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Exploring the Role of Simulation and Visualization Tools in Improving Learning Outcomes in Support of Technology Programs

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EXPLORING THE ROLE OF SIMULATION AND VISUALIZATION TOOLS IN IMPROVING LEARNING OUTCOMES IN SUPPORT OF TECHNOLOGY PROGRAMS

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by
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ABSTRACT

Online educational opportunities have provided students with the flexibility to advance their careers and complete certificate and degree programs. These have also provided educational institutions with increased capacity without the investment of costly brick-and-mortar expansions at campuses. Technology programs, however, have shied away from integrating these advances due to their program outcomes being heavily dependent on the use of tools and hands-on learning. This dissertation explores the use of digital learning lectures on linear measuring instruments accompanied with virtual reality tools in technology programs and its effects on both cognitive and psychomotor learning outcomes compared to current modality – face-to-face instruction. The research then investigates the differences in problem-solving self-efficacy and transfer of knowledge that occurs between the two groups. All three studies refer back to the Vygotsky's Zone of Proximal Development as the theoretical framework (1978).

The initial study recruited participants from entry level mathematics courses. It aimed to determine if the digital learning group performed at least as well as the conventional learning group in the educational gains, in skilled-based assessment scores, and perception of learning measures. Additional measures for the digital learning environment were collected to determine usability, technology acceptance, and workload. The between subjects experimental analysis showed statistical difference in the cognitive gains in favor of the digital learning group, but no statistical difference in the skilled-based assessment scores nor the perception of learning measures. A post hoc power analysis determined that a sample size of 102 participants, 51 per group, would be needed

to obtain a statistical power at the recommended 0.80 level for a one-tailed test (Cohen, 1988).

The second study replicated the first study with adjustments based on lessons learned and a larger sample size (N=86). One major change was that the participants were recruited from first semester students in automotive, aircraft maintenance, and avionics technology programs. This population better reflects the target population for the topic selected to test, metrology. Similar to the initial pilot study, the large scale study aimed to determine the effects of the digital learning materials on the educational gains, in skilled-based assessment scores, and perception of learning measures. The between subjects experimental analysis showed no statistical difference in the cognitive gains nor in the skilled-based assessment scores. However, the results did show statistical difference in the perception of learning measures in favor of the conventional learning group.

The final study utilized a subset of the population from the large-scale study for a two-fold investigation: (1) problem-solving self-efficacy scores before and after completing a complex metrology task and (2) the transfer of knowledge that was uncovered during the completion of a complex metrology task. For the former, no significant difference was found in the pre- or post- problem solving self-efficacy scores between the digital learning group and the control group. In addition, both groups experienced positive self-efficacy gains after completing the complex task. These gains were also not statistically significantly different from one another. A transfer of knowledge framework by Rebello et al, (2005) and Hutchinson (2011) was used to analyze think aloud interviews conducted during the completion of a complex task. These revealed various instances of problem feature identification (*target tool*), mental processes to obtain an answer (*workbench*), and scaffolded and spontaneous transfer. In addition, themes emerged regarding the measurement systems used and the effectiveness of the digital learning environment.

The implications of this work apply to the development of digital learning environments and virtual reality tools for 2-year technology programs. The performance based findings failed to reject that hypothesis that the digital learning group performed as least as well as the conventional learning group. Thus, we can recommend use of the digital learning environment to achieve at least the same mastery level. The qualitative findings, however, showed that participants did not feel that the digital learning environment prepared them well. Therefore, further attention should be paid to the development, scaffolding, and feedback loops of the digital learning environment in order to improve the perception of participants.

DEDICATION

This work is dedicated to my unconditionally supportive and loving family. To my grandparents, Alex Hedman and Antonia Alas de Hedman, who saw infinite potential in my education and inspired me to always strive for more. I will always be grateful for their trust and investment in my future. To my father, Dr. Roberto Zelaya, who helped develop in me a sense of curiosity and exploration through intellectual conversations about science, math, medicine, and life in general. I miss you terribly. To my mother, Iving Hedman, who has always been there for me unconditionally and carried on, with no protests, the promise my grandparents made. To my loving husband and partner in crime, Jeremy Floyd, without your patience, understanding, support, and companionship this work would not have been possible. And finally, to our son, Oscar Steven, you gave me a surge of motivation when completing this work every time I felt you kicking around in my stomach. I hope to make you proud.

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CHAPTER ONE

INTRODUCTION: DIGITAL LEARNING AND ITS ROLE IN TECHNOLOGY EDUCATION

Increasingly, the demand for a highly skilled workforce has been front and center among media outlets, legislative initiatives, and political speeches. Two-year technical and community colleges continue to play a key role in providing new and expanding industries with the highly skilled workforce they require in a short period of time. However, the expansion of exceedingly sought after technical programs at two-year colleges has not kept up with demand from local industry. Online and hybrid education have often been proposed as a solution for increasing capacity at two-year colleges without the need of a brick-and-mortar investment. Enrollments in online courses have continued to increase at a higher rate than higher education enrollments (Allen & Seaman, 2011). Allen et al. (2011) also found that 31% of all higher education students took at least one course online during 2011. Although online courses have expanded greatly at South Carolina technical and community colleges, options providing contextual hands-on learning in technology education are rare.

According to a report by the Georgetown University Center on Education and the Workforce, by 2018, South Carolina will have 630,000 vacant jobs due to job creation and worker retirement (Carnevale, Smith & Strohl, 2010). Of these vacancies, 56% will require a postsecondary education (Carnevale et al., 2010). Indeed, labor statistics seem to bear this out; South Carolina job growth for 2007 was at its highest rate in six years, up 2.3 percent to more than 1.95 million. Capital investment in South Carolina grew by 35 percent during the same year to more than $4 billion, representing more than 15,000 new jobs. A more recent study showed that since the recession in 2007, 11.5 million jobs have been added and of those, 1.3 million require an associate's degree or some college education (Carnevale, Jayasundera, & Gulish, 2016). The report also notes that manufacturing added 1.7 million jobs since the recession with the largest gains experienced in wood products manufacturing, automotive manufacturing, and fabricated metal products manufacturing (Carnevale et al., 2016).

The projections for technical jobs also show an increase in available employment. For aircraft mechanics and service technicians in South Carolina, employment opportunities are projected to increase 10% from 2008 to 2018, higher than the national average of 6% increase (Career One Stop, 2012). From 2014 to 2024, this this projection is leveling out at 2% higher than the national increase of 1% (Career One Stop, 2017). Similarly, employment opportunities for automotive and service technicians and mechanics in South Carolina are projected to increase by 8% from 2008 to 2018 (Career One Stop, 2012). From 2014 to 2024, this increase will continue at 6% higher than the national increase of 5% (Career One Stop, 2017). Additionally, manufacturing and production employment opportunities show a promising increase from 2014 to 2024, as follows: production worker jobs increase by 12% vs. 3% nationally, industrial engineering technician job increase 5% vs. a 5% decrease nationally, and industrial machinery mechanics 24% vs. 18% nationally, to name a few (Career One Stop, 2017). In 2011 alone, manufacturing and production occupations totaled over 170,000 (U.S. Department of Labor, Bureau of Labor Statistics, 2012). Clearly, the technical and community colleges in South Carolina must meet this growing demand by ensuring that it produces a well-educated and qualified technical workforce.

Technology programs at two-year colleges prepare their students in a traditional face-to-face classroom environment. These programs' growth is constrained by instructor, classroom, laboratory, and equipment availability. Although online or hybrid course formats are common in non-technical courses at technical and community colleges, they may offer a similar increase capacity in technology program courses as well. The addition of web-based hands-on visualization can also enables class size to as much as double, with one group of students learning through online lectures and visualization lessons and tasks while others are working in the available laboratory space. Technology advances now make it possible for off-site access which will increase accessibility and provide more flexible scheduling for students (anytime, anywhere).

Over the past decade, instructional technologists have developed numerous technology-based devices with improved efficiency and effectiveness, ushering in a revolution in education and workforce preparedness (Gramopadhye, Melloy, Chen, & Bingham, 2000; Held & Durlach, 1993; Song, Balamuralikrishna, Pilcher, & Billman, 2001; Huk & Flotto, 2003; Nalanagula et al., 2004; Sadasivan et al., 2004; Goldsby & Watson, 2000, National Academy of Engineering, 2012). Their use in technical education has yet to be fully realized, however (National Academy of Engineering, 2012). Some research has shows that education supplemented with simulation and 3-D visualization helps students learn faster and retain knowledge longer (Hewitt, 1991; Turkle, 1995; Kozma, 1997; Dede, Salzman, Loftin, & Ash, 1997; Moreno & Mayer, 2001; Torres, Candelas, Puente, Gil, & Ortiz, 2006; Smith et al., 2007; Crane, 2008; Rupasinghe, 2009; Ashoori, Shen, &Miao, 2009; Rupasinghe, Kurz, Washburn, & Gramopadhye, 2010). Although technical and community colleges have persistently adhered to traditional educational delivery modes, we now find them ready to embrace quality e-learning. The National Academy of Engineering (NAE) considers dissemination of e-learning tools to technical/community colleges to support technical of STEM education to be of the highest priority (National Academy of Engineering, 2012).

Therefore, an alternate pedagogical and technological approach is proposed: student-centered e-learning content with visualization and simulation tools that would enhance hands-on learning. This model addresses two grand challenges for engineering and engineering technology as described by the National Academy of Engineering (2012): i) the advancement of personalized learning, which moves from a generic type of educational style to one with more innovative, engaging, computer enhanced teaching techniques; and ii) the enhancement of virtual reality to create imaginative environments for education and entertainment.

Research Objectives

It is clear that online education is becoming, for many, the primary way to advance their education. The objective of this research is multifold. First, the impact and pedagogical effectiveness of the use of e-learning modules and the accompanying simulation and visualization tools for students in technology programs on cognitive and psychomotor performance will be evaluated through experimental studies. Second, this research will develop a mapping of the transfer effects of the use of simulation and visualization tools to specific learning outcomes and their mastery level for both cognitive and psychomotor domains. Next, this research seeks to provide insight into the usability, perception of learning and acceptance of e-learning, simulation and visualization tools for education by the learners.

Research Activities

In order to address the objectives described in the previous section, the primary activities for this research are outlined below:

(1) A literature review focusing on the following areas:

a. Overview of the current state of online learning in technology programs.

b. Simulation and visualization tools applied in education with an emphasis in technical education and skills training.

c. Studies on transfer effects literature with an emphasis in simulation and visualization applications.

(2) Two quasi-experimental studies to:

a. Evaluate the impact and pedagogical effectiveness of the digital learning environment integrated with visualization tools for students in technology programs in comparison to conventional face-to-face instruction.

b. Map the impact and pedagogical effectiveness of the digital learning environment integrated with visualization tools for students to specific learning outcomes and their mastery level.

c. Determine the software usability, perception of learning and acceptance of e-learning simulation and visualization tools for education by the learners.

(3) A third qualitative analysis conducted through interviews to understand the transfer of previous knowledge and new instruction to a complex hands-on task.

Conclusion

As the demand for a skilled workforce increases, two-year institutions will have to provide innovative solutions that deliver quality education and a substantial number of employable workforce applicants. Utilizing technology to meet this demand can provide the answer to the expansion of classrooms. Technology, however, can also be disruptive and inefficient. This research hopes to provide insight in the effectiveness of a new model for developing online technical education through the use student-centered content supported by simulation and visualization tools.

CHAPTER TWO

LITERATURE REVIEW

"I have long held the belief that education and technology are the two great equalizers in life."

- John Chambers (2010)
Chairman & CEO of Cisco Systems Inc.

This research will explore two varied fields that today have reached an interesting coming together – distance education and virtual reality. Distance education, in its most basic definition, started during the ninetieth century to provide educational opportunities through correspondence (Watkins & Wright, 1991). Since then, distance education has seen four additional incarnations: broadcast radio and television, open universities, teleconferencing, and finally, the internet or world wide web (Moore & Kearsley, 2012).

