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Understanding The Effectiveness Between Modern Technologies And Traditional Training Methods Of e-Learning On An Individual's Learning Curve, Content Retention, And Satisfaction

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Understanding the effectiveness between modern technologies and traditional training methods of e-learning on an individual's learning curve, content retention, and satisfaction

by

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Abstract

Title: Understanding the effectiveness between modern technologies and traditional training methods of e-learning on an individual's learning curve, content retention, and satisfaction.

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E-learning has become a widespread and valuable tool for skill development. After the COVID-19 pandemic, the necessity and adaptability of this method increased drastically. Hence, numerous studies focused on understanding the effectiveness of this method. The academic literature highlights the need to explore alternative solutions that can increase a learner's content retention and satisfaction when learning remotely. Modern technologies can be a great solution for this need with the correct application and development. This thesis analyzes the effects of technology on content retention, satisfaction, and learning curve through the following technologies: online platform, virtual reality (VR), and hologram display. A quantitative and qualitative pilot study was developed to analyze the impact of the three different methods where participants learned the basics of 3D printing. Based on the results, the online platform and the hologram display had a similar impact on content retention and hands-on performance. However, the hologram display had the highest satisfaction score among all the groups. VR was not the ideal tool for this type of training.

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Dedicated to my parents, sisters, and nephews

Chapter 1
Introduction

Training and skill development have been shown to increase an organization's productivity, profit, and engagement. Based on Deloitte's report, companies with a strong learning culture are 92% more likely to be more innovative, 52% more likely to show higher productivity, 17% more profitable than their peers, and have a higher talent retention rate from 30-50% [1]. Based on the 2022 LinkedIn Global Talent Trends Report, it was concluded that employees see professional development as one of the main drivers to improve the company's culture, where upskilling was ranked number 4 in candidates' priority list [2]. Around 86% of employees reported that they would consider a job change if additional opportunities for professional development were offered elsewhere [3]. On the other hand, research showed that 94% of employees would stay longer with a company willing to invest in their professional development [4].

These statistics show the importance of creating an effective learning culture in your organization. Critical to this objective would be to understand which methods/tools of education would be the most appropriate to achieve this goal. There has been a considerable change in education methodology in the past years. A recent article from Indeed showed eight of the most successful training methods: technology-based learning, simulators, on-the-job training, coaching/mentoring, instructor-led reading, roleplaying, instructional videos, and case studies [5]. For this study, different content delivery methods within technology-based learning, also known as e-learning, will be compared.

Even before the coronavirus pandemic, e-learning was a growing field, but the pandemic needs led to rapid implementation. Many companies already had adopted online training, and some schools would offer online courses/certifications/degrees. In the past two years, reports showed that more than 1.5 billion students worldwide were affected by school closures due to the pandemic lockdown [6]. During the pandemic, MIT needed to transition 1,250 courses to e-learning within only 25 days [7]. In addition, the COVID-19 pandemic forced companies to transition to remote jobs. This trend did not stop with the end of the pandemic as every day more employees are opting for this option because of its work flexibility. In February 2022, 20% of US remote jobs were posted, and they received 50% of applications for these remote jobs. This is also happening around the world, as for the UK, the data shows 9% job postings vs 20% applications received, for Germany 9% vs 22%, and for India 10% vs 21% [2]. Hence, quick transition and adaptation are needed to keep the world moving forward. This forced condition is allowing the education system to be reinvented.

Since the preference for remote jobs is constantly increasing, on-site training is becoming a challenge that can be addressed by creating appropriate e-learning options. There are various advantages and disadvantages to e-learning training. Some advantages include:

- The material can be reviewed at the individual's own pace, with no need of in-person instruction
- Access to a larger audience as the training can be accessed from anywhere and anytime

However, a significant disadvantage is the limitation on monitoring the engagement and retention of the content presented. One way to overcome this

limitation is by utilizing tools like quizzes and interactive techniques to understand and measure the learner's performance and make any adjustments to improve the training if needed [8].

One way to improve the learners' experience is by identifying the ideal content delivery method that enahances their engagement and content retention. Multiple technologies can be tested to find the answer. Thus, the objectives of this study are:

1. Understand the effects of different technologies in e-learning. The three technologies are online platform, virtual reality, and hologram display
2. Understand how the retention rate can be improved in e-learning
3. Understand how satisfaction can be improved in e-learning
4. Understand if there is any impact on the learning curve based on the type of content delivery received

Chapter 2
Literature Review

2.1 Skill Development

Today, we live in an incredibly competitive world. If you want to keep growing in your field, you must update your skillset as quickly as ever before. Also, companies must be ready to invest in upskilling to retain their talent.

It was shown that skill development is a sustainable approach to employability and competitiveness in the workforce. Lozanoska developed a survey to analyze the main barriers to the lack of certain skills acquisition. 133 mid and small-sized firms participated in this survey, and it was shown that some of the main causes include inadequate recruitment of talent, lack of motivation from employees, and insufficient training offered. The reason for the last cause is also impacted by the cost of the training, this affects especially smaller firms [9]. However, it is important that employers, regardless of the size of their company, understand the importance of investing in skill development to acquire a competitive advantage over other companies.

There has been a need to look for better methods of training to increase the second cause of lack of skill acquisition, motivation. Sahinidia and Bouris showed a correlation between the perceived effectiveness of the training to satisfaction, motivation, and commitment of the employee [10]. In other words, if the training is effectively developed, the learner perceives the value and is more encouraged to continue learning. In Smith's paper, it is also emphasized the need to find better methods to increase engagement, hence increasing the effectiveness of the training.

Smith summarizes three main steps to create an effective training:

1. First, perform a needs assessment. This should reveal what type of training is needed based on the employees' responses. This is a great tool because the training offered becomes more precise on what the employee's learning needs are.
2. The second step is to determine the proper tools for content delivery that can increase engagement.
3. Finally, the third step involves the introduction of two measurements:
    - Content retention: this can be done by utilizing quizzes or review tools
    - And feedback: this can be done by observing the employee's performance and receiving feedback about the training.

    These two measurements can provide tangible data about the training success and help improve many aspects of the training, like the delivery method, the training design, and the content itself [8].

Smith proposed a simple and effective framework that can be implemented and provide answers to our objectives. Therefore, the proposed steps are going to be used as a guide to develop this study.

Training Content

This study is taking place at Florida Institute of Technology (Florida Tech); therefore, an understanding of its population needs is analyzed. Since the College of Engineering and Science is its largest program, a technical skill was considered [11]. 3D printing was the chosen manufacturing skill as it became a widely used and recognized technique. Based on a Harvard Business Review article, D'Aveni explained that companies like GE, Lockheed Martin, Boeing, Google, and others

use this manufacturing method to boost production. This technology has become very popular due to the advantage of creating physical prototypes or products in a fast and cheap manner [12]. In the education setting, 3D printing enhances creativity, design thinking, and innovation, and it is an effective way of integrating science, engineering, technology, and other disciplines [13].

To be able to produce a 3D model, computer-aided design (CAD) software is used. Today, there are multiple libraries where people can download pre-made objects or step-by-step instructions on how to create the model. Since CAD requires multiple steps and varies based on what is created, it was decided to not use this tool as the training focus. Hence, we move on to the next step in the 3D printing process.

Once you have the 3D model, the next step to be able to 3D print is to slice the part. Slicer software works by translating the 3D model file into single layers so that the printer can understand the code. This type of file is known as gcode [14]. In this case, this is going to be the focus of the training as it is a more simple and consistent process, and it is an essential step to successfully 3D print a model.

