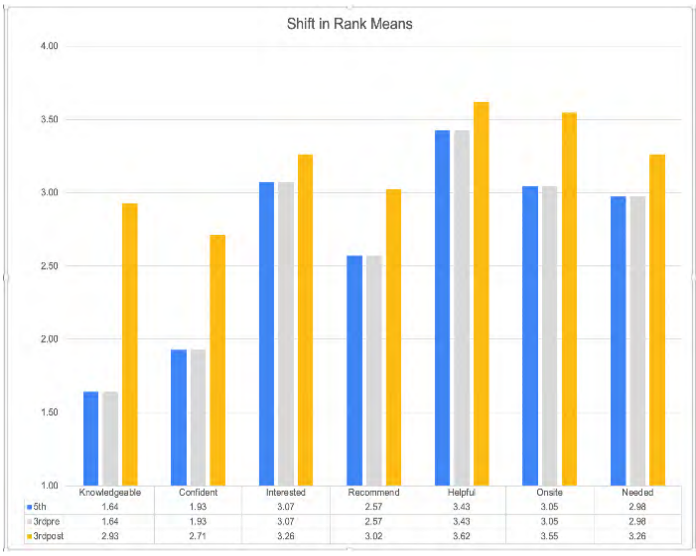

Figure 2. Shift in Mean Response Rank

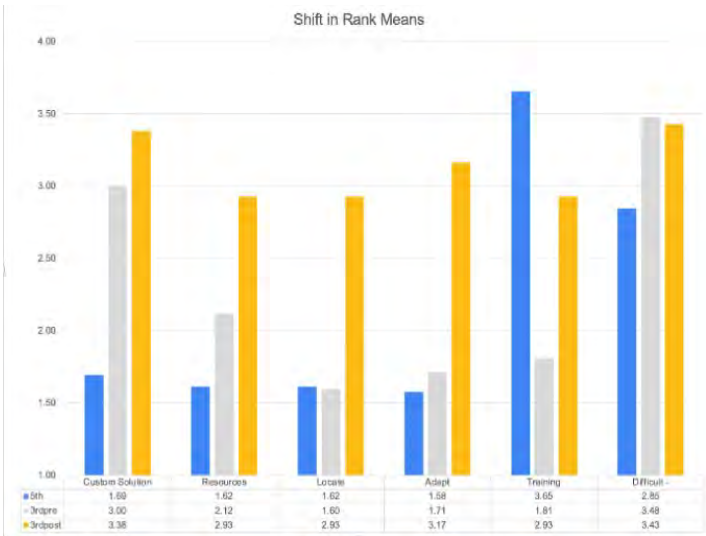

Figure 3. Shift in Mean Response Rank

A quick comparison of pre-post response mean values in excel shows a positive shift in responses towards increased self-efficacy. Wording of the questions (see Table 1) was such that the higher the numbers reported, the stronger the agreement with a positive self-confidence in technology indicated. Likert scale values from Strongly Disagree (1) to Strongly Agree (4) were used in the survey questions.

Several questions demonstrated little to no increase in positive response strength. This was expected as some questions focused on concepts that many have already formed thoughts about. These concepts included beliefs about the "interest, helpfulness, and usefulness". In a technology aware world, it would be expected that students would consider the broad topic of technology interesting and helpful in the healthcare field. Similarly, the belief about the level of" difficulty demonstrated minimal shift in response strengths as expected since the participants had just experienced training in the topic and now recognize the need for training.

Table 1. Survey Questions

I am knowledgeable about technology.
I am knowledgeable about 3D printing in healthcare.
I am confident in my ability to learn new technology.
I am confident in using 3D printing.
I am interested in 3D printing.
I am confident in recommending technology for clients.
I believe technology is helpful for clients.
I would recommend 3D printing in practice if a printer was onsite.
I feel the need to study technology based on its use in healthcare.
I find it easy to identify a customized solution using 3D printing.
I know of resources available for 3D printing.
I am able to locate 3D printing designs to use in practice.
I am able to adapt a 3D design to meet client needs.
When I think of 3D printing, I identify it as something that:
Requires training
Is difficult implement
Something I could use in practice

Further comparison of the paired Likert scale responses collected were analyzed using Kruskal-Wallis and Mann-Whitney U Post Hoc. The Kruskal-Wallis test evaluates two paired sets of responses from different participant groups. Results show a significant shift in response means in efficacy based responses (see Table 2).