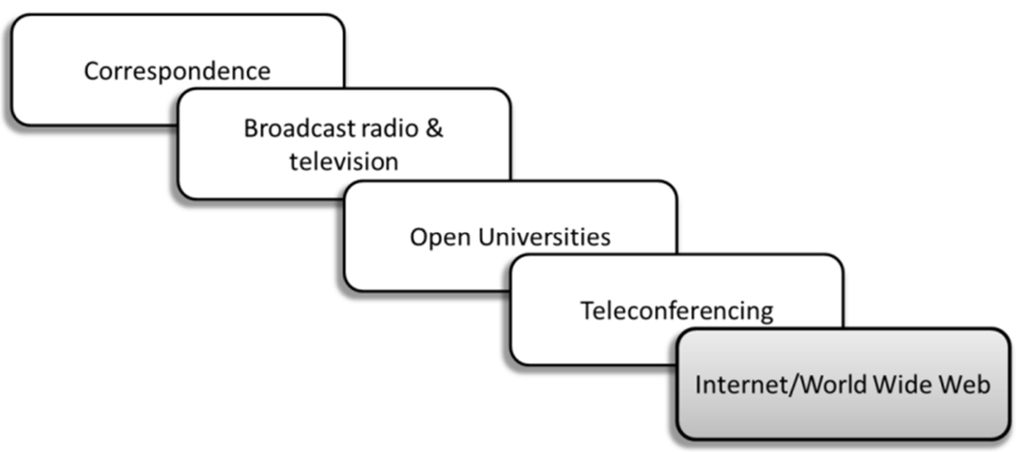


Figure 2.1. Five incarnations of distance education (adapted from Moore et al., 2012)

Correspondence through distance learning came about from a need to supplement summer school education at a four year college (Scott, 1999). This method also provided access for to women of all classes in society to an education (Ticknor, 1891). As technology has continued to advance, distance education has included other modalities for learning which include: broadcast radio and television (Watkins et al., 1991; Pittman, 1986; Langdon, 1988; Levenson, 1945; Corporation for Public Broadcasting, 1981), open universities (Tunstalls 1974; Ferguson 1976; Perry, 1997; Koul, 1990), teleconferencing (Curtis & Biedenbach, 1979; Martin, 1993; Worley, 1993), and, more recently, the internet or world wide web (Halverson, Graham, Spring, & Drysdale, 2012; Tseng and Walsh, 2016; Harjoto, 2017).

Since the introduction of the first personal computer, the Altair 8800, to the market, computer based instruction has been able to expand to what it is today (Moore et al., 2012). In 1989, 15% of households in the United States had a personal computer (U.S. Bureau of the Census, 1990). In 2010, 77% of households have internet access (Miniwatts Marketing Group). Just as the previous four technologies matured, distance learning has taken full advantage of this emerging technology to increase access, support recruitment, and advanced education to various diverse, and otherwise, isolated populations.

Similarly, virtual reality applications have come a long way from its initial conceptualization. Dating back to the 1960's, virtual reality was first designed by Morton Heilig for entertainment in a video arcade device named Sensorama Simulator (Burdea & Coiffett, 2003). In 1971, early models of haptic devices had been developed (Batter and Brooks, 1971). By the 1980s, the military took a particular interest in virtual reality technologies to provide software simulations of their current expensive flight simulators. This provided the first educational/training application of virtual reality components.

Since then, software based virtual reality simulations have been implemented in various fields and have resulted in devices that enhance the virtual reality experience. Virtual reality, applicable to this research, is best defined by Cruz-Niera (1993) as “immersive, interactive, multi-sensory, viewer-centered, three-dimensional computer-generated environments and the combination of technologies required to build them.” For this purpose, the user must be able to aptly interact, manipulate, and receive feedback from the virtual objects/environment.

Human factors research in virtual reality environments and tools have also evolved as the technology has matured. Three areas of human factors research were identified by Stanney, Mourant, and Kennedy (1998) as: user performance and system usability, health and safety issues, and virtual reality societal implications (Figure 2.2).

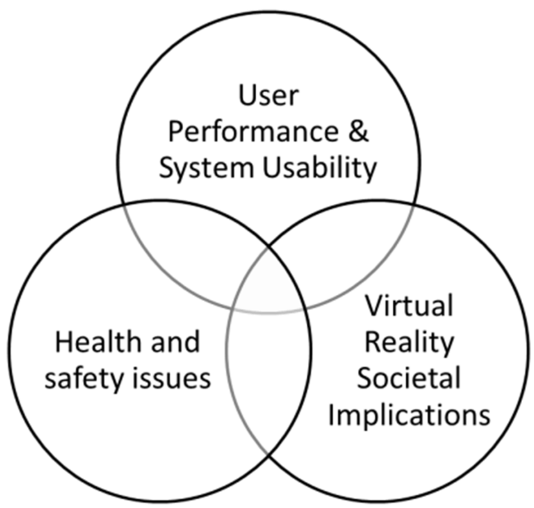


Figure 2.2. Areas of human factors research in virtual reality (adapted from Stanney, et al., 1998).

Various human factors research studies have taken place and test one, two or all three areas Stanney et al. (1998) have identified. For example, Bowman, Johnson and Hodges

(2001) developed an environment which contained various obstacles that participants had to travel through and avoid using different interaction techniques. In this case, performance would help determine the best interaction technique for this particular virtual environment. Similarly, Watson et al., (1998), Ranadive (1979), Massimino and Sheridan (1989), and Piantanida, Bowman and Gille (1993) investigated the effect on participant performance based on refresh rate (frames/sec). These studies fall primarily under the user performance and system usability category of human factors research.

In the area of health and safety, researchers may have tested how virtual reality can affect health and safety of participants to understand the causes of these issues. The virtual reality environments may have direct effects on the visual system through the use of lasers that can cause retinal damage (Kestenbaum, 2000) or bright light that may cause users to develop migraines (Viirre and Bush, 2002). VR can also have a direct impact to the auditory system by simulating noise levels above 115 dB for more than 15 minutes/day (U.S. OSHA). And finally, they can have an effect on the musculoskeletal system like those resulting on the misuse or overuse of haptic devices that can cause tendonitis, carpal tunnel syndrome, and other types of inflammation. Motion sickness is another possible health issue that can be encountered during the use of virtual reality simulations which is theorized to be caused by neural conflict involving the vestibular sensors (Lathan, 2001; Stanney, Mourant, & Kennedy, 2002; Harm, 2002). Other research involving health and safety includes adaptation and aftereffects (Welch, 2002) where adaptation is a "semi-permanent change of perception and/or perceptual-motor coordination that serves to reduce or eliminate a registered discrepancy between sensory modalities or errors in behavior induced by this discrepancy" (Welch 1978). DiZio and Lackner (2002) investigated adaptation and its aftereffects and concluded that a user may experience including "deviated body movements, erroneous estimation of external forces on the body, and even auditory mislocation." In a real world application, Welch (2002) found that delay as an aftereffect of exposure to VR simulations can have a profound effect when a user's corrective response is needed to protect their safety and the safety of others. Welch used the example of an oil tanker operator. Although research described in this dissertation will not involve crucial actions, this adaptation and aftereffect must be considered in further iterations.

Finally, researchers have investigated the role of virtual reality as it impacts social issues and as it relates to professional, public, and private life. Burdea & Brooks (2003) argued that, professionally, virtual reality can increase productivity, allow for more teamwork and expert consultation, provide an alternate for long commuting, and have positive effects on family life. Various researchers have also looked at the effect of virtual reality on public life. For example, Franzen (2000) and Clavert (2002) showed that the internet and virtual reality has the potential to both foster a stronger societal interaction, as well as have adverse effects on social interaction. Although there are cases where the internet and virtual reality has been found to be addictive, these can mark a "positive substitute for drugs in pathology cases and is already used clinically to alleviate symptoms of phobia, anxiety, and other psychiatric disorders" (Hodges et al., 2001; Burdea & Brooks, 2003). Thus, this is a question of use of these activities in moderation. Impact on public life has also been documented by various researchers. Participation in online communities may have a positive impact on interaction with a large number of people than that experienced through text messaging or in 2D world with limited interaction (Schroeder, 1997).

Virtual Reality and Education

In 1995, Psotka explored the use of virtual reality in education and training updating the previous overview of intelligent tutoring and computer based instruction completed by Nickerson & Zodhiates (1988). Technology and use of virtual reality components has had an exponential improvement over the last three decades. Among the studies current to that time, Psotka foresaw various elements of learning and training that had the potential of advancement and growth. Among these are VR and intelligent tutoring systems, VR simulations, situated learning through VR, networked virtual reality, and edutainment or gamification. The following addresses Psotka's prediction for future application and current status for each.

VR and intelligent tutoring systems. Postka (1995) envisioned an intelligent tutoring system that served as "ghost presence… [that] can interact with a student through digital speech, through text that floats in the air, or through replays." Since then, VR and intelligent tutoring systems have appeared in commercially available software and have shown to effectively scaffold learning in well-structured tasks (Shute & Psotka, 1996; Koedinger, 2001; Aleven & Koedinger, 2002; Azebedo & Hadwin 2005; Feng & Heffernan, 2007).

VR simulation. VR simulations have been around for a quite some time in multi-user dungeons and microworlds (Psotka, 1995). Current simulations have improved due to better graphics and computing power, increased interactivity, and advancement in equipment.

Situated learning through VR. Postka (1995) reasoned that VR provides development of a relationship between learning and experience; experience that is both social and perceptual and conducive to learning (Vygotsky, 1978). This reasoning is also consistent with research emphasizing problem based learning (Brown, Collings, & Duguid, 1989; Nasr & Bassem, 2008; Barge, 2010; Allen, Donham, & Bernhardt, 2011; Lou, Shih, Diez, & Tseng, 2011; Ehlert, 2004).

VR as a means for edutainment and gamification. Postka said it best when he wrote:

> "The convergence of technology and entertainment has enormous potential consequences for education, particularly in the form of simulation games that have been branded edutainment, from the synthesis of video games, and educational simulations. There is a vibrant creativity in the development of these games that promise rich fantasy experiences that liberate imagination and promote probing explorations of new hypotheses and great quantities of information."

According to Deterding et al. (2011), gamification is the use of game mechanics for applications that are non-game related. Gamification through VR is only one of the forms that this practice can take. Currently, digital forms of edutainment and gamification have become notable fields in epistemology as they transform teaching and learning into a more engaging environment (Pavlus, 2010) with personalized fast feedback (Flatla et al., 2011) that can raise motivation (Shneiderman, 2004; Muntean, 2011) and attention (Von Ahn and Dabbish, 2008). Although many, including Vygotsky, would argue that there needs to be social interaction, Fogg (2002) showed that participants can learn from computers as if they were persons, specifically when gamification is applied. Fogg also found that participants respond to games within the same social structure that they are accustomed to in the real world. They follow social rules and develop feelings. Fogg (2009) later developed the Fogg Behavior Model for persuasive products (games, videos, social networks, etc.) that include three factors: (1) motivation, (2) ability, and (3) triggers.

Research related to effectiveness of virtual reality as an educational tool has covered a wide variety of disciplines: to convey abstract scientific concepts (Dede et al., 1997), to determine effectiveness for aircraft maintenance technicians (Dorlette-Paul, 2010; Rapasinghe et al., 2011), to improve operating room performance (Seymour et al., 2001; Lehmann et al., 2005), to assist students with learning disabilities acquire skills (Cromby et al., 1996; Hall, Conboy-Hill, & Taylor , 2011), to improve physical fitness (Mantovani & Castelnuovo, 2003; Rizzo & Kim, 2005; Lotan, Yalon-Camovitz, & Weiss, 2010), to rehabilitate victims of stroke and other neurological conditions (Mirelman, Bonato, & Deutsch, 2009). The most common example of virtual reality effectiveness involves tested flight performance. Donching, Fabiani, & Sanders (1989) had a control group of Israeli Air Force cadets and treatment group training with the game Space Fortress. As it turns out, flight performance of the treatment group was significantly better than those in the control group. The authors noted that the game was later incorporated into the Israeli Air Force regular training program.