Gunther et al. discuss the methods of teaching 3D printing technology. One of the most common ways is presenting the theoretical content by using image and video aids, and it was shown the importance of hands-on experience for an in-depth understanding of this technology [15]. Dagman and Warmefjord showed how the transition to online education affected when teaching computer-aided design software. The professors created video aids and exercises for the students, and there was a good level of satisfaction overall. Moreover, the authors make an emphasis

about the future of hybrid learning [16]. Hence, what type of content delivery should be the focus of this study?

Method of Content Delivery

As discussed previously, e-learning is having a major influence in education, but there are still many improvement opportunities to work on to be recognized as an effective and reliable method of education. Figure 1 shows the SWOT analysis (strengths, weaknesses, opportunities, and threats). These are key factors captured in [17], [18] and they must be considered at the time of implementing this method of education. In this case, one of the opportunities identified is innovation and this can be explored by analyzing methods of content delivery through different technologies.

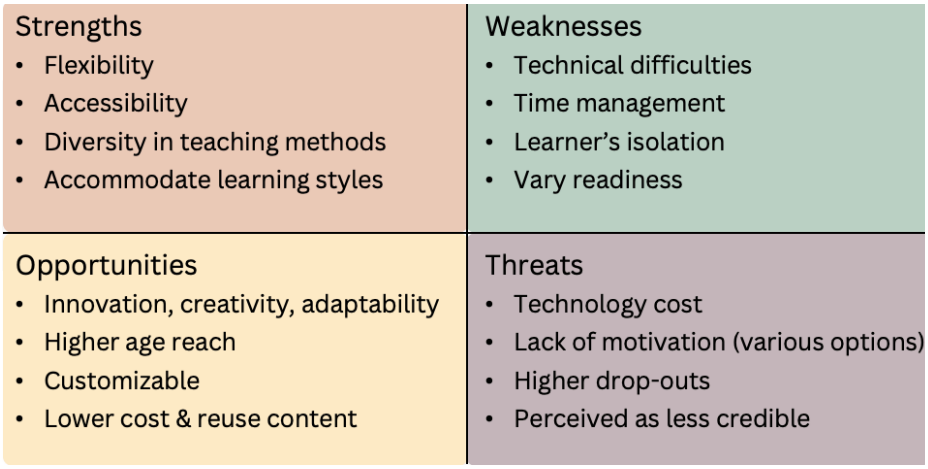

Figure 1: SWOT analysis for e-learning

E-learning can happen in two ways: synchronously and asynchronously. Synchronous e-learning is when the training occurs at a specific time, meaning that all participants must be connected to the online platform simultaneously. On the

other hand, asynchronous e-learning has the advantage that participants can join at their convenience and see the content at their own pace [19]. In both cases, it is geographically flexible, meaning anyone can watch it by increasing its accessibility, regardless of location. Usually, online training accounts for a reduced cost as there is no need for travel packages, hotels, and other miscellaneous expenses. E-learning is also more efficient by reducing the traveling time (flying or commuting) as learners can connect from anywhere with just internet connection. Figure 1 conveys a summary of the benefits of e-learning [20].

Table 1: Benefits of asynchronous and synchronous e-learning

Advantages	**Synchronous**	**Asynchronous**
Connect anytime	No	Yes
Connect from anywhere	Yes	Yes
Flexibility in learning pace	No	Yes
Reduced costs	Yes	Yes
Reduced time (traveling, commute, others)	Yes	Yes
Expand accessibility	Yes	Yes
Allows live interactions	Yes	No

A survey study was developed with students transitioning into virtual courses during the COVID-19 pandemic. This study showed that most students enjoyed classes online and were satisfied with this method's flexibility. The highest-rated element of most preferred content delivery included "Teacher-made text material," "Teacher-made video," and "Textbook and reference book materials." These elements are part of the conventional methods used through an online platform. Some of the most disliked elements were: "poor network and connectivity," "distractions," and "lack of interaction" [21].

These results showed that people had a positive experience with online training despite some technical difficulties, but also suggests there are elements to be improved to have a more engaging experience. Hence, another study was reviewed where different tools were tested to measure satisfaction and engagement. The three methods were:

1. Active: an asynchronous course through a Massive Open Online Course (MOOCS) like Coursera
2. Passive: a blended course with videos and online links to supportive material
3. Interactive: a method where the instructor interacts live with students through polls, quizzes, and other tools

The results of the study showed that the preferred method was "Interactive" (score of 4.34 and 4.35 out of 5 - from the two participating groups respectively), and the lowest graded method was "Active" MOOCS (score of 3.74 and 3.67 out of 5) [22]. Today "Active" can be considered one of the most common e-learning methods used in skill development training in the workforce. Since many institutions are opting for this type of training, it is imperative to provide content where learners feel engaged and satisfied while retaining the information and the content presented. Whether the training is mandatory or non-mandatory, learners should be able to perform tasks related to what was learned. Hence, this study aims to determine more engaging methods to increase content retention and satisfaction.

In this case, two modern technologies are of interest in this study: Virtual Reality and Hologram Display.

Virtual reality (VR) and augmented reality are two immersive 3-dimensional technologies that many companies have already adopted. Some applications already in place include customer service, employee training, product design and development, and more. Moreover, simulation-based or VR is very well-known for industries like aviation, construction, medicine, and space exploration with an interactive experience. The application of this technology has resulted in increased productivity and quality; studies have found a reduction of 25% in manufacturing time [8]. 3D technologies have two distinct advantages compared to traditional methodology. The first is a reduction in mental effort, also known as cognitive load, as they don't require converting 2D images into 3D content like paper or computerized manuals. The second is a reduction in external distracting factors due to the ability of trainees to be immersed in a virtual classroom [23].

VR is a mature technology that, through technological advancements, is becoming more accessible. Moreover, organizations can benefit from cost reduction when training requires complex instruments or infrastructure, as well as developing safer training in a controlled digital environment. VR still provides the advantage of distance learning and home education [24].

Another exciting technology to be explored is the hologram display for teaching applications. In a study done by Ali and Ramlie, a 3D cartoon hologram tutor was developed to understand the user experience. The study determined that learners had a positive and pleasing experience with a holographic tutor [25]. A study by Li and Lefevre looked to understand the effects of video conferencing synchronous seminars. The results showed that the holographic presence enhanced

the experience. Attendees showed engagement; this was attributed to the novelty of the experience [26].

Apart from computers, tablets, and smartphones, the most common devices used in online courses, the VR and hologram technologies show a promising improvement in education and training applications.

Important Measurements

After determining the population needs and identifying key technologies to improve the learners' experience, the last step is to measure the retention and feedback from participants. In this case, it was also seen that satisfaction is a crucial factor to measure the effectiveness of the training [10]. Hence, in this study, the retention and satisfaction will be analyzed, and participants will be encouraged to provide feedback about their experience in this study. This information will be key for the data analysis section.

Further data can be collected to analyze the effectiveness of the training. Since 3D printing needs hands-on steps, the learning curve can be measured. Learning curve means that through repetition, the time of completing a task is reduced by a fixed percentage [27]. This is very critical at the time of decision making in production management. Hence, this can be valuable information for companies to focus on training that can increase their performance. Thus, in this study, the learning curve will be measured, where the data can provide awareness on how well the content retention from a theoretical lecture is translated into hands-on experience.

Chapter 3
Methodology

3.1 Protocol

This study is divided into two main parts, the theoretical section, where students learn the topic, and the practical section, where participants get hands-on experience with what they learned. Figure 4 shows a summary of the steps taken. Each participant performs the study individually to minimize any external variability.