Table 2. Kruskal-Wallis and Post Hoc Analysis

Item	Kruskal-Wallis				Mann-Whitney U Post Hoc Analysis		
	Significance	Control Group	Pre-Activity	Post-Activity	Control - Post	Control - Pre	Pre - Post
[Knowledgeable] I am knowledgeable about 3D printing in healthcare.	$\chi^2(2)$ = 56.943, *p* < 0.001	42.33	36.15	83.00	**U(N*Control* = 26, N*Post*= 42) = 160.50, z = -5.367, p = 0.000**	U(N*Control* = 26, N*Pre*= 42) = 503.00, z = -0.605, p = 0.545	**U(N*Pre* = 42, N*Post*= 42) = 112.50, z = -7.315, p = 0.000**

Item	Kruskal-Wallis				Mann-Whitney U Post Hoc Analysis		
	Significance	Control Group	Pre-Activity	Post-Activity	Control - Post	Control - Pre	Pre - Post
[Confident] I am confident in using 3D printing.	$\chi^2(2)$ = 51.476, *p* < 0.001	26.85	49.63	79.11	**U(N*Control* = 26, N*Post*= 42) =60.00, z = -6.469, p < .001**	**U(N*Control* = 26, N*Pre*= 42) = 287.000, z = -3.636, p < 0.001**	**U(N*Pre* = 42, N*Post*= 42) = 376.500, z = -4.897, p < 0.001**
[Recommend] I am confident in recommending technology for clients.	$\chi^2(2)$ = 11.360, *p* = 0.003	48.40	48.05	67.35	**U(N*Control* = 26, N*Post*= 42) = 352.000, z = -2.742, p = 0.006**	U(N*Control* = 26, N*Pre*= 42) = 536.500, z = -0.133, p = 0.894	**U(N*Pre* = 42, N*Post*= 42) = 578.500, z = -2.972, p = 0.003**
[Onsite] I would recommend a 3D printed device in my practice if a printer was onsite.	$\chi^2(2)$ = 27.679, *p* < 0.001	39.73	48.38	72.38	**U(N*Control* = 26, N*Post*= 42) = 232.000, z = -4.462, p < .001**	U(N*Control* = 26, N*Pre*= 42) = 450.000, z = -1.567, p = 0.117	**U(N*Pre* = 42, N*Post*= 42) = 487.000, z = -4.122, p < 0.001**
[Custom Solution] I find it easy to identify a customized solution using 3D printing.	$\chi^2(2)$ = 48.068, *p* < 0.001	31.42	46.83	79.07	**U(N*Control* = 26, N*Post*= 42) = 21.000, z = -6.919, p <0.001**	**U(N*Control* = 26, N*Pre*= 42) = 61.00, z = -6.624, P <0.001**	**U(N*Pre* = 42, N*Post*= 42) = 343.500, z = -5.238, p < 0.001**

Item	Kruskal-Wallis				Mann-Whitney U Post Hoc Analysis		
	Significance	Control Group	Pre-Activity	Post-Activity	Control - Post	Control - Pre	Pre - Post
[Resources] I know of resources available for 3D printing.	$\chi^2(2) = 66.835$, $p < 0.001$	37.58	36.70	85.39	**U(N*Control* = 26, N*Post*= 42) = 99.000, z = -5.990, p <0.001**	**U(N*Control* = 26, N*Pre*= 42) = 338.000, z = -3.004, p = 0.003**	**U(N*Pre* = 42, N*Post*= 42) = 91.500, z = -7.527, p < 0.001**
[Locate] I am able to locate 3D printing designs to use in practice.	$\chi^2(2) = 75.249$, $p < 0.001$	33.92	36.98	87.38	**U(N*Control* = 26, N*Post*= 42) = 81.000, z = -6.404, p < 0.001**	U(N*Control* = 26, N*Pre*= 42) = 545.000, z = -0.014, p = 0.989	**U(N*Pre* = 42, N*Post*= 42) = 48.000, z = -7.913, p < 0.001**
[Adapt] I am able to adapt a 3D design to meet client needs	$\chi^2(2) = 55.435$, $p < 0.001$	33.88	42.02	82.36	**U(N*Control* = 26, N*Post*= 42) = 24.000, z = -7.106, p <0.001**	U(N*Control* = 26, N*Pre*= 42) = 476.000, z = -1.016, p = 0.309	**U(N*Pre* = 42, N*Post*= 42) = 219.000, z = -6.308, p < 0.001**
[Difficult] When I think of 3D printing, I identify it as something that Is difficult to implement	$\chi^2(2) = 10.986$, $p = 0.004$	60.54	63.94	43.94	**U(N*Control* = 26, N*Post*= 42) = 317.000, z = -3.141, p = 0.002**	**U(N*Control* = 26, N*Pre*= 42) = 303.000, z = -3.315, p = 0.001**	**U(N*Pre* = 42, N*Post*= 42) = 551.500, z = -3.389, p = 0.001**