In all, "the objective of training using games and simulators, of course, is to achieve greater positive transfer than slower, more costly, or more dangerous training methods, often relying on real-world technologies" (Alexander, Brunyé, Sidman, & Weil, 2005). Another important comparison between training methods is time. Roscoe & Williges (1980) developed two transfer of training formulas. First, the percent transfer formula measures the ratio of time, trials or errors saved using virtual reality training versus real-world training.

$$\text{Percent transfer (Roscoe \& Williges, 1980)} = \frac{Y_x - Y_0}{Y_0} \times 100, \qquad (2.1)$$

where, Y_0 is the control group's score, time, trials, or errors to reach a certain criterion after zero training units prior or interpolated, and Y_x is the experimental group's time, trials, or errors after having received X training units on a prior or interpolated task. A more useful percent transfer formula for this research developed by Ellis (1965)

$$\text{Percent transfer (Ellis, 1965)} = \frac{L_x - L_0}{T - L_0} \times 100, \qquad (2.2)$$

where, L_x is the average learning of a control group after zero training units on a prior or interpolated task, L_x is the average learning of an experimental group after having received X training units on a prior or interpolated task, and T is the total possible score on the transfer task. And finally, Murdock (1957) developed a percentage of transfer formula that yields a symmetrical transfer curve with definite lower and upper limits of -100% transfer and +100% transfer.

$$\text{Percent transfer (Murdock, 1957)} = \frac{Y_0 - Y_x}{Y_0 + Y_x} \times 100, \quad (2.3)$$

where, Y_0 is the control group's time, trials, or errors to reach a certain criterion after zero training units prior or interpolated, and Y_x is the experimental group's time, trials, or errors after having received X training units on a prior or interpolated task. These formulas are able to communicate effectively the overall picture of the percent transfer between control and treatment group. However, Roscoe & Willigens (1980) argued that they fail to consider prior knowledge and the amount of practice on the prior task. Additionally, they do not permit any conclusions about the effectiveness of transfer.

Transfer effectiveness is just as important to understand as percent transfer. There are two measures of transfer effectiveness that apply to this work: incremental transfer effectiveness and cumulative transfer effectiveness. In other words, what happens to learning as more and more training is incorporated. This is especially important in answer the questions (1) how much VR training is enough? and (2) can too much VR training negatively affect performance? For example, in verbal language learning McGeoch (1929) found that "in terms of saving score, retroactive inhibition [interference] varies inversely as the number of presentation given the material to be learned." As such, Roscoe & Williges (1980) introduced the Cumulative Transfer Effectiveness Function (CTEF) and the Incremental Transfer Effectiveness Function (ITEF). CTEF is the curve resulting of the "rations of total savings on the criterion task to total time spent on the prior or interpolated tasks are plotted." ITEF is the "curve that results when the incremental relative savings in learning a criterion are plotted to successive increments of pertaining or interpolated training on another task." Both formulas are described below.

$$\text{CTEF (Roscoe \& Williges, 1980)} = \frac{Y_0 - Y_x}{X}, \tag{2.4}$$

where, Y_0 is the time, trials, or errors required to reach a performance criterion by an the control group, Y_x is the measure for an experimental transfer group having received X training units on a prior or interpolated task, and X is the time, trails, or errors during prior or interpolated practice on another task.

$$\text{ITEF (Roscoe \& Williges, 1980)} = \frac{Y_{x-\Delta X} - Y_x}{\Delta X}, \tag{2.5}$$

where, $Y_{x-\Delta X}$ is the time, trials, or errors required to reach a performance criterion by an experimental transfer group having received $X - \Delta X$ training units on a prior task, Y_x is the measure for an experimental transfer group having received X training units on a prior or interpolated task, and ΔX is the incremental unit of time, trails, or errors during prior or interpolated practice on another task. Additional cost effectiveness measures can also be derived from these calculations.

Knowledge Transfer

Before a discussion of knowledge transfer is established, it is important to understand the type of knowledge that a student possess and acquires through instruction. First, Eraut (2009) explains, before students receive instruction they possess cultural and personal knowledge. Cultural knowledge is often acquired through social interactions which influences behavior. Personal knowledge and capabilities, Eraut (1997, 1998) defines as “what individual persons bring to the situations that enable them to think, interact, and perform.” The effects of personal knowledge can be then separated to that of knowledge presented from instruction. According to Eraut (2009), educational programs provide five kinds of knowledge: (1) Theoretical knowledge: “concepts and theories to help students explain, understand and critique occupational practices and arguments to justify them." (2) Methodical knowledge: "how evidence is collected, analyzed and interpreted in academic contexts and in occupational context, and the procedural principles and theoretical justifications for skills and techniques in the occupational field" (3) Practical skills and techniques: those "acquired through skills workshops, laboratory work, studio work, project work, etc. (4) Generic skills: "basic skills in number language and information technology, modes of interpersonal communication, skills associated with learning and thinking in an academic context, and self-management skills." (5) General knowledge: information "about the occupation, its structure, modes of working, cultural values and career opportunities." This work will focus on the transfer of theoretical knowledge, methodical knowledge and practical skills and techniques.

Early transfer theories stated that transfer would only occur if simulated task and real tasks had common elements (Thorndike, 1906; Thorndike & Woodworth, 1901). Since then, various researchers (e.g., Singley & Anderson, 1989) have suggested that this theory is too constrained and thus proposing that transfer can also be effective when simulated tasks have similar logical or deep structures (Lehman, Lempert, & Nisbett, 1988). Detterman, Strenberg, & Turnure (1993) provided a definition of transfer which states that transfer occurs when a desired behavior will be replicated in a new situation. Eraut (2009) also describes transfer similarly as "the learning process involved when a person learns to use previously acquired knowledge/skills/competence/expertise in a new situation." There are also various levels at which transfer takes place: (1) simple application: just one or a few pieces of knowledge were relevant to new situation (2) situational adaptation: utilizing the current situation to match to a previous encountered problem (Klein, 1989) (3) problem solving: a plan must be devised following known principles (Eraut, 2009). Detterman et al. (1993) also broke down transfer into several categories near/far transfer, specific/non-specific transfer, and vertical/lateral transfer. Near/far transfer occurs when a new situation is similar or dissimilar to a task previously seen during instruction or in their personal or cultural knowledge. Specific/non-specific transfer occurs when the context of the situation has been explored during instruction or in their personal or cultural knowledge. If it has, transfer is specific. If it has not, transfer is non-specific. Finally, vertical/lateral transfer occurs when knowledge is spread among various situations but still uses one skill set (lateral); or, the participant must navigate between various skill sets and utilize those skills within a small number of situations.

Theoretical Framework

To assist with developing research hypothesis, this work will utilize the situated learning and Vygotsky's theories, in particular the zone of proximal development. Vygotsky (1978) aimed to discover how skills begin to develop. Vygotsky understood that a learner must have a basic knowledge of tools and signs or symbols that are used in our environment. Although this terminology was used for language (spoken and written) it is applicable to particular disciplines. Vygotsky described the beginnings of skill development as "those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in embryonic state". He later termed this stage as 'buds' or 'flowers', and not yet 'fruits'. Figure 2.3 shows Vygotsky's Zone of Proximal Development (ZPD). Vygotsky (1978) defined the Zone of proximal development as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers.”

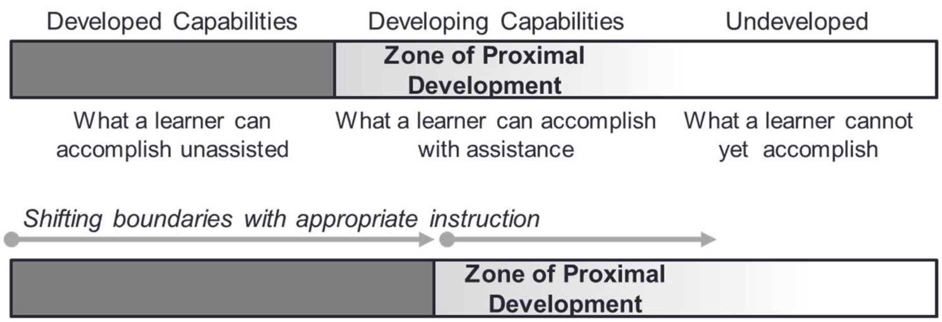


Figure 2.3. Vygotsky Zone of Proximal Development (adapted from Driscoll 2005)

At any given time, a learner has developed capabilities, developing capabilities, and undeveloped capabilities. Within the zone of proximal development, a learner can accomplish certain tasks with assistance. Thus, the zone of proximal development should be considered a “dynamic construct that addresses … human learning” (Doolittle, 1997). In the same context, the size of the zone of proximal development is not a fixed property of an individual that remains constant (Chaiklin, 2003). The size of the ZPD may lengthen or shorten based on the individual’s capabilities, the complexity of the task, the level of mastery, among other factors.

With appropriate instruction, the boundary between the developed capabilities and the developing capabilities – the zone of proximal development – shifts. This type of instruction can take the form of play, formal instruction or work and still provide shifting boundaries (Vygotsky 1978, Wertsch 1985). Vygotsky meant this instruction to be a social interaction, either with a peer or an instructor. However, as noted earlier, Fogg

(2002) showed that participants can learn from computers as if they were persons. The assistance provided during the zone of proximal development is consistent with the notion of scaffolding as a supportive tool for learners as they develop knowledge (Greenfield, 1984; Wood, Burner, & Ross, 1976). Once a learner has developed all capabilities, they have mastered the skill.

Hung and Chen (2001) identified four dimensions based on situated cognition and Vygotskian thought that must be applied to e-learning environments: situatedness, commonality, interdependency and infrastructure. *Situatedness* involves development of e-learning environments with rich contexts of practices that enable learners to acquire implicit and explicit knowledge (Brown and Duguid, 1996). When c*ommonality* is provided to a community of learners, they are able to participate and work together in a manner that works for them, thus emphasis joint effort (Lave and Wenger, 1991) that Hung and Chen (2001) argue, should be demand driven, thus there should exist an *interdependency* between the learner and the virtual or e-learning environment. Finally, the e-learning environment must have the necessary *infrastructure* to facilitate experiences and the learner must be accountable for their own learning. Hung and Chen (2001) also laid out various implications based on these four dimensions which will be address in Chapter Four of this work. Situated cognition and Vygotskian thought work with the notion that a learner and their environment form a whole, and as such, the relationship between the two must be active, interactive, and adaptive and should focus on the experiences that is able to change both (Maturana and Varela, 1987; Bickhard, 1992; Dewey and Bentley, 1949).

CHAPTER THREE

A PILOT INVESTIGATION ON THE EFFECTS OF DIGITAL LEARNING INTEGRATED WITH VISUALIZATION TOOLS ON PERFORMACE IN COGNITIVE AND PSYCHOMOTOR ASSESSMENTS

"If a picture is worth thousand words, then an interactive 3D model is worth a thousand pictures."

- Jack Morgan (1997)

Educational resources and technology are constantly changing causing learning to take place in a variety of learning modalities. This experimental study focuses on two of these modalities. The first is the conventional or face-to-face instruction. This instruction method is most used at technology programs and includes a lecture, in-class activities, and interactions between instructor and participants, as well as between participants. The second modality used in this experimental study was digital learning integrated with visualization tools. The digital learning environment provides users the opportunity to engage in active learning through visualization tools with authentic scenarios. The purpose of this investigation is multi-fold: First, this research study serves as a pilot and will aid in informing the development for a larger and more in-depth analysis proposed in Chapter Four and serve as a blueprint for testing of digital learning modules in other domains.