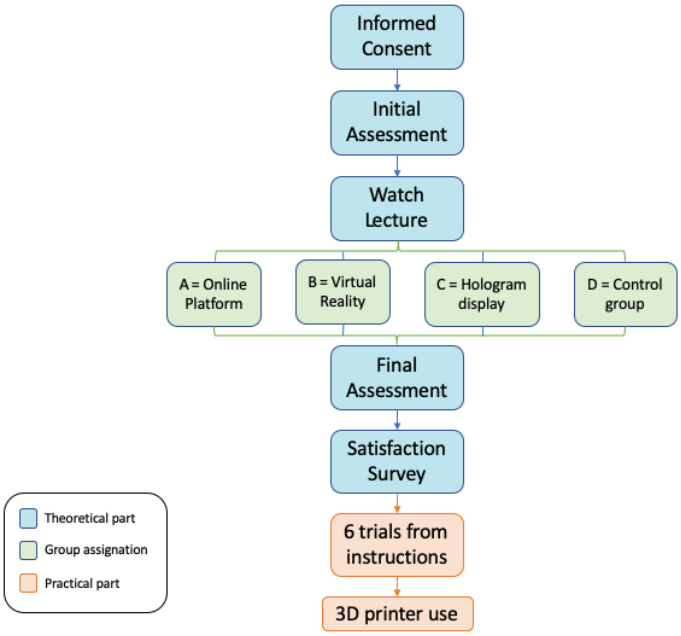

Figure 2: Walkthrough of the protocol

PART 1: Lecture – Theoretical Section

1. The participant will be invited into a quiet room where the experiment will occur. The procedure will be explained in detail, and the participant will be informed that they can withdraw from the study at any time (participant signs informed consent).

2. The participant will be randomly assigned to a type of content presentation study (A, B, C, or D).
3. Once assigned, the participant will take an initial assessment to understand the level of prior knowledge.
4. Then, the participant can start watching the theoretical part when ready.
    - Note: taking notes was not allowed to minimize variability in the study, as group B (VR) would be at a disadvantage
5. After the lecture, a final examination was provided to analyze content retention.
6. Finally, the participant completes a survey that will analyze the level of satisfaction.
    - Questions from the survey are taken from [30], with some questions added or modified for this study.

PART 2: Practice Section

1. The participant will be given access to a computer and Cura (slicer software), where the participant can upload the given file.
2. The participant will have time to get familiarized with the mouse movement and notify when ready.
3. The participant receives a set of instructions (5 main steps) to put their knowledge into practice.
4. The participant will repeat the instructions provided 6 times based on [27]. Each trial will require changes to specific printing settings.
    - The steps for each trial are the same, with minor adjustments like input values and orientation of the part (Refer to the Appendix for the detailed instructions).

        - These changes validate that the participant learned how to change print settings properly. This process is designed to prove that the participant is not repeating the process automatically.
    5. The time will be recorded for each trial to analyze the learning curve. The timer starts with a countdown (3,2,1), where the participant reads the instructions and finalizes when the participant slices the part (mouse click).

Once the participant finishes with all six repetitions or withdraws at any point, the study is completed. After this point, the participant can ask for clarification about the content. The participant is then allowed to use the 3D printer under supervision.

3.2 Materials

After understanding all the steps from the protocol, this is the list of materials needed to develop the study. A detailed description of how these materials were used will be provided in their corresponding sections.

- For creating the content presentation:
    1. Online platform: computer's screen recording tool, podcast equipment for voice recording
    2. Virtual Reality: 180 video camera system for recording
    3. Hologram display: green screen and camera for recording
- For showing the content presentation:
    1. Online platform: Computer
    2. Virtual Reality: VR headset (Oculus Go)
    3. Hologram display: ARHT Media Holopod

- For editing the content: Premiere Pro (Adobe)
- For survey/assessments: Google forms.
- For the practical part: computer and mouse to use Cura Software, Ender-3 Pro 3D printer
- For recording the time of each repetition: timer
- For observations: notebook and pen

3.3 Content Development

In this study, participants learned the basics of the following topics:

1. What is 3D printing?
2. How to use slicer software to 3D print?
3. How to use a 3D printer?

To create the content for the training, information has been collected from four diverse sources. The first one is the online course currently used to train students in 3D printing at Florida Tech. The other sources included the Ultimaker official website, the Cura Software help tool, and the Ender-3 Pro brochure.

Different steps were taken for the content creation of each method. The first method is an Online Platform (OP). In this case, Canvas, a widely used web-based learning management system, was utilized to show the training content. Florida Tech and other institutions already use this OP to manage online learning material and skill development. Based on instructure.com, the official website, Canvas has more than 6,000 customers worldwide [28]. Hence, this platform is a relevant tool to use for this study. The content for this group was developed using the computer's screen recording tool. The instructor did a walkthrough of the presentation while recording his voice using podcast equipment. In this case, the participant acquired the course information in a 2-dimensional format and could only hear the instructor's voice while looking at steps performed in the software.

The second method is Virtual Reality (VR). For this method, the content was created using 180 video recording equipment. The VR used by participants in this study was the Oculus Go headset. The idea is that a video is transformed into a 3-dimensional format as if the participant was physically present in the classroom; the participant had an immersive experience. For the first portion of the presentation, the participant experienced a view equivalent to sitting in the front row of a classroom (Figure 2). While for the second part, the perspective was like being seated next to the instructor while he uses Cura software (Figure 3).

Figure 3: Participant's first perspective – front row

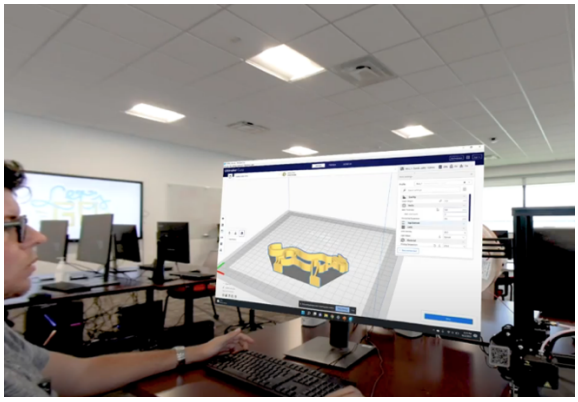

Figure 4: Participant's second perspective – sitting next to instructor

Finally, the third method of content presentation was a hologram display (HD). For this method, the instrument used was ARHT Media Holopod. The content presentation was recorded using a green screen room and edited using Premiere Pro. The concept is to give participants the feeling of a classroom setting, but the instruction is done using a hologram display. The instructor's hologram was displayed in the Holopod, while the steps of the software were displayed on a TV next to the hologram as if the instructor was using a digital whiteboard (Figure 4).

Figure 5: Hologram display layout

Another critical factor to consider when creating the content was the training length. The idea was to keep the time close to the length of a standard class (50 minutes). One-hour courses with engaged students can be achieved by having a well-structured, interactive, and satisfying experience [29]. Hence, the total time of the study was less than 60 minutes, which included the following steps: reading and signing the informed consent, watching the content presentation (length of ~12 min), completing the assessments and survey, and executing the practical portion.

3.4 Group Assignation

Since this study requires the participation of humans, a *Research Involving Human Participants Expedited/Full Application* was approved by the IRB board.

The study was developed by randomly assigning 40 participants into four groups (10 per group). The following groups were decided to be explored based on the literature review and the accessibility to the technologies. Each group was composed of college engineering students with zero or minimal prior experience with 3D printing.