Kruskal-Wallis showed a significant difference between groups for the questions addressing knowledge, recommending technology, use of technology if available onsite, being able to locate designs and the ability to adapt for an individual's needs. The post-hoc analysis with Mann-Whitney U showed a significant difference between the control and pre-test groups from the post-test group. There was no significant difference between the control and pre-test groups for this item. The control and pre groups did show a difference from the post technology model results, however.

For the questions assessing confidence, ability to customize solutions, the ability to locate resources, and the belief that 3D printing is difficult to implement, the Kruskal-Wallis showed a significant difference between groups. The post-hoc analysis with Mann-Whitney U test shows there is a significant difference between all groups. The mean shift data showed an increase between all groups.

There were a number of items that resulted in no significant differences (see Table 3). These results indicate that a teaching module around technology is not needed to improve a student's belief that technology is needed and relevant to healthcare, and that they do need training in the use.

Table 3. Kruskal-Wallis with Post Hoc Analysis

Item	Kruskal-Wallis		Mann-Whitney U Post Hoc Analysis		
	Significance	Across All Groups	Control - Post	Control - Pre	Pre - Post
[Helpful] I believe technology is helpful for clients.	No Significant Difference Between Groups		Kruskal-Wallis and Mann-Whitney U test shows no significant difference between groups. This confirms our expectations of perceptions of technology relevance within healthcare.		
[Needed] I feel the need to study technology based on its use in healthcare.	No Significant Difference Between Groups		Shift in Means Charts show participants between all groups to have a 2.98 or higher ranking with 4 being Strongly Agree. No significant difference indicates student's value technology education in healthcare across all groups.		
[Training] When I think of 3D printing, I identify it as something that requires training.	No Significant Difference Between Groups		As expected, groups indicated that 3D printing technology requires training to implement.		

Qualitative Themes

Qualitative responses to the question asking participants how they would apply technology in healthcare were initially varied (see Figure 4). While there are good connections, none are overly strong as noted by the thickness of the lines that are connecting the themes. When we look at the same themes in the post survey (see Figure 5), participants recognize the utility and application of the 3D printing technology and identified significant connections to cost, speed, efficiency and help.