For this experimental study, participants were introduced to an introductory lesson about metrology, the science of measurement, and how to properly manipulate and read measurements using three popular linear measuring instruments: the scale, the Vernier caliper, and the micrometer.

Research Hypotheses

Fogg (2002) showed that participants can learn from computers as if they were persons, thus digital learning can provide the same scaffolding effect as conventional instruction. Furthermore, literature has shown a positive and significant relationship between learning outcomes and transfer (Ford et al., 1998), which in laymen's terms implies that after instruction, participants had a sense that they learned. More interesting, however, is the question of whether groups that performed significantly different also have a different perception of learning. Thus, the hypotheses for this study are as follows:

Hypothesis 1: The digital learning group will perform at least as well as the conventional learning group in normalized gains post treatment.

Hypothesis 2: The digital learning group will score at least as well as the conventional learning group in the skilled-based assessment.

Hypothesis 3: The digital learning group will score at least as well as the conventional learning group in the perception of learning measures.

METHOD

Participants

Technical college students enrolled at Greenville Technical College in three courses or programs were targeted: MAT 101, MAT 155, and Auto Body Certificate and recruited through emails. These mathematics courses were targeted based on the level of math often required by technology programs at Greenville Technical College. The students in the Auto Body program were also recruited due to their technical interest and because they are not taught to use analog versions of the Vernier caliper and micrometers. An email blast (Appendix A) was sent to the students enrolled in these programs. This provided them a link to an online registration. The online registration also included a general questionnaire (Appendix B) for the purpose of collecting demographic information and level of mastery of precision measuring instruments. Those participants that were ineligible for the study due to high level of mastery received an email informing them of their ineligibility (Appendix C). In total, 28 participants completed the study: 13 males and 15 females between the ages of 19 and 72 (M=33.8, SD= 13.55).

Apparatus

All participants were provided a notepad, a pen and a pencil. During instruction, participants in the conventional instruction also had access to various precision measurement tools: two Vernier calipers (0-150mm and 0-300mm); four outside micrometers (0-25mm, 25-50mm, 50-75mm, and 75-100mm); four inside micrometers (0-25mm; 25-50mm; 50-75mm; 75-100mm); and one depth micrometer (0-50mm). These instruments were also used in the skilled-based assessment for both groups.

Participants in the digital learning group viewed recorded lectures and interacted with virtual reality components using a computer equipped with a 17” monitor with a resolution of 1280x1024 pixels and were provided with a keyboard, a mouse, and headphones. Lectures were recorded and delivered using Echo360 software and the web-based virtual reality components were developed using Unity3D version 3.

Independent variable

The independent variable for this study was the mode in which instruction was delivered: conventional or digital learning. The conventional learning mode is a face-to-face method of instruction. This mode represents a 90 minute lecture from an automotive technology instructor with over 20 years of industry and teaching experience. The instructor delivered instruction materials currently being used to teach student enrolled in the Automotive Technology program the use of these precision measuring tools. During the lecture, the students had access to the precision measuring tools and they are allowed to ask questions.

The digital learning mode is a web-based method of instruction that includes interactive virtual representations of the precision measuring tools. Participants watched three videos totaling 90 minutes of instruction. Figure 3.1 shows examples of the recorded lectures. This mode also includes virtual reality precision measuring tools. The materials used in these videos and the virtual reality components were developed through a National Science Foundation Advanced Technological Education grant (DUE 1104181) and have been vetted by various instructors in different technology programs. Figure 3.2 shows the virtual reality precision measuring tools participants utilized: the scale, the Vernier caliper (inside, outside, and depth, and the micrometer (inside, outside and depth).

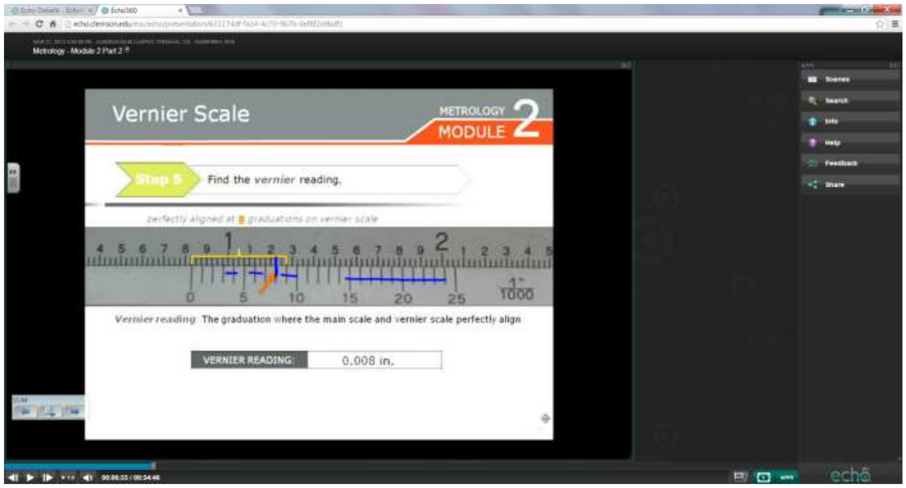
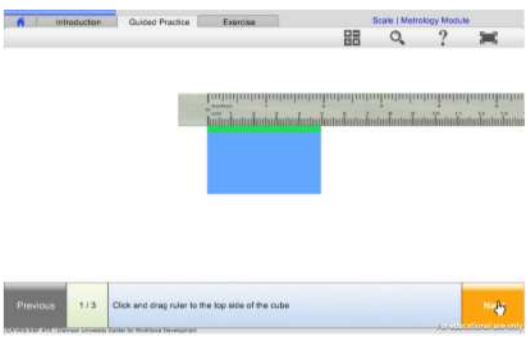
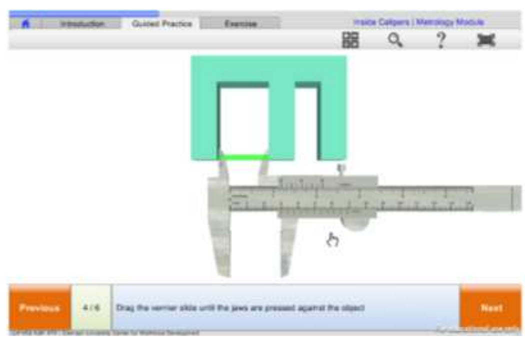


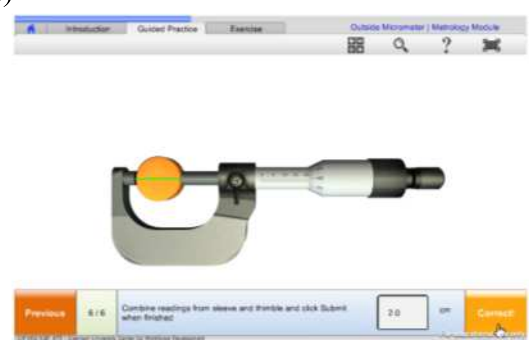
Figure 3.1. Examples of the recorded lectures



(a)



(b)



(c)

Figure 3.2. Virtual reality precision measuring tools: (a) the scale, (b) the Vernier calipers, and (c) the outside micrometer

Other independent variables that will be collected using the general questionnaire (Appendix B) included gender, age, race and ethnicity.

Dependent Variables

Six measures of interest were collected for the study. The first three measures were based on the participant's performance on the pre- and post- cognitive assessment (Appendix D and E, respectively), and a skilled-based performance assessment post treatment (Appendix F). The fourth measure, perception of learning, was collected using an instrument adapted from Hiltz (1988) (Appendix G). This instrument contains four constructs: (1) interest, (2) communication of topic, (3) critical thinking and (4) overall perception of learning. Each was measured using a Likert scale ranging from 1 to 5, with 5 indicating strong agreement.

Three additional measures were collected from the digital learning group. This was primarily done to understand the issues associated with the digital learning platform. These included a usability measure collected through the IBM designed Computer Usability Satisfaction Questionnaire (Lewis, 1995) (Appendix H); a technology acceptance measure collected using the technology acceptance instrument adapted from Saadé and Bahli (2005) (Appendix I); and workload indices were collected using NASA TLX (Hart & Staveland, 1988) (Appendix J). Figure 3.3 shows the experimental study and the instruments each group completed.

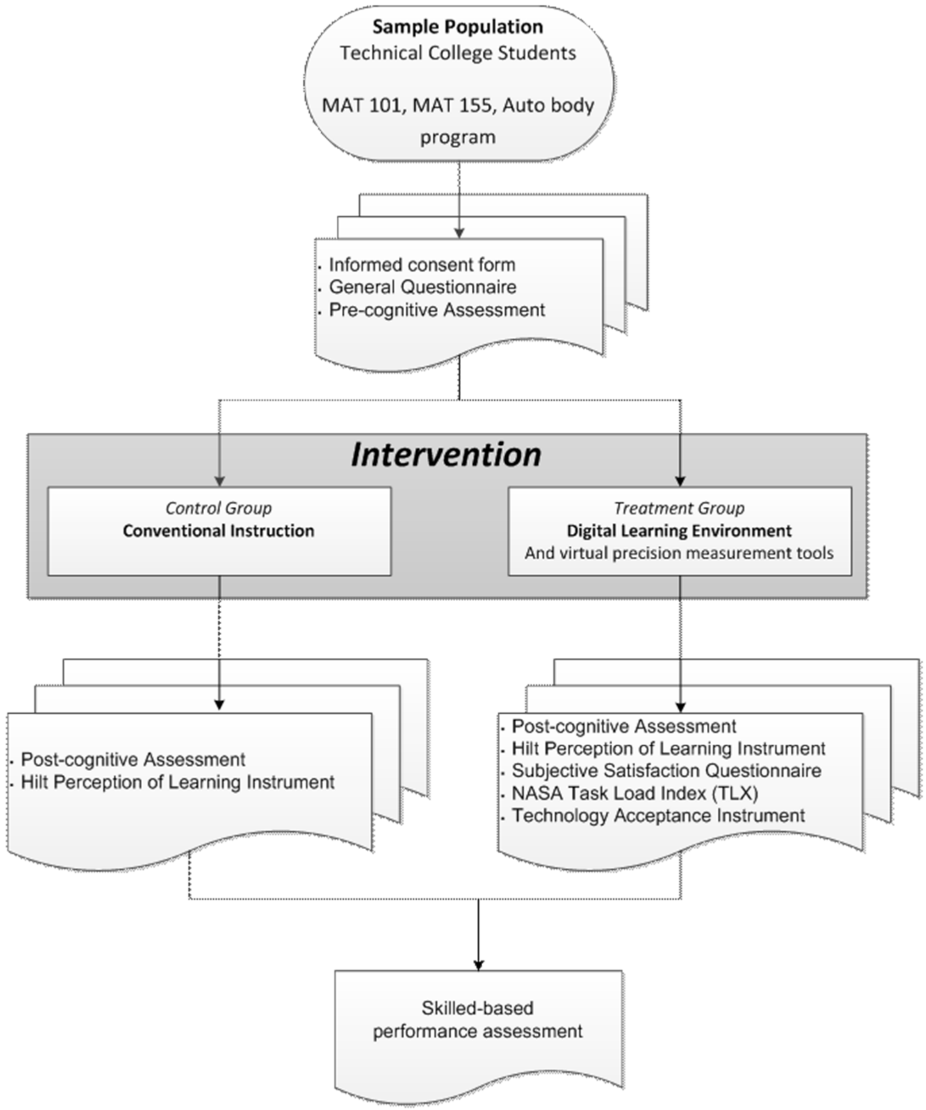


Figure 3.3. Experimental study flowchart

Performance Assessment Instruments: The pre- and post- cognitive assessment and the skilled-based assessment were developed through an iterative process with three automotive technology instructors at Greenville Technical College, an instructional designer, and the researcher. There are ten questions in the pre- and post- cognitive assessments, and six scenarios in the skilled-based performance assessment.