- Group A: Online Platform (OP)
- Group B: Virtual Reality (VR)
- Group C: Hologram Display (HD)
- Group D: No Treatment (NT)
    - Note: This group did not have any treatment, meaning that participants did not receive any training, but they would still be required to perform the tasks given by the principal investigator. This group will be used as a point of comparison to understand the training's impact on the criterias measured.

Both VR and Hologram display technologies are available at CAMID (Center for Advance Manufacturing and Innovative Design), a part of Florida Tech, allowing us to use these technologies and try to identify the best way both can be used for teaching and training applications. This study showed promising results that can serve as a source of reference for implementing this type of training method for any student who wants to expand/improve their skills.

Some important clarifications for the study are:

- The Online Platform (OP) represents the traditional method
- Virtual Reality (VR) and Hologram Display (HD) represent modern technologies

- A college student is defined as any male or female individual enrolled at the Florida Institute of Technology
- It was intended to recruit participants with similar academic backgrounds
- Recruited students should have zero or minimal prior experience using either a 3D printer or any software for 3D printing.

3.5 Measuring Tools

Measuring Content Retention

A comprehensive assessment with 11 questions was given to the participants to measure content retention. The main objective was to understand if participants had different retention rates based on the method of content received. The assessment had nine multiple-choice questions and two fill in the blank. Participants were encouraged not to guess the answer so more reliable data could be collected. Hence, an extra option was added to each question. In this case, for the initial assessment, participants could choose the option "I do not know yet" (Figure 6); on the other hand, for the final evaluation, participants could choose "I do not remember" (Figure 7). The same was encouraged for filling in the blank questions, participants would leave it blank if they did not know the answer.

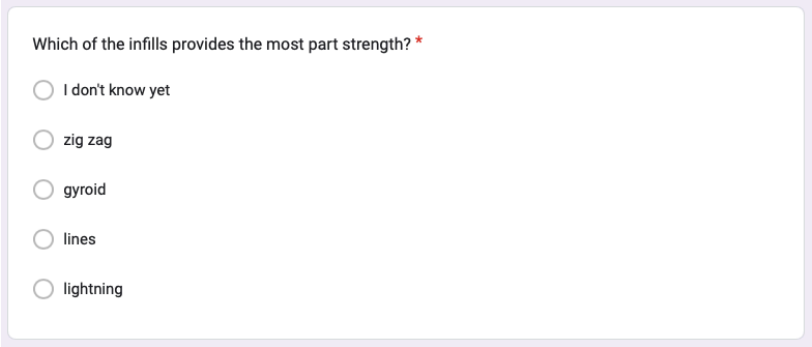

Figure 6: Example of "I don't know yet" option for multiple questions

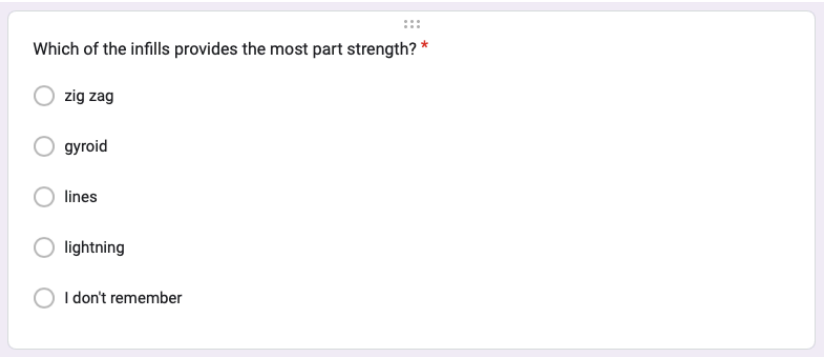

Figure 7: Example of "I don't remember" option for multiple questions

Measuring Satisfaction

Satisfaction was measured using a survey. Surveys are usually used to determine how subjects feel about a specific matter, which helps clarify assumptions or myths about the discussed topic. Ideally, some researchers use previous surveys; this can save time and help compare the results with other studies. Before utilizing the survey, it is important to determine its purpose. Hence, this study aims to understand the subject's level of engagement based on the method of training received.

The study uses two types of survey questions: open-ended questions and close-ended questions. For open-ended questions, the advantage is that you can make unpredictive findings because the subject may reveal something unexpected in the study. However, this takes more effort from the participant, hence, in long studies, it may be better to use close-ended questions or only a limited number of open-ended questions. On the contrary, close-ended questions are easier to analyze, create, and standardize. Errors can come up in this type of questionnaire due to the misinterpretation of the question. To reduce any error, participants will record their response in two places [31]. For instance, in this study, four main questions are

going to be asked using the Likert scale, each question will be reworded in a way that asks the same but in the opposite way: question 1) is an affirmation, and question 5) is a negation, but both questions are related to each other (For further reference, the survey is detailed in the Appendix).

Example:
Question 1) I stayed satisfied during today's training
Question 5) I thought that today's training was boring

Hence, the answers should match the participant's experience to confirm that no misinterpretation happened. As mentioned, the Linkert scale is used in this study as it measures the magnitude of the opinion.

Based on Alabi and Jelili, it is recommended that a Likert scale has symmetry, meaning that both the agreed and disagreed options have the same distance in each side to the middle point. The most common are 5 or 7-point scales. The advantage of a 7-point scale is that it allows expansion to the responder. It is important to note that a scale below 5 or higher than 11 decreases the accuracy of the survey [32]. Also, another study showed that 7, 8, 9, and 10 scales are preferred to be used due to reliable scores, and scales of 5, 7, and 10 are easier to use [33].

Hence, based on the ease and reliability of the different scales, it was decided to use a 7-point scale with the following categories:

(1) strongly disagree
(2) disagree
(3) somewhat disagree
(4) neutral

(5) somewhat agree

(6) agree

(7) strongly agree.

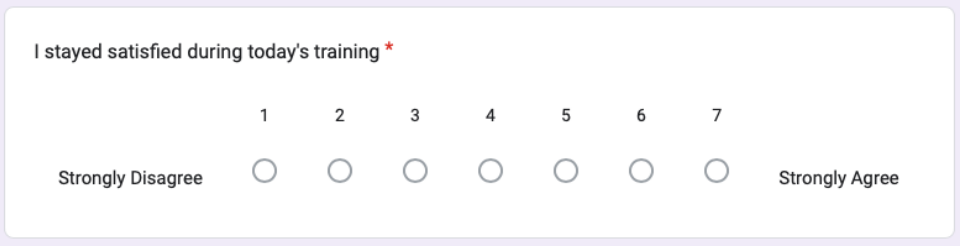

Figure 8: Example of how the Likert scale is used in the survey

Measuring Learning Curve

The learning curve shows the progress an induvial or group makes with the gained experience. There are many ways that learning curves can occur; one of them is individual learning that happens through repetition. A study conducted by Robbins aimed at measuring the learning curve where students performed an assembly task using a Lego product. The instructions were provided, and 6-8 repetitions were performed based on the time available to complete the project [27].

For this study, a similar protocol will be followed. Participants will perform multiple slicing trials using the Cura software explained in the theoretical section instead of performing an assembly task. The practical section comprises 5 main steps to be followed with the respective repetitions.