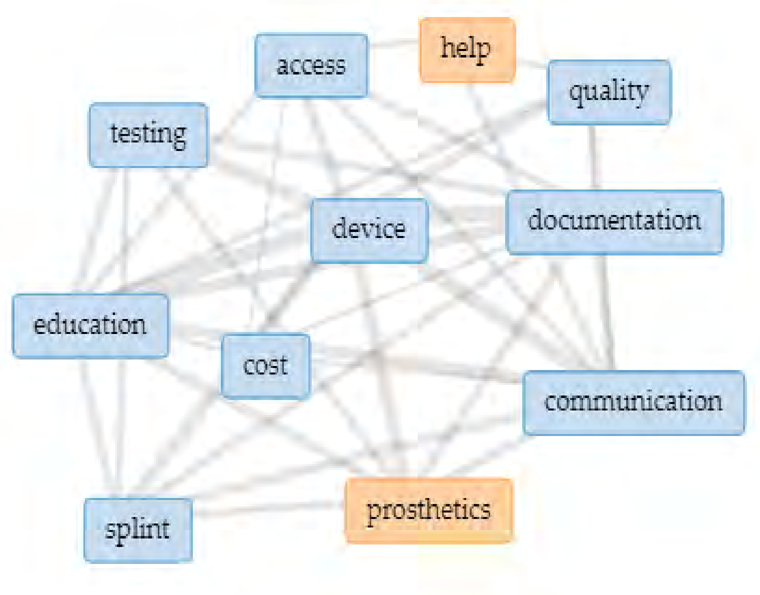

Figure 4. Pre-test Qualitative Themes

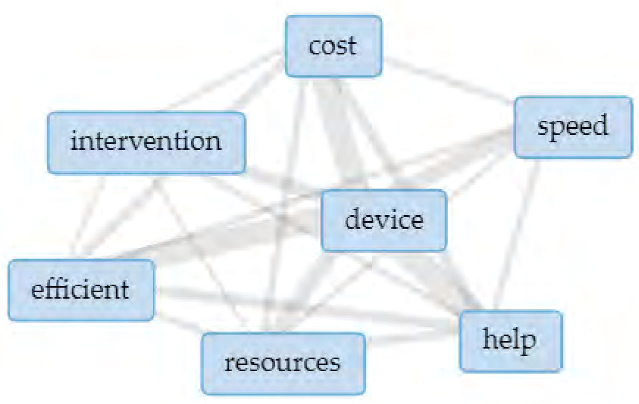

Figure 5. Post-test Qualitative Themes

Qualitative responses were analyzed for the control group participants. The results indicate a strong use of technology as a method to improve communication. The themes included computerized documentation, as an intervention (iPad and gaming systems), used to locate research and resources and as a cost savings method for education (see Figure 6).

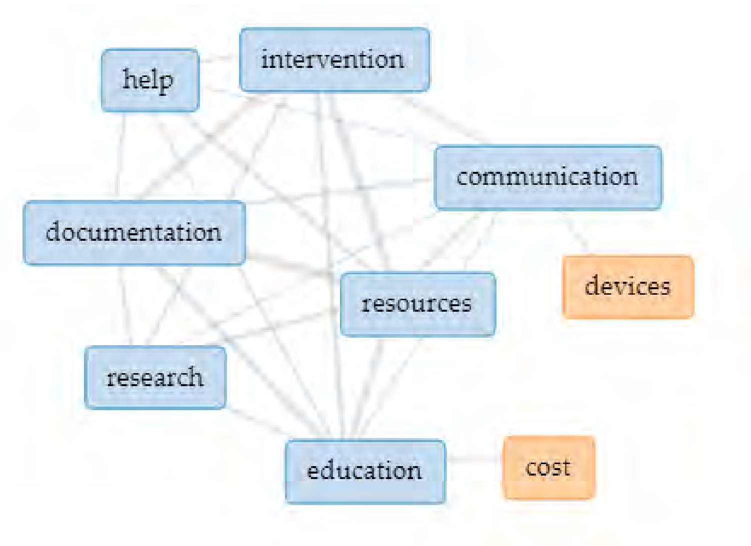

Figure 6. Qualitative Response Themes for Control Group

The top five themes taken from the pre-test narratives included: technology, healthcare, using/application, 3D printing, and devices. The post-test responses had technology, 3D printing, devices, clients, and healthcare as the top five terms used. These responses complimented the increase in technology efficacy evidenced in quantitative responses. The most commonly used words identified with the control group included clients, technology, 3D printing, recommending, and adaptive. This was encouraging to see the themes matching the healthcare profession's focus as occupational therapists who create adaptive solutions to assist clients in performing everyday tasks. These themes directly correspond with their educational goals in the undergraduate program and demonstrate a consideration of technology as a tool to assist in the creation of adaptive improvements for clients. This corresponds with the findings of Ludwig et al. (2017), that using real-world problems to introduce healthcare students to technology based solutions resulted in students expressing value in problem-based and experiential learning.

The shift in mean rank response analysis using Kruskal-Wallis and Mann-Whitney U Post Hoc Analysis, supported the study's assumption that exposure to technology increases technology self-efficacy in students. Value was gained by the experimental group using a project-based 3D printing exposure. Participants had an increased awareness of technology use within their career field as shown in the qualitative responses.

Conclusion

Similar to other studies with occupational therapy students that focused on the technology acceptance model (TAM), this study's focus on self-efficacy demonstrated consistent findings with Benham and San's study from 2020. As shown in the analysis above, the participants demonstrated a statistically significant positive shift in self-efficacy based responses regarding technology and 3D printing in healthcare settings. The increased mean responses in a positive direction and qualitative responses evidences strengthen technology self-efficacy and improved perception of importance within their career field. Introducing technology through scaffolded modules, using problem-based learning and real world ‘clients/recipients’, increases student engagement and positively impacts technology self-confidence. Further research into the impact of technology self-efficacy on healthcare students is recommended. A longitudinal study is planned to track the changes over time in this population.

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