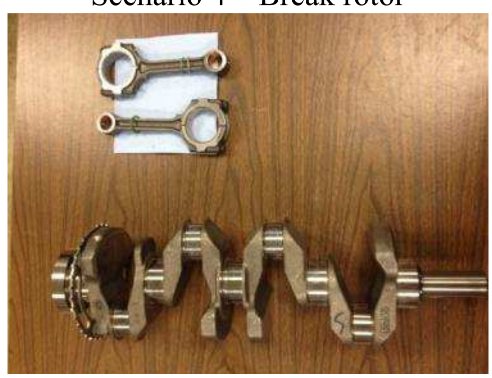
Scenario 1 – Piston & Pin

Scenario 2 – Valve stem

Scenario 3 – Break drum

Scenario 4 – Break rotor

Scenario 5 – Engine block



Scenario 6 – Cam shaft and pistons

Figure 3.4. Images of components utilized in the skilled-based assessment

The questions were developed using two Bloom's Taxonomy domains of learning: Cognitive and Psychomotor. Appendix K and L show the breakdown of each question and how they map to each of Bloom's Taxonomy domains. Figure 3.4 shows images of the components used in the experiment by scenarios. Participants were able to choose from the instruments described in the apparatus section to complete measurements on each of the scenarios.

Experimental Task

The study used a between-subjects experimental design. Participants were exposed to one of the two conditions to be investigated:

Group 1: Control condition – conventional instruction method

Group 2: Treatment condition – digital learning integrated with visualization tools.

To minimize differences between the two groups, participants were assigned to each group using their cumulative GPA as a measure for the pre-test and through random assignment paired participants with similar GPAs to each group.

Procedure

After students were selected for the study, they were placed in one of two groups based on GPA. The research study took place at Greenville Technical College's McKinney Regional Automotive Technology Center in Greenville, SC.

For the control condition, participants were given a specific time to arrive to the center. Participants were provided the consent form (Appendix M) and asked to verify the information they submitted via the registration form. Once all students that had confirmed participation were present, the group, usually of three to seven participants, was placed in an automotive technology classroom to complete a pre-cognitive assessment (Appendix D). After the instruction, participants completed the post-cognitive assessment (Appendix E), as well as the perception of learning instrument. Finally, in a separate classroom, students completed the skills-based assessment individually (Appendix F). At the completion of the study, participants received a $25 gift card.

For the treatment condition, participants were given a range of time to arrive at the computer laboratory at McKinney Regional Automotive Technology Center. Participants were provided with the consent form (Appendix M) and asked to verify the information they submitted via the registration form. Once a student had confirmed the information, they completed the pre-cognitive assessment (Appendix D). After instruction and interaction with virtual precision measuring tools, participants completed the post-cognitive assessment (Appendix E), the perception of learning instrument (Appendix G), the subjective satisfaction questionnaire (Appendix H), the technology acceptance questionnaire (Appendix I), and the NASA TLX (Appendix J). Finally, in a separate classroom, the student completed the skills-based assessment individually (Appendix F). At the completion of the study, participants received a $25 gift card. The entire study took on average four and a half hours per participant to complete.

RESULTS

The demographic characteristics of all the participants in the study are presented in Table 3.1.

Analysis

SPSS 21.0 was used to analyze the data on the dependent variables: normalized gains, total score of the skilled based assessment, and perception of learning instrument. A Shapiro-Wilk test for normality revealed that all variables fit a normal distribution, except for two subjective variables: lectures and activities. Thus, a Student's *t*-test was used for the performance assessments scores and the perception of learning instruments data and a Mann-Whitney test was conducted for the remaining. Results of the normality test are found in Appendix N.

Table 3.1. Demographic characteristics (N=28)

Variable	N	%
Gender		
Male	13	46.4
Female	15	53.6
Race		
African American	7	25.0
White	19	67.9
Prefer not to answer	1	3.55
More than one	1	3.55
Ethnicity		
Hispanic or Latino	1	3.55
Not Hispanic nor Latino	27	96.45

Performance Assessments

Pre- and post- cognitive assessments. The results of the pre- and post- cognitive assessments for the control and treatment group are shown in table 3.2.

Table 3.2. Pre- and post- cognitive assessments

	Control Group Mean (SD)	Digital Learning Group Mean (SD)
Total Score Pre-Cognitive Assessment	14.77 (8.24)	19.88 (5.55)
Percentage Score Pre-Cognitive Assessment	36.92% (19.90%)	48.80% (13.26%)
Total Score Post-Cognitive Assessment	26.33 (6.33)	31.85 (3.66)
Percent Score Post-Cognitive Assessment	65.83% (15.29%)	79.62% (8.79%)

Normalized Gains. To better compare the efficacy of the treatment, normalized gains were calculated using the following formula:

$$G = \frac{PostCog\% - PreCog\%}{100 - PreCog\%}, \tag{3.1}$$

where G is the normalized gains, *PostCog%* is the Post-Cognitive assessment score, and *PreCog%* is the pre-cognitive assessment score.

A one-tailed independent sample *t*-test showed a statistical difference between the normalized gains of the conventional learning group (M = 0.465, SD= 0.117) and digital learning group (M = 0.586, SD = 0.171), *t*(26) = -2.219, *p* = 0.0175. In this case, the digital learning group out-performed the conventional learning group in the normalized gains of the cognitive assessment. Figure 3.5 illustrates the bar graph of the mean normalized gains for cognitive assessment scores.

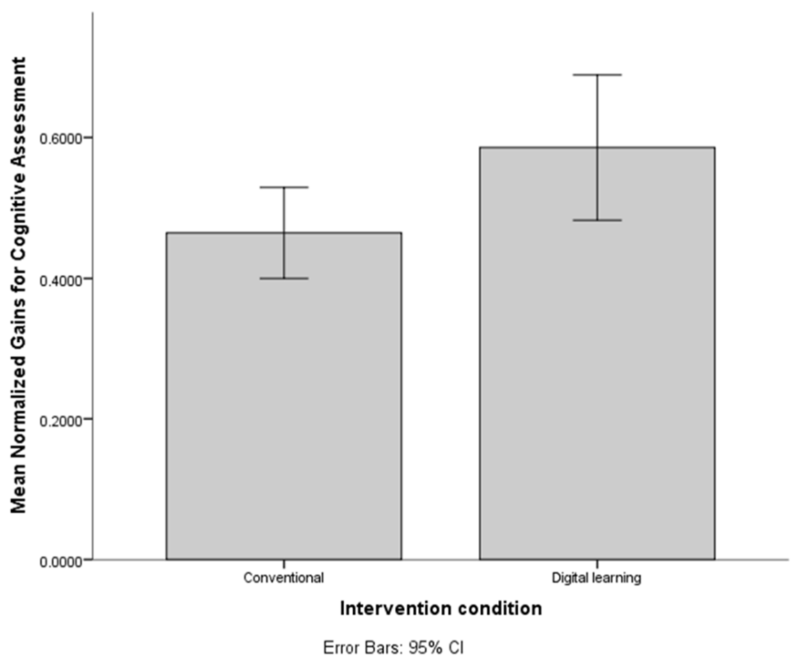


Figure 3.5. Mean Normalized Gains for the Cognitive Assessment

Skilled-based assessment. A one-tailed independent sample *t*-test showed no significant difference on the total scores of the skilled-based assessment for the conventional learning group (M = 18.40, SD = 11.24) and the digital learning group (M = 16.77, SD= 2.81), *t*(26) = 0.401, *p* = 0.346. Figure 3.6 illustrates the bar graph of the mean of the total scores for the skilled-based assessment for both groups.

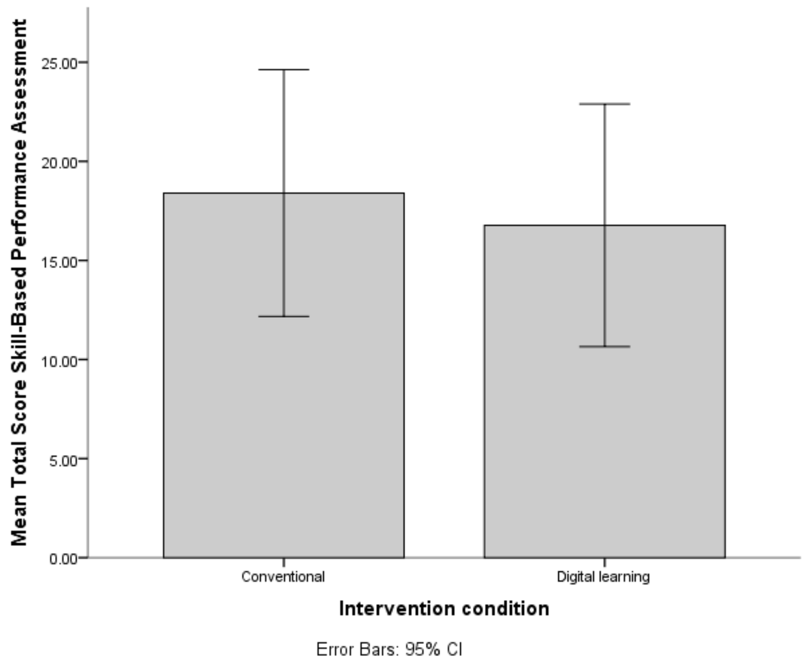


Figure 3.6. Total score skilled-based assessment bar graph for conventional and digital learning groups.

Subjective assessment

Perception of learning. This measure was calculated by adding all the questions in the perception of learning instrument (Appendix G). With a mean of 29.80 (SD = 2.71) for the conventional group and 29.46 (SD = 6.15) for the digital learning group, the *t*-test showed no significant difference between groups for the overall reported perception of learning, $t(26) = 0.193$, $p = 0.424$.

To further investigate each construct within the perception of learning instrument, independent sample *t*-tests were performed on the dependent variables that fit a normal distribution. In all cases, there was no significant difference on perception of learning instrument between the two groups (Table 3.3). Figure 3.7 shows the graphical representation of the data for the perception of learning instrument.