For the study, 6 repetitions are performed for the following reasons:

- Time constraint as the study should be completed within an hour

- When performing pre-trials, it was determined that the time difference after multiple repetitions was more related to the mechanical ability of participants rather than the conditions being tested

Each repetition has slight changes to prove that participants could perform the task without automatic repetition. Once participants started with the task, the time was recorded. In this case, the data is recorded in an excel sheet, and any observations are also written for further analysis. The mathematical equation to model the learning curve is:

$$Y_x = Kx^n \quad (1)$$

Where, K = effort, Y_x = hours to produce the xth unit, and n = learning index. In this case, n is calculated with the following equation:

$$n = \frac{\log b}{\log 2} \quad (2)$$

Where b = learning rate. Like Robin's paper, the study is looking to find the learning rate. Hence, we solve for b:

$$b = 10^{n \cdot \log 2} \quad (3)$$

Once all the trials are recorded, the log of each value is calculated to help find the learning rate b. This step is done whenever using empirical data. The log-log transformation calculates the slope of the regression line, which in this case represents n. Once n is found, it can be replaced in equation 3. The learning rate was calculated for the four groups.

A crucial step is verifying if the data was normally distributed for all the numerical data. This step was required due to the small sample size as it is harder to determine normality using the bell curve. Hence, quantile-quantile plots (Q-Q plots) were used for this purpose; a Q-Q plot is a scatterplot where the sorted sample data is plotted against the quantile calculated. If the data is normally distributed, then it follows a straight line. If skewed, the data follows a curve shape [34]. This analysis is done in the next chapter with the data collected.

Chapter 4

Results & Discussion

During this chapter, it is important to keep in mind that the same content (same script, instructor, tools, and others) was presented for groups A, B, and C. To start with the analysis, the Q-Q plots were created for the numerical data. All the samples had a pattern closer to a straight line than a curve; hence, we can assume the data has a normal distribution (Figure 8). Therefore, the ANOVA test is a valid method to determine significance. If the data showed significance, t-tests are performed to compare the mean of one group against the other to determine if difference exists. An 85% confidence interval will be used for the analysis as the sample size is small. If the data showed no significance, then an analysis is done by observations.

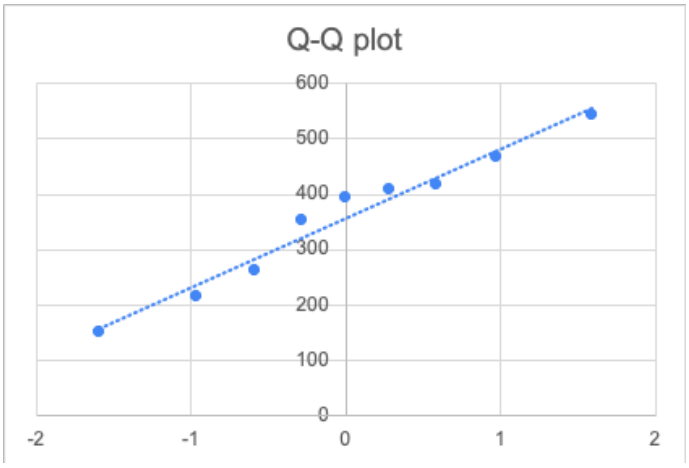

Figure 9: Example of Q-Q plot behavior of sample

4.1 Theoretical Part Analysis

Assessments

As mentioned in the methodology, participants received an initial assessment to determine if there was any prior knowledge about the topic to be learned. For this part of the analysis, the initial assessment will serve as the control group, as this information was collected before any training. This data will be used as a point of comparison for the final assessment and will reveal if the presented content methodology was effective.

It is important to note that group D (NT) also participated in the theoretical part by performing the initial and final assessment. However, for this section, group D is not used for the analysis as no changes should have happened before and after due to participants not being exposed to any treatment. As expected, the results showed no changes between the initial and final assessment (refer to Table 2 and Table 3). This is important to emphasize because it proves that with no training presented, no learning is acquired.

A single-factor ANOVA was performed between the groups. When comparing groups, A, B, C, and D, there is a significant difference between the groups. This makes sense because there is a big variance in results between the groups exposed to a type of content versus the group with no treatment. On the other hand, if ANOVA is performed only for groups A, B, and C, no significance is found within an 85% confidence interval. Hence, the analysis can be better understood by observing the data.

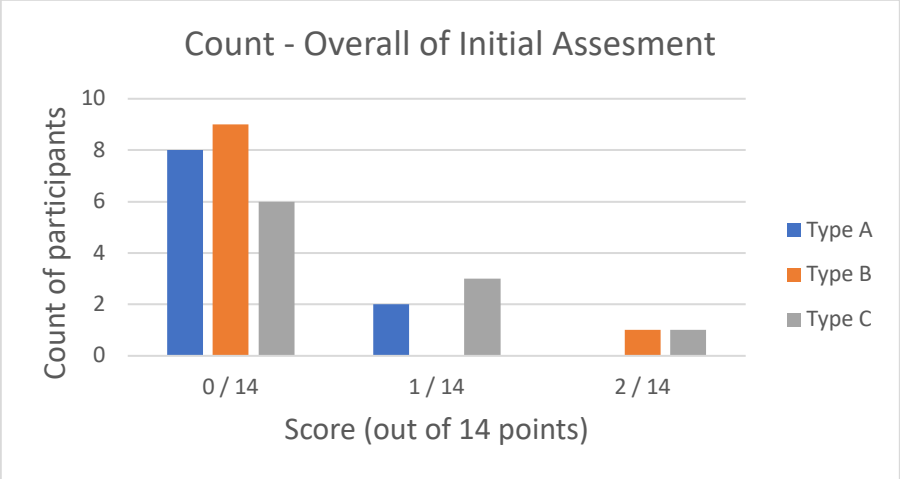

Figure 10: Scores for groups A, B, and C for the initial assessment

Table 2: Average, standard deviation, max and min values for initial assessment scores

Type	Average	STDEV	Max	Min
A	0	0.42	1	0
B	0	0.63	2	0
C	0.5	0.71	2	0
D	1.5	2.01	5	0

During the recruitment process, it can be challenging to control who enrolls in the study, meaning that someone with expertise or more than minimal knowledge on the topic could have enrolled in it. However, as is shown in Figure 10, all participants had zero or minimal prior knowledge about the topic. This allowed us to have a relevant control group for the study. As can be seen, groups B and C had one participant each with the highest score for the initial assessment (2/14). Also, group A had two participants and group C had three participants with a 1/14 score. This shows minimal knowledge prior to the study.

After the initial assessment was submitted, participants watched the training lecture with their respective technology based on their group assigned. Once the training lecture finished, participants completed the final assessment.

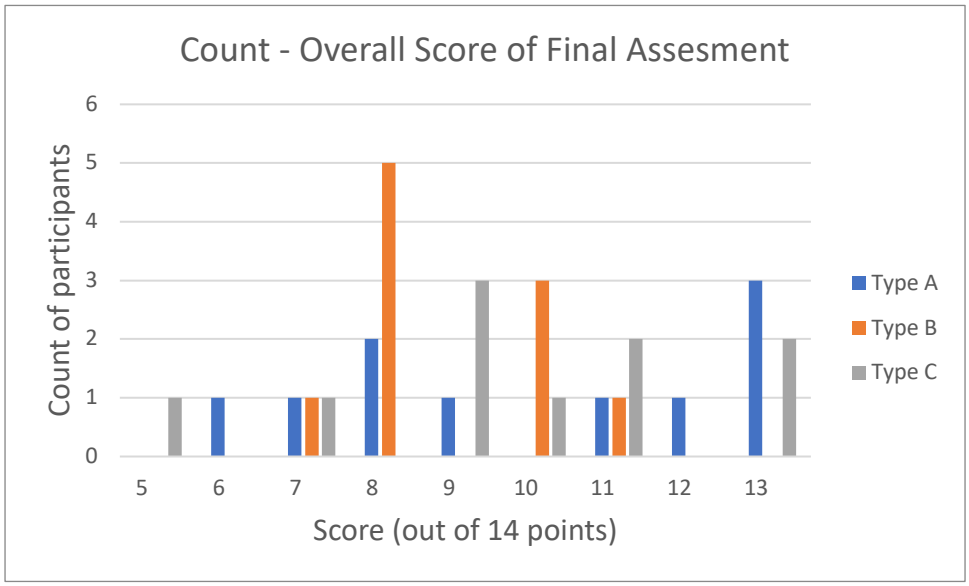

Figure 11: Scores for groups A, B, and C for the initial assessment

Table 3: Average, standard deviation, max and min values for final assessment scores