Table 3.3. Independent sample *t*-tests results for perception of learning by construct

	Conventional Learning M (SD)	Digital Learning M (SD)	*t*(26)	*p*-value
Hilt Perception of Learning	29.80 (2.71)	29.46 (6.15)	0.193	0.424
Hilt Learning	11.87 (1.81)	11.08 (2.87)	0.884	0.193
Hilt Communication of topic	6.87 (1.36)	6.85 (2.08)	0.031	0.488
Hilt Critical Thinking	11.07 (1.33)	11.54 (1.81)	-0.793	0.218

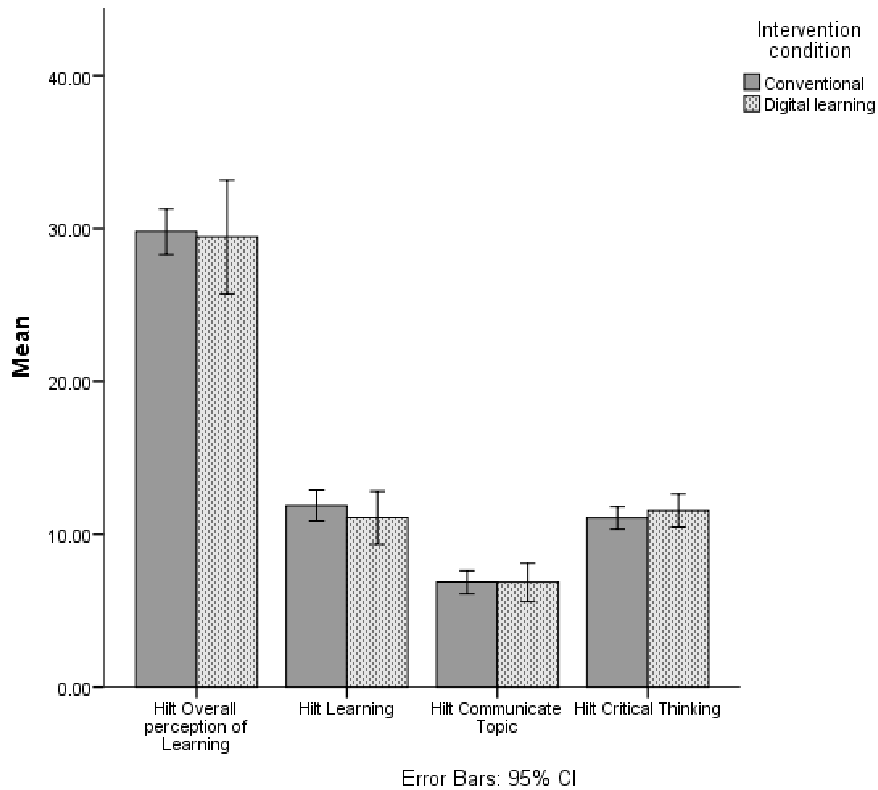


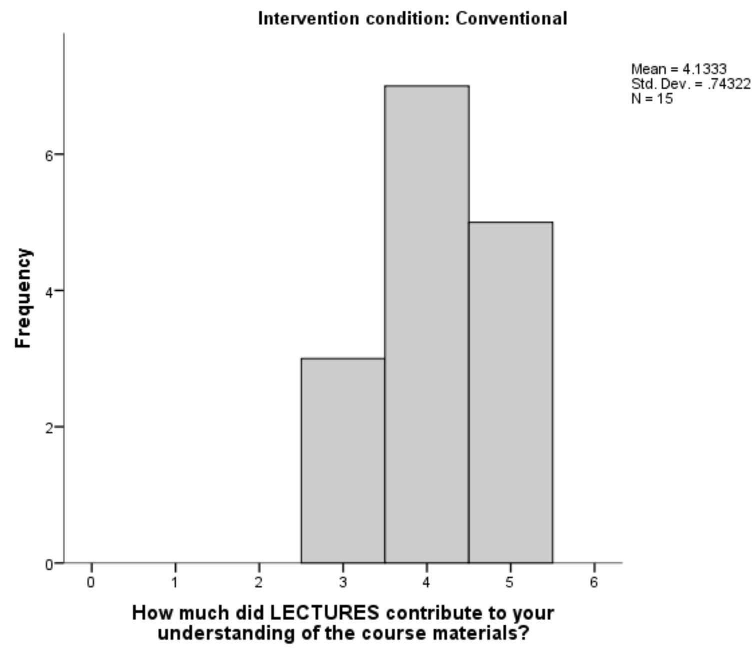
Figure 3.7. Mean total scores for perception of learning overall and by construct.

The two remaining dependent variables were the result of two questions that asked participants in both groups to rate from 1 to 5 how much did the each component of the instruction contributed to the understanding of the course material and from, where 1 was defined as very little and 5 was defined as very much. The data for the subjective questions regarding lectures and activities both rejected the null hypothesis of a Shapiro-Wilk test for normality. This is evidence that the data sets are not normally distributed.

Thus, a Mann-Whitney test was used instead to test the medians of these dependent variables. For both of these dependent variables, the one-tailed Mann-Whitney test showed no significant difference between the groups. Table 3.4 shows the summary statistics for the two dependent variables and Figures 3.8 and 3.9 shows the histograms for this data by group.

*Table 3.4***.** Mann-Whitney test for subjective measures of the lectures and activities

	Conventional Learning		Digital Learning		U	p-value
	Mean (SD)	Median	Mean (SD)	Median		
Lectures	4.133 (0.743)	4.0	3.53 (1.506)	4.0	80.0	0.203
Activities	4.00 (0.845)	4.0	4.39 (1.043)	5.0	70.0	0.104



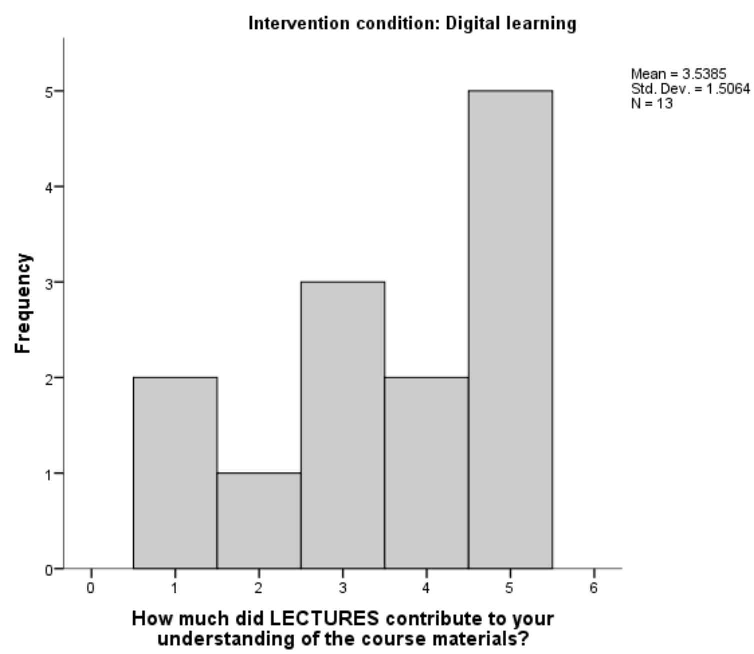
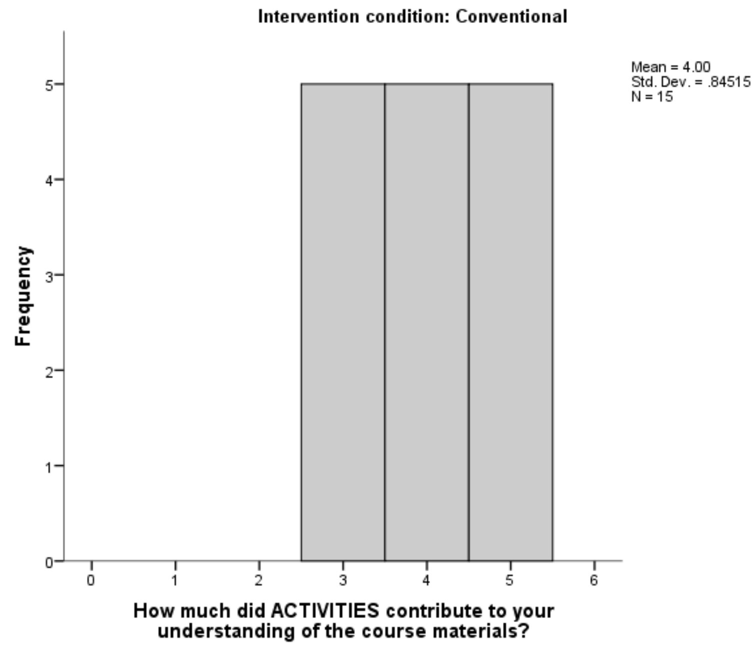


Figure 3.8. Histogram for the lectures subjective question by group



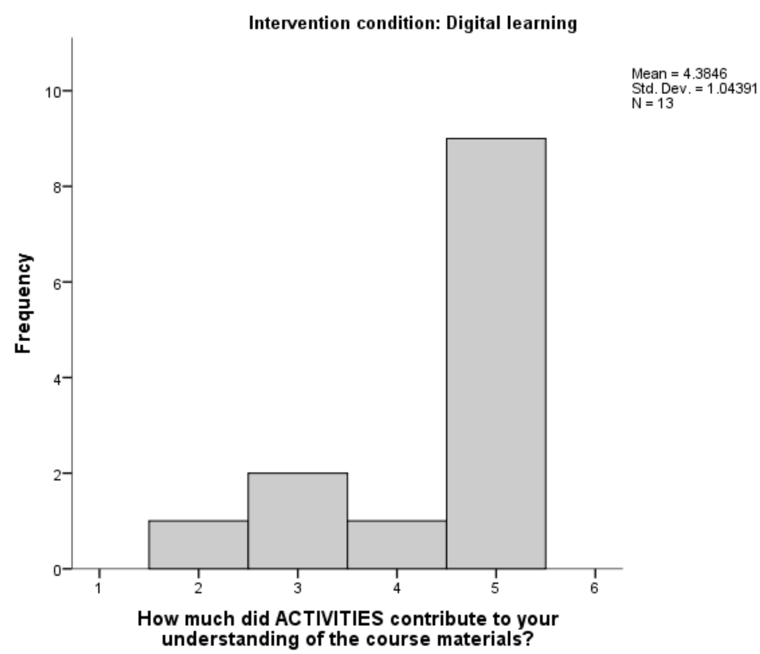


Figure 3.9. Histogram for the activities subjective question by group

The digital learning group submitted additional subjective information about the digital learning environment. These included the questions regarding the visualizations (part of the perception of learning instrument), a subjective satisfaction questionnaire (Appendix H), the technology acceptance instrument (Appendix I), and the NASA TLX total workload (Appendix J).

Figure 3.10 shows the histogram of the results for the subjective ratings of visualizations (M = 4.38, SD = 0.96).

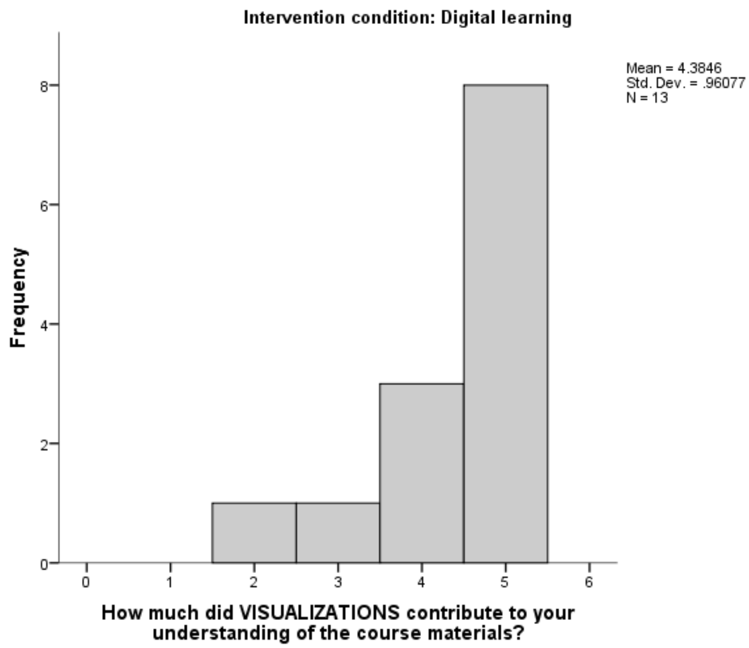


Figure 3.10. Histogram for the visualizations subjective question for the digital learning group.

Subjective satisfaction questionnaire. This overall usability measure for the digital learning environment was calculated by adding all the questions in the subjective satisfaction questionnaire (Appendix H). The measures for the internal constructs for system usability, information, and interface quality were calculated by adding eight, six, and three questions within the questionnaire, respectively. The digital learning group rated the total usability of the digital learning environment with a mean percentage of 73.38 (M = 73.38, SD = 13.65). The system usability subscale was given an average percentage of 72.50% (M = 29.00, SD = 8.08). The information subscale was given an average percentage of 83.83% (M = 25.15, SD = 5.64). Finally, the interface quality subscale was given an average percentage of 74.87% (M = 11.23, SD = 2.31). Figure 3.11 shows the average percentage for each of the subscales of usability.

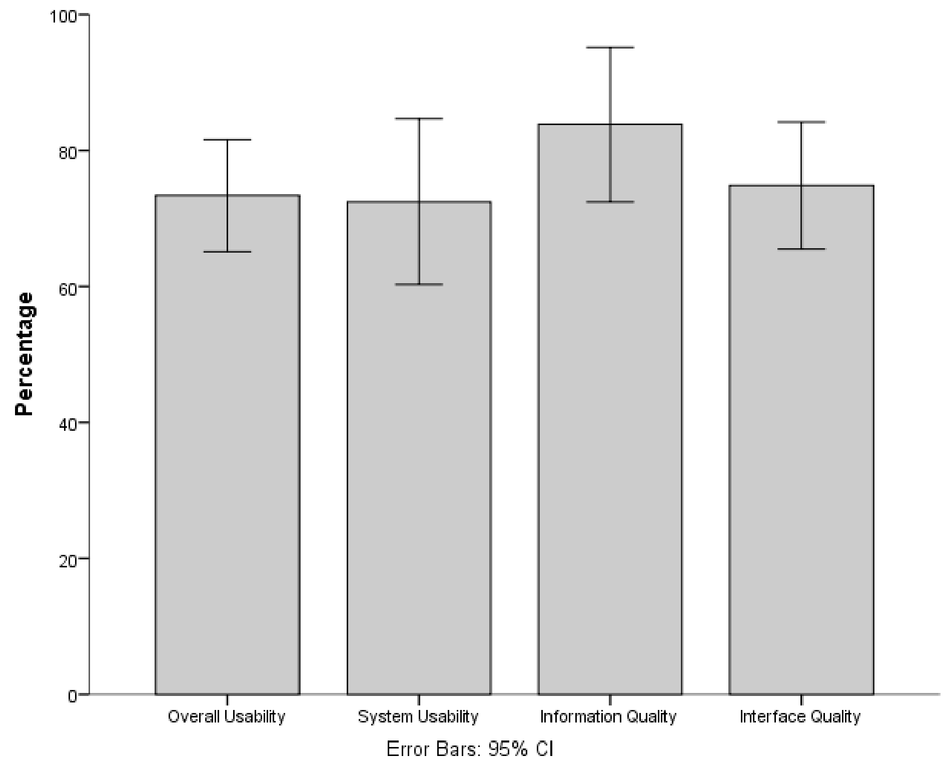


Figure 3.11. Average percentage for the subscales of usability.

Technology Acceptance. The technology acceptance measures are calculated by adding the questions under each of the subscales (Appendix I). The digital learning group rated the perceived usefulness of the digital learning environment with an average percentage of 85.13% (M = 12.77, SD = 1.74). They also rated the perceived cognitive absorption with a mean percentage of 76.06% (M = 26.62, SD = 3.52). Additionally, the digital learning group rated the digital learning environment for ease-of-use with an average percentage of 84.60% (M = 12.69, SD = 1.75). Average percentages were also reported for the remaining subscales: information quality 78.47% (M = 35.31, SD = 6.99), service quality 77.80% (M = 27.31, SD = 6.17), system quality 77.70% (M = 23.31, SD = 2.50), confirmation 75.87% (M = 11.38, SD = 2.75), satisfaction 79.00% (M = 11.85, SD = 2.44), and continuance intention 80.53% (M = 12.08, SD = 2.36). Figure 3.12 shows the average percentage for each of the subscales of the technology acceptance instrument.

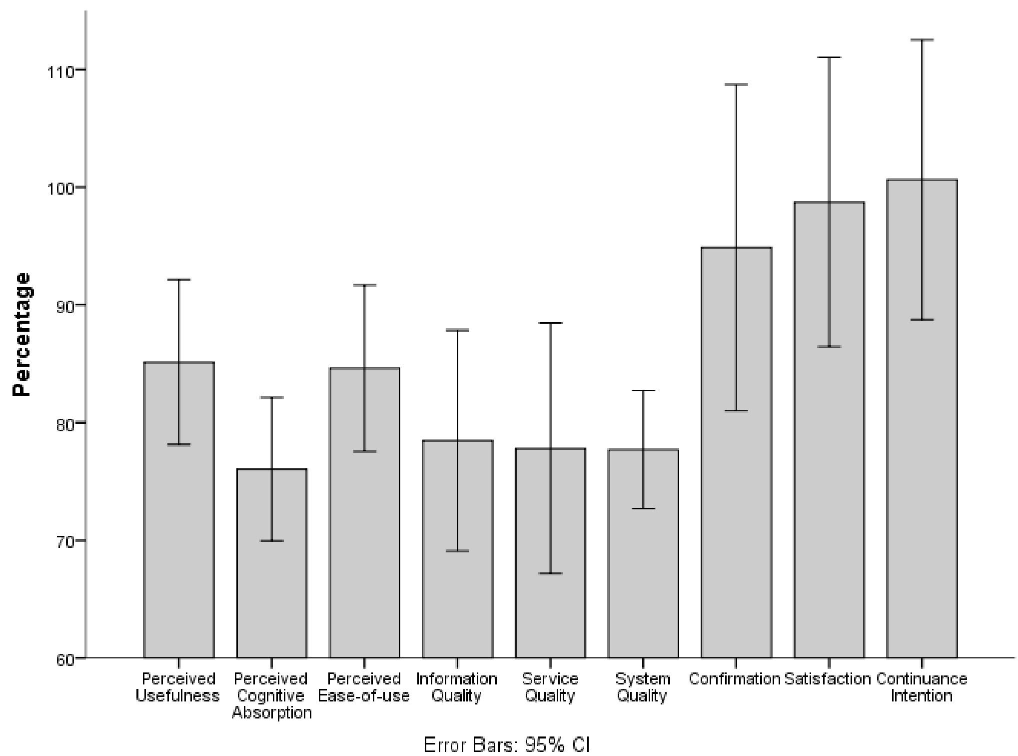


Figure 3.12. Average percentage for the subscales of technology acceptance

Workload. The digital learning group rated the total workload experience of the digital learning environment with a mean of 49.84 (SD = 24.94) out of 100. Each of the following subscales is reported out of 100. The mental demand subscale was given an average score of 18.33 (SD = 11.28). The physical demand subscale was given an average score of 1.46 (SD = 2.60). The temporal demand subscale was given an average score of 5.56 (SD = 6.20). The performance demand subscale was given an average score of 7.13 (SD = 5.67). The effort demand subscale was given an average score of 11.92 (SD = 6.06). Lastly, the frustration demand subscale was given an average score of 8.90 (SD = 13.85). The average scores for these subscales are shown in Figure 3.13.

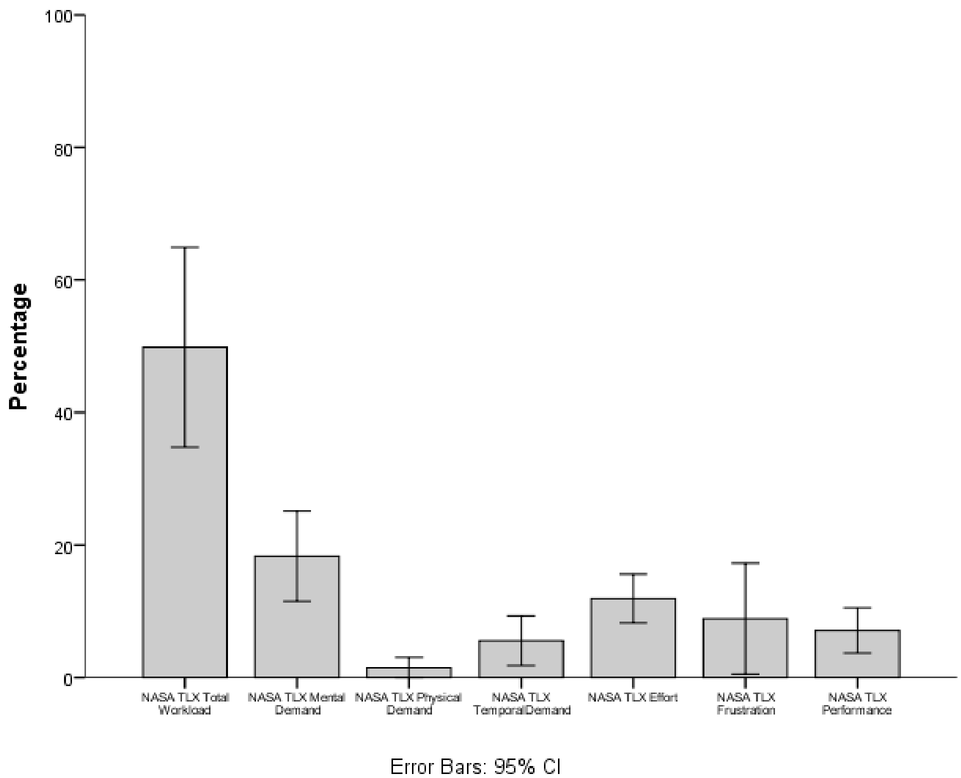


Figure 3.13. Average percentage for the subscales of workload

Appendix O provides a summary of the subjective data submitted by the digital learning group.

The limited statistical power may have limited the significance on the comparisons of this this study (N = 28). A post hoc power analysis computed using G*Power revealed that on the basis of the mean, between-groups comparison effect size of d = .05 with an alpha of 0.05, an *n* of 102 participants, 51 per group, would be needed to obtain statistical power at the recommended 0.80 level for a one-tailed test (Cohen, 1988) (Appendix P).

DISCUSSION

The result of this study failed to reject the null hypothesis that the digital learning group would perform at least as well as the conventional learning group. The results show that the digital learning group out-performed the conventional learning group in normalized gains of the cognitive assessment. This suggests that the digital learning environment acts as a better scaffolding method in the zone of proximal development (Vygotsky, 1978) than the conventional instruction. This can be explained by the self-regulating learning models, most specifically the self-oriented feedback loop that occurs during learning (Carver & Scheier, 1981; Zimmerman & Schunk, 1989, 2013; Zimmerman, 2000). The loop describes “a cyclical process in which students monitor the effectiveness of their learning,” thus providing an opportunity for participants to review content and interact with virtual precision measuring tools based on their perceived knowledge. The implications for these results are very important to the field of online education, and although further testing with a larger sample size must be conducted, these are very promising results.

The results of the this initial study failed to reject the second hypothesis that the digital learning group will perform at least as well as the conventional learning group in the skilled-based assessment. The results are equally important to distance education as they signify that students can be prepared for a more rigorous hands-on activity by spending time learning about a topic and utilizing virtual tools. The virtual tools serve a two-fold purpose: they provide an opportunity for participants to synthesis knowledge they received during the recorded lectures; and they serve as another scaffolding tool. Huang, Gillespie, Kuo (2007) developed a model for online feedback as it relates to hands-on activities. Their model shows that the interaction between body dynamics and object dynamics provide by virtual tools provide the proprioceptive input necessary for the central nervous system to convert the knowledge to motor function. Additionally, the movement and object dynamics of the virtual environment can provide the visual input to the central nervous system. They suggest that visual, haptic and proprioceptive feedback is ideal to achieve desired psychomotor outcomes. They note that others have found visual and proprioceptive feedback to be sufficient (Sternad, Duarte, Katsumata, & Schall, 2001a, 2001b). This supports the results that, although the convention learning group had access to the tools and were familiar with their operation, the digital learning group had the opportunity to develop adequate psychomotor skills through the visual cues provided by the object dynamics of the virtual reality components.

For the third hypothesis, the results of the study failed to reject the null hypothesis that the digital learning group would perceive learning at least as well as the conventional learning group. The results apply to the overall learning score as well as, each construct within the instrument. As described by (Ford et al., 1998), students would report that they have learned a specific topic after instruction. Lim & Morris (2006) also found that trainees rated their perceived learning higher three months after instruction than they did immediately after instruction. Perception of learning is an important measure as it may determine if participants will utilize the digital learning environment. LaBay & Comm

(2011) found that students perceived that less learning occurred about a particular topic when learning occurred in online environments. Though not the case in this study, this finding should be noted for future studies as students are less likely to utilize the digital learning environment if they did not perceive learning, even though learning did occur.