Type	Average	STDEV	Max	Min
A	10	2.71	13	6
B	8.8	1.32	11	7
C	9.7	2.50	13	5
D	1.5	2.01	5	0

For groups A, B, and C, scores were improved after watching the content presented. This evidences that the content had an impact on the learner. Table 3

shows the average, standard deviation, maximum and minimum values of the scores in the final assessment. Interestingly, A and C showed almost the same average, 10 and 9.7, for the final assessment. However, group A has more variability of the mean with 2.71 compared to group C with 2.50. It can be said that the online platform and the hologram display have a similar impact on content retention. On the other hand, group B has a lower average (8.8), but it is the group with the least variability (standard deviation of 1.32). Thus, the retention rate could be considered less effective but more consistent than the other groups.

If each question is analyzed individually, the results showed variation in the level of understanding based on the type of content delivery. For this analysis, the questions were categorized as Strong, None, or Weak. If the sum of the correct answers from all participants is greater than 2/3 of the sample, then the question is considered strong because more than 2/3 of the sample understood the content. If the correct answers are less than 1/3 of the sample, then it is considered weak. Anything in between is considered as none.

Table 4: Level of understanding of each question

Type	Strong	None	Weak
A	7	7	0
B	6	6	2
C	9	4	1

In this case, group A does not have any questions considered to be weak, group B has two weak questions, and group C has one weak question. It is important to note that the weak questions are not the same for each group. This can prove that information can be better conveyed with the correct technology. For

instance, the weak question for group C had to do with identifying the symbol used to align the part to the build plate (Refer Appendix question 3). In this case, HD may not show this information effectively as the participant can be distracted looking at the hologram, or the distance to the monitor could have been a limitation. Since the symbol was not described verbally on how it looks like, then the participant may have not seen it, then not being able to recognize it. This information is valuable because it identified factors that can be improved in the training.

Each group also had a difference in the number of strong questions. Group C has the highest number of strong questions with 9 out of 14 questions, group A has the second highest number with 7 out of 14, and group B has the lowest with only 6 out of 14. In this case, group B (VR) has the lowest number of strong questions and the highest number of weak questions. Although group C (HD) has one weak question, it has the highest number of strong questions. If the information from the final assessment average score and the number of strong questions is considered, group C provides the highest retention overall. Moreover, it is important to see that Group A is also a great tool for high retention rates. In this case, due to OP's higher variability and lower number of stronger questions, HD can be determined as a better retention tool.

Satisfaction Survey

After analyzing the assessments, participants completed the satisfaction survey as the last step for the theoretical part. In this case, the survey serves as the second measuring tool to understand the effectiveness of the technologies in a training setting. Table 5 shows the responses to the survey.

Table 5: Satisfaction responses for groups A, B, and C

	Average per group type		
Question	**A**	**B**	**C**
Q1: I stayed satisfied during today's training	4.9	5.4	6.1
Q2: I put effort into doing today's training	6.3	6.0	6.3
Q3: I stayed focused during today's training	5.8	5.6	6.0
Q4: I understood today's training	6.0	5.6	6.5

(1) strongly disagree, (2) disagree, (3) somewhat disagree, (4) neutral, (5) somewhat agree, (6) agree, (7) strongly agree

Group D responses were not used for the analysis as the overall result was a score of 4, meaning that the satisfaction was neutral. This makes sense, as no training was provided. Starting with the analysis of the other groups, group C (HD) has the highest score. Some comments from different participants regarding engagement for the hologram training include:

"The only thing that would have helped me retain more would be to be able to take notes, otherwise I found it more engaging than normal lectures." [Group C]

"I enjoyed being able to see a person describe the steps of how to set-up the 3d printer. For example, the part when he was using a sheet of paper to test the distance between the printer and the print bed, it was very helpful to see the hologram of the person." [Group C]

On the other hand, there are other comments that put into question whether this is the ideal technology to use in this type of training, where a software program is learned. Since the hologram has a portrait orientation, it is perfect to show the instructor's hologram. However, to explain each step on the software program, a secondary monitor was needed with a landscape orientation (Figure 4). However, this could impact on the participants' experience of having to rotate their head to pay attention to both displays. In this case, since a hologram is used, it can be more distracting than just having the instructor in person teaching the course. Hence, the ideal application for this technology could be using the hologram only in portrait mode, presentations that do not require detailed attention to the secondary monitor, or locating both displays more effectively.

"The use and necessity of head rotation during today's lecture was rather obnoxious while trying to gain the knowledge from 3D printing." [Group C]

"The switch between video and hologram was a bit confusing but understandable still." [Group C]

Moreover, group B has a higher score than group A for question 1 regarding satisfaction. This means that VR is still a great tool to bring satisfaction to the participant even though this was not an interactive training, but yes it was an immersive experience. Some limitations were identified by participants using VR, this also can show that for this specific application (learning a software program), VR may not be the best option.

"Being able to zoom should be an option if not already." [Group B]

"Inside the VR headset the video can become blurry towards the edges of the screen. This made it hard to see where exactly he was in the menus and what the menu was." [Group B]

After analyzing the scores and some comments from the participants, an ANOVA test (with 85% confidence) was made for the four questions using excel as a tool. For questions 2 and 3 no significant difference was found. However, questions 1 and 4 did show a significant difference. Hence, a t-test was performed to identify which groups differ from the others. To reduce the risk of a Type 1 error, the alpha level was adjusted by using the Boneferroni correction. This procedure is repeated for all the executed t-tests.

$$corrected\ p\ value\ = \frac{\alpha}{n}$$

In this case, groups A, B, and C (n=3) were compared. Hence, an alpha of 0.15 was divided by 3. For question 1, group A vs C was significant. This shows that with 85% confidence, C (HD) is more satisfying than A (OP). Moreover, for question 4, significance was found in B vs C. The results can be interpreted as C (HD) was more understood than B (VR) based on the participants perspective.

Table 6: Questions from Satisfaction Survey

Group	Would you recommend this training method to your friends? (Y/N)	Does this training aid in your professional development? (Y/N)
Type A	6 yes	8 Yes
Type B	8 yes	8 yes
Type C	9 yes	10 yes
Type D	4 yes	4 yes

Moreover, Table 6 shows that HD has the highest positive responses, where participants would recommend this method to their friends, and they felt this training aids in their professional development. This shows once again that HD is a great tool to increase satisfaction.

4.2 Practical Part Analysis

Once participants successfully completed the first part, they started with the practical part. Participants received a set of instructions which needed to be repeated 6 times, and each repetition was timed to analyze the learning curve. For this part, group D (NT) was part of the analysis, allowing the comparison between experimental groups with treatment and the control group without treatment.

Before starting with the practical part, the principal investigator communicated with participants that they can withdraw from the study at any time. If they do not know how to proceed from the instructions provided, then they can stop the study. Very interestingly, 2 out of 10 participants withdrew from the study for groups A, B, and C, respectively. However, group D had only 1 participant that did not continue. De Giorgio, Cacace et al. paper compares the effects of receiving or not receiving instructions through a video aid for an assembly. The results show that watching the video aid may be more detrimental than not having it. The reasoning is that operators try to imitate what the video instructs by reducing their freedom of applying their prior knowledge [35]. Hence, a similar effect might be happening in this study.

Based on other observations made by the principal investigator for groups with treatment, choosing the printer in the software is one of the steps that cause most of the participants to withdraw from the study. Participants explained that

there was a lot of content to retain. Since the printer step was shown at the beginning, they forgot how to do this step. This shows how participants are dependent on what the training shows. However, participants with no treatment could explore the software without imitating. Participants in group D found different ways to complete the instructions. However, there is one participant that withdrew from this group. Based on the notes from the principal investigator, this participant was not able to complete any of the steps. Compared to groups A, B, and C, the people that withdrew from the study only missed completing one or two steps. Hence, this shows that it is still important to have training for guidance and understanding. The advantage of the slicer software used in this study is that it is very intuitive, however, if the software to be used is more complex, then it will be difficult to use it without proper training.

First Trial Time Analysis

There are two analyses performed in the practical part, the first one is an analysis of only the first trial, and the second one is an analysis of the learning curve. For the first trial, it is important to analyze it independently because the first time it shows the direct correlation between the content learned and how to apply it hands-on.

Table 7: First trial time for all groups

Type	First Trial Time (sec)
A	228
B	351
C	240
D	356

In this case, an ANOVA test was performed, and it showed a significant difference within the 85% confidence interval. The t-test shows that only A and D have a significant difference. In this case, it can be interpreted that training had a relevant impact for OP in the practical part compared to the control group that did not receive any prior training. However, the other groups did not show any significance among the others.

Each group's first trial is compared, and it shows that group A (OP) is the one that took the least amount of time, the second group is C (HD), then group B (VR), and finally group D (NT). This shows that training does still have a positive impact on the learning process. However, as Table 7 shows, VR did not have a substantial difference compared to NT in their first trial. Once again it shows that VR might not be the most appropriate method to teach the topic.

Learning curve analysis

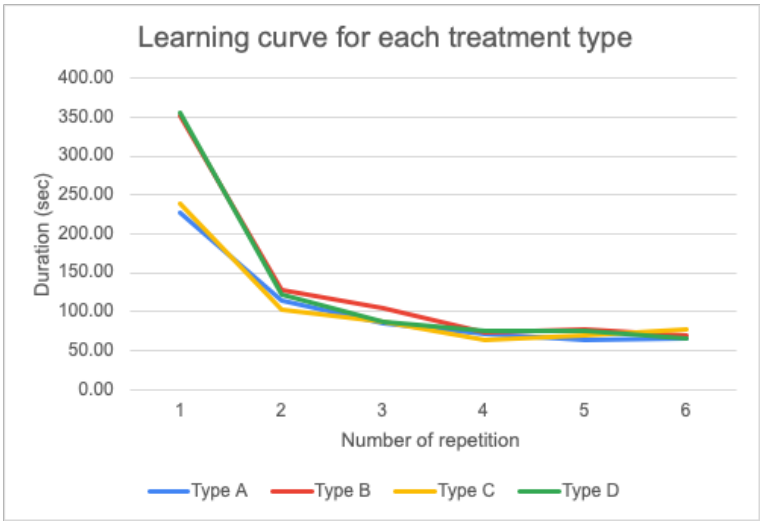

Figure 12: Learning curve for all groups

Table 8: Learning rate for all groups

Type	Learning Rate
A	61%
B	54%
C	63%
D	53%

For the second analysis, the learning curve is compared among the groups. Figure 12 shows the learning curve for each group. After taking the average of each trial for each group, the results for the learning rate are shown in Table 8. As mentioned in the previous analysis, groups B and D do not have too much of a difference, and this minimal difference can also be observed in the learning rate. On the other hand, group C has the highest learning rate, meaning there is less margin of improvement due to the participants being more capable of performing the task from the very first time. Group A also shows a high learning rate, this makes sense as OP had the group with the smallest average duration for the first trial.

4.3 Patterns and Overall Performance Findings

Patterns Identified

After analyzing all the results from each individual measuring tool, some patterns were found. The following symbols are going to be used to classify the observations.

* Lowest score compared to the sample
** Second lowest score compared to the sample
+ Highest score compared to the sample
++ Second highest score compared to the sample

Table 9: Example of participants' overall performance showing patterns in group A

Participant ID	Final Assessment Score (out of 14)	Satisfaction (out of 7)	First trial (sec)
RM	13+	6++	139+
HT_	6*	4*	323**
ALS_	7**	7+	withdrew

Table 10: Example of participants' overall performance showing patterns in group B

Participant ID	Final Assessment Score (out of 14)	Satisfaction (out of 7)	First trial (sec)
EG_	10++	6+	205++
SF_1108	8**	5**	withdrew
NH_	7*	3*	288
MC	13+	3*	203

Table 11: Example of participants' overall performance showing patterns in group C

Participant ID	Final Assessment Score (out of 14)	Satisfaction (out of 7)	First trial (sec)
NR_10	11++	7+	180
DM_1012	7**	5*	withdrew
PR_1014	5*	7+	withdrew

Based on the data collected, there are some patterns identified between content retention, satisfaction, and the first trial time. In this case, the first trial time is used for the analysis, as this is directly affected by the type of content delivery received. Tables 9, 10, and 11 are showing specific examples of identified patterns.

For most of the cases, the data showed a good final score along with a good satisfaction score. As well as it showed that higher grades were related to good first

trial times. Examples of this pattern are in the first row of the above tables. For instance, for group A, Table 9 shows participant RM with the highest final score (13/14), the second highest satisfaction score (6/7), and the fastest time of the first trial from its group. The same can be observed for participants listed in the first row of groups B and C.

As expected, the contrary also happened, lower final grades were usually related to lower satisfaction and longer first trial time. This can be observed in the second row of the above tables. For instance, participant HT had the lowest final score (6/14), the lowest satisfaction score (4/7), and the second longest time for the first trial from its group.

However, some interesting patterns were observed in specific participants. For instance, participant ALS from group A showed the second lowest final score (7/14), the highest satisfaction score (7/7), and withdrawal for the trials. A similar pattern was found for participant PR from group C. This evidences that even if the participant was satisfied with the course, it does not mean that retention is guaranteed. Therefore, the use of quizzes is a great way to verify the level of retention, and in what areas the learner needs to improve.

For the second pattern identified, the opposite occurs. In this case, participant MC from group B showed the highest final score (13/14), the lowest satisfaction score (3/7), and a relatively good time for the first trial compared to its group. It is more common to see that satisfaction does improve content retention as found in the literature review, however, it can happen that the retention is great even if the learner was feeling bored. This can happen in any educational scenario. However, if engagement does not occur, it can decrease the learner's motivation

and commitment to continue learning [10]. So, it is important to pay attention to this type of behavior.

Finally, the last pattern was found in group B. Participant NH showed the lowest final score (7/14), the lowest satisfaction score (3/7), but the time to complete the first trial was considered good compared to its group. Based on the comments from the satisfaction survey, the participant commented:

"In my opinion a VR training isn't as effective as a more traditional method" [Group B]

This shows the participant may have had a preconceived opinion about VR that may influence his performance during the first part of the study. Moreover, the participant's first trial time can evidence that the software used is intuitive so that the participant was able to achieve a good time for the trial with a low retention rate. This is true in group D (NT), 90% of the participants were able to successfully complete the trials without having prior knowledge.

Other factors can also influence the behavior of these four patterns found. However, a larger sample size will be needed to understand the main causes of these behaviors and validate the observations made.

Overall Analysis

In general, it can be said that OP is a great tool for this type of training as the average retention and first trial times were higher for this group. However, the results were high because the training took place in a controlled environment. This retention can decrease because usually, learners are taking these trainings from a

comfortable place like home. Hence, many external distractions may influence the learners' performance. Therefore, it is important to have dedicated working environments to increase the attention [36].

Satisfaction was increased with the HD experience. Based on comments and performance from the participants, it showed that this technology can increase engagement during training. HD had the highest performance in terms of satisfaction, strong understanding level, and learning curve, hence it will be important to further investigate how this technology can be beneficial in an educational setting. Some disadvantages mentioned are the need for head rotation and the need for a dark room to be able to see the hologram display. However, ARHT media is working on a new model called "Capsule" that can be used in all light conditions. It is less bulky compared to the Holopod, so head rotation should decrease, and it can be more portable to use in different settings [37]. Another interesting study to understand the level of effectiveness of the HD is by comparing in-person vs hologram training.

Then, based on the participants' comments, VR still showed being an engaging tool. However, this type of training (non-interactive) is not the ideal application for this technology. It will be interesting to see what differences augmented reality (AR) brings to this type of training. Therefore, there is a lot more to investigate about the effects of technology on education.

Finally, the no-treatment group showed good performance in the practical part. Two main lessons were learned from their performance. First, it is important to encourage the freedom to explore and expand the experience to all learners, what is being taught is not the only way to reach the final result. And the second lesson

is that education is still important. Although the participants were able to complete the task, they did not learn what the settings meant and what the purpose of this training was. Moreover, the participant that withdrew from the study evidenced that some learners need more guidance than others.

Chapter 5
Conclusions & Future Work

The E-learning transition increased after the pandemic, and it arrived to stay as a skill development method. Based on the literature, there is a need to find better solutions that can increase content retention and satisfaction. Modern technologies can be an excellent solution for this need with the correct application and development.

Based on the final assessment's results, in terms of retention rate, the online platform and the hologram display had a similar impact. The online platform had the highest average score on the assessments and the shortest first trial time among the other groups. The hologram display had the strongest level of understanding from the assessment questions, and the best learning curve overall. On the other hand, VR participants obtained lower scores from all the methods.

The online platform showed that it is still a great tool to be used in education, but it is important to eliminate as many external distractions as possible to dedicate attention to the training. Also, creative interactive tools may need to be implemented to increase the engagements when using this technology. On the other hand, the hologram display showed that this is a great tool to bring engagement as HD had the highest score for satisfaction. It will be important to make further studies about this technology to understand its strengths and weaknesses compared to in-person classes. Finally, VR was not the ideal technology for this type of training, but it did still bring satisfaction to the learners. Therefore, based on all the results and the participants' overall performance, it seems that the HD is the best

method for this type of training compared to the other technologies tested, and OP will be the second better option.

For future work, it will be important to have a larger sample size to validate the patterns found in this study. Based on the participants' feedback, adjustments can be made to the content presentation, as well as choosing the specifications of the technologies to improve their experience. Moreover, other modern technologies can be tested to find the ideal technology for the correct application. For instance, augmented reality can be a great solution for this application.

It may also be beneficial to develop a software tool that facilitates the data gathering and analysis processes. Critical to the development and implementation of an effective software tool for this purpose would require following a requirement engineering approach to ensure that critical functional needs are incorporated into the proposed solution [38][39]. Finally, it would be interesting to consider multiple criteria for evaluations. The current approach presented in this paper to evaluate participants was a pre and post assessment in the form similar to an exam. It will be interesting to evaluate candidates with multiple assessment tools (e.g., written, and oral exams, hands-on activities, etc.) and employ techniques to consider multiple criteria, such as the use of desirability functions [40].

Limitations include the time constraint to develop the study, as well as being in its early stages of research.

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Appendix

Final Assessment

1. What type of file do you need to use in the slicer?
    a. .stl
    b. .prt
    c. .gcode
    d. .sld
    e. I don't rembemer

2. The most generic nozzle size for a 3D printer is _____ mm *(Leave blank if you don't remember)*.

3. Which icon can be used to align the selected face to the build plate?

a. 

b. 

c. 

d. 

e. I don't remember

4. What happens if you decrease the layer height of your print setting?
    a. Decreased quality & decreased printing time
    b. Decreased quality & increased printing time
    c. increased quality & decreased printing time
    d. increased quality & increased printing time

5. How do you calculate the number of walls?
    a. Wall thickness – nozzle size
    b. Wall thickness / nozzle size
    c. Nozzle size – nozzle speed
    d. Nozzle size / nozzle speed
    e. I don't remember

6. Which of the infills provides the most part strength?
    a. Zig zag
    b. Gyroid
    c. Lines
    d. Lightining
    e. I don't remember

7. Which one of these nozzle temperatures could be used for PLA filament?
    a. 100 degrees Celsius
    b. 200 degrees Celsius
    c. 150 degrees Celsius
    d. 300 degrees Celsius
    e. I don't remember

8. What is a common bed temperature when using PLA filament?
    a. 25 degrees Celsius
    b. 30 degrees Celsius
    c. 60 degrees Celsius
    d. 80 degrees Celsius
    e. I don't remember

9. Name one build plate adhesion type *(Leave it blank if you don't remember).*

10. What type of file does the 3D printer use?
    a. .stl
    b. .prt
    c. .gcode

d. .sld
e. I don’t remember

11. Which side should the micro SD be inserted to the printer?
    a. Contacts facing down
    b. Contacts facing up
    c. Contacts facing right
    d. Contacts facing left
    e. I don’t remember

12. Which menu option on the printer should you select to find your file?
    a. Print from SD
    b. Prepare
    c. Control
    d. Print from TF
    e. I don’t remember

13. What can you use to measure the distance between the hot end and the bed?
    a. A piece of cardboard
    b. A sheet of paper
    c. Your thumb
    d. No measure needed
    e. I don’t remember

Satisfaction Survey

1. I stayed satisfied during today's training
2. I put effort into doing today’s training
3. I stayed focused during today's training
4. I understood today's training
5. I thought that today's training was boring
6. I didn’t want to do today’s training
7. I wasn't focused during today’s training

8. I didn’t understand today's training

9. Would you recommend this training method to your friends?

10. Does this training aid in your professional development?

11. Additional comments, limitations, or more

Instructions for Practical Part

Instructions were the same, but the highlighted parameters were changed for each trail (6 total)

Instructions 1st Print

The .stl file to be adjusted is located on the desktop as “wild_catz.” You already have it open.

1. Select in the Cura session the appropriate non-networked printer **(Creality3D > Ender 3)** and click Next.

2. Leave PLA as your material and a nozzle size of 0.4mm

3. Set the panther orientation **standing up** by selecting the appropriate face

4. Open Print Settings and Custom Settings
    1. Select Layer Height to 0.28
    2. Select Wall Line Count to 4
    3. Select Infill Density 35%
    4. Select Infill Pattern Lines
    5. Select Generate Support
    6. Select Build Plate Adhesion Method Brim

5. Slice your part and look at the preview (generate .gcode)