In a study by McArdle and Bertollotto (2012) assessing the application of three-dimensional collaborative technologies within an e-learning environment, their application, CLEV-R scored an 82.27% for system usability and 85.47% for interface quality. McArdel and Bertollotto (2012) considered these results providing a high level of satisfaction to the users. Thus, our reported results for the overall usability, system usability, and interface quality provide a moderate level of satisfaction to the users. The information quality subscale, however, scored an 83.83% and shows a high level of satisfaction for the participants.

The technology acceptance subscales also showed some promising results for the digital learning environment. Both perceived usefulness and perceived ease of use provided favorable scores. In the next iteration, the researcher must take into account other measures that did not score as favorable. Interestingly, the subscale for information quality in the technology acceptance instrument scored lower than information quality in the usability instrument. An important subscale to consider is the continuance intention subscale. It is important for participants to have a positive experience with the digital learning environment to foster continual use. In this case, the measure resulted in an 80.5% and the researchers would like to see this increase for the next iteration of the study.

Knapp and Hall (1990) considered a total workload score of 40 or above as high. For each subscale Knapp and Hall (1990) considered workload slightly differently with 0 – 15 as low, 15 – 30 as moderate and 30 and above as high. Thus, the total workload score for this study was found to be in high workload (49.84%) with the highest contributing subscale being the mental demand (18.33%) which is considered providing moderate workload to the participants. This result is not surprising as the digital learning environment will require mental demand as learning occurs. All other subscales – physical demand, temporal demand, performance, effort and frustraction – fall into the low workload. As expected, the lowest contributor to workload is physical demand (1.46%).

The results of this pilot will help inform future studies in various ways. First, post hoc power analysis determined that the sample size of any future studies must be increased 102 participants, 51 per group, to validate results and obtain a statistical power of 0.80. Subjective measures will also inform changes to the digital learning environment, specifically the interface quality from the usability measures and continuance intention from the technology acceptance. A final limitation of this study is that participants in the conventional learning group were not taught the material in a single session. This is a limitation that will be hard to mitigate on future studies due to the participant's and the instructor's schedule and the newly determined sample size.

CHAPTER FOUR

A LARGE SCALE INVESTIGATION ON THE EFFECTS OF DIGITAL LEARNING INTEGRATED WITH VISUALIZATION TOOLS ON PERFORMACE IN COGNITIVE AND PSYCHOMOTOR ASSESSMENTS

"The medium that tantalizes us so has gone by a number of names: computer simulation, artificial reality, virtual environments, augmented reality, cyberspace, and so on…Virtual reality is not a technology; it is a destination.

- Frank Biocca & Mark Levy (1995)

As the results of the pilot study showed, digital learning can provide a means for students to achieve a level of mastery at a distance and be better prepared when they participate in a laboratory environment. In the case of metrology and linear precision measuring instruments, various 2-year technology programs require the knowledge needed to adequately utilize these tools. The ability of students to understand how to use precision measuring instruments is important, but understanding how to apply them in crucial. For example, the goal of an automotive technology student is to be able to diagnose and repair automobiles at the end of their 2-year degree. Although being able to read measuring instruments is a stepping stone to that goal, it should not be consuming a large portion of time in the laboratory. If results in the previous study are validated, students will be able to utilize these tools at their own pace before attending class or a laboratory and the instructor will feel confident about their mastery level.

Utilizing the framework and results of the previous study, this proposed study aims to serve as a blueprint for testing of digital learning modules for use in technology programs. Similar to the pilot study, participants were presented with introductory information about metrology, the science of measurement, and how to properly manipulate and read measurements using three popular linear measuring instruments: the scale, the Vernier caliper, and the micrometer.

Research Hypotheses

The previous study showed that there was a difference in the post-cognitive assessment performance between groups and no difference in the skilled-based assessment, but a major limitation of the study was the small sample size. From the power analysis conducted in the previous study, 102 participants (51 per group) must be recruited in order to achieve a 0.80 power assuming an effect size of d=50 (Appendix P) Thus, the hypotheses for this study are as follows:

Hypothesis 1: The digital learning group will perform at least as well as the conventional learning group in normalized gains post treatment.

Hypothesis 2: The digital learning group will score at least as well as the conventional learning group in the skilled-based assessment.

Hypothesis 3: The digital learning group will score at least as well as the conventional learning group in the perception of learning measures.

METHOD

Participants

86 technical college students with little or no prior experience with linear precision measurement tools were recruited from two partnering technical colleges:

Trident Technical College in Charleston, SC and Greenville Technical College in Greenville, SC. They were screened to ensure that they were at least 18 years old, had a 20/20 vision either naturally or through the use of corrective lenses, had no auditory problem either naturally other through the use of corrective equipment, and did not experience any difficulty with motor function. Participants were recruited during the fall semester of 2014 through introductory courses of three degree programs: Automotive Technology, Aircraft Maintenance Technology, and Avionics Maintenance Technology. To determine participant eligibility, a general questionnaire (Appendix Q) was provided to each student and reviewed by the researcher prior to the start of the study. The general questionnaire included items that pertain to mastery level of the tools to be investigated. If a student has a self-reported mastery level of three or higher on any of the precision measuring tools, they were excluded from the study and informed of their ineligibility.

Apparatus

All participants were provided a notepad, a pen and a pencil. During instruction, participants in the conventional instruction had access to various precision measurement tools: including metric and English system calipers, outside micrometers, inside micrometers and depth micrometers.

Participants in the digital learning group viewed recorded lectures and interact with virtual reality components through the Educate Workforce (www.educateworkforce.com) online portal. They were also provided with a keyboard, a mouse, and headphones. Lectures were recorded using Adobe Presenter 9 and delivered through the Educate Workforce online portal. Virtual reality components were developed using Unity3D version 3 and were integrated into the online portal. The lecture materials and the virtual reality components were developed through a National Science Foundation Advanced Technological Education grant (DUE 1104181).

Independent variable

The independent variable for this study was the mode in which instruction was delivered: conventional or digital learning. The conventional learning intervention is a face-to-face method of instruction which represents a 90 minute lecture from two technology instructors with over 25 years of industry and teaching experience. Unlike the last study, the instructors were given the instructional materials and had the freedom to modify the materials as they saw fit. This will allow for a better comparison between both groups. During the lecture, the students had access to the precision measuring tools, were able to manipulate them, and they were allowed to ask questions.

The digital learning intervention is a web-based method of instruction that was delivered through the Educate Workforce online portal and included recorded lectures and interactive virtual representations of the precision measuring tools. Participants watched several videos totaling about 90 minutes of instruction which were recorded by the researcher and vetted by technical college instructors. The instructional material was the same as the one provided to the instructors and presented to the conventional learning group. Figure 4.1 shows examples of the web-based platform with the recorded lectures. Figure 4.2 shows the virtual reality precision measuring tools participants utilized: the scale, the Vernier caliper (inside, outside, and depth, and the micrometer (inside, outside and depth) within the online portal.

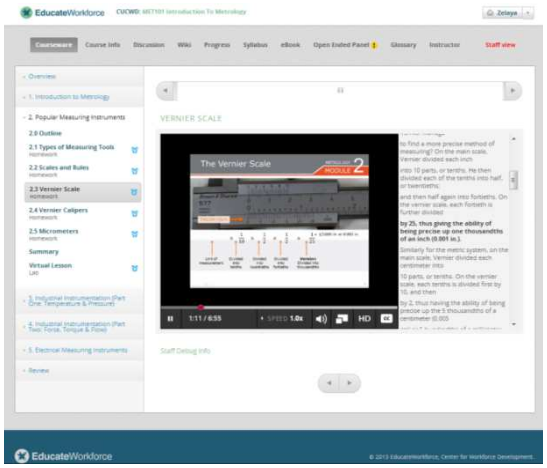
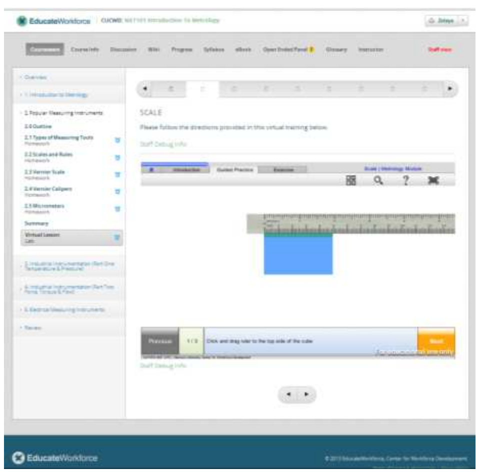
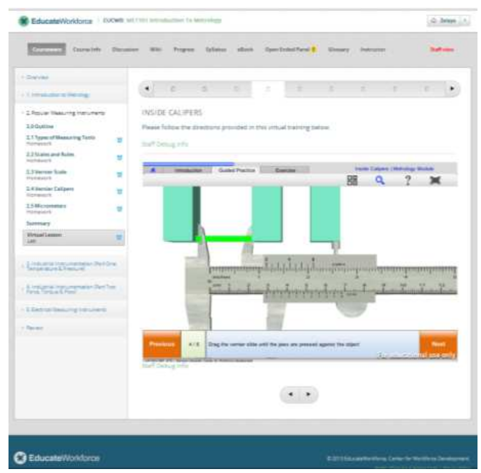


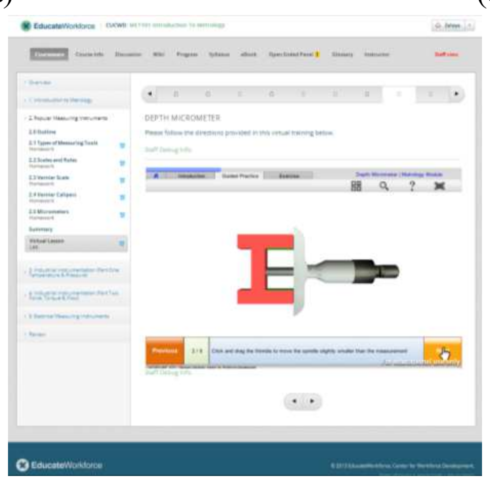
Figure 4.1. Example of the recorded lectures in the Educate Workforce online portal



(a)



(b)



(c)

Figure 4.2. Virtual reality precision measuring tools in Educate Workforce online portal: (a) the scale, (b)the Vernier calipers, and (c) the micrometers

Other independent variables that will be collected using the general questionnaire (Appendix Q) include gender, age, race and ethnicity.

Dependent Variables

Nine measures of interest were collected for the study. The first three measures were based on the participant's performance on the pre- and post- cognitive assessment (Appendix R and S, respectively) and a skilled-based performance assessment post treatment (Appendix T). The fourth measure, perception of learning, was collected using an instrument adapted from Hiltz (1988) (Appendix U). This instrument contains four constructs: (1) interest, (2) communication of topic, (3) critical thinking and (4) overall perception of learning. Each was measured using a Likert scale ranging from 1 to 5, with 5 indicating strong agreement.

Three additional measures were collected from the digital learning group. This will be primarily done to understand the issues associated with the digital learning platform. These were used in the pilot study described in Chapter Three and were not changed. They included a usability measure collected through the IBM designed Computer Usability Satisfaction Questionnaire (Lewis, 1995) (Appendix H); a technology acceptance measure collected using the technology acceptance instrument adapted from Saadé and Bahli (2005) (Appendix I); finally, workload indices were collected using NASA TLX (Hart & Staveland, 1988) (Appendix J). Figure 4.3 shows the experimental study and the instruments each group used to complete the skilled-based performance assessment instrument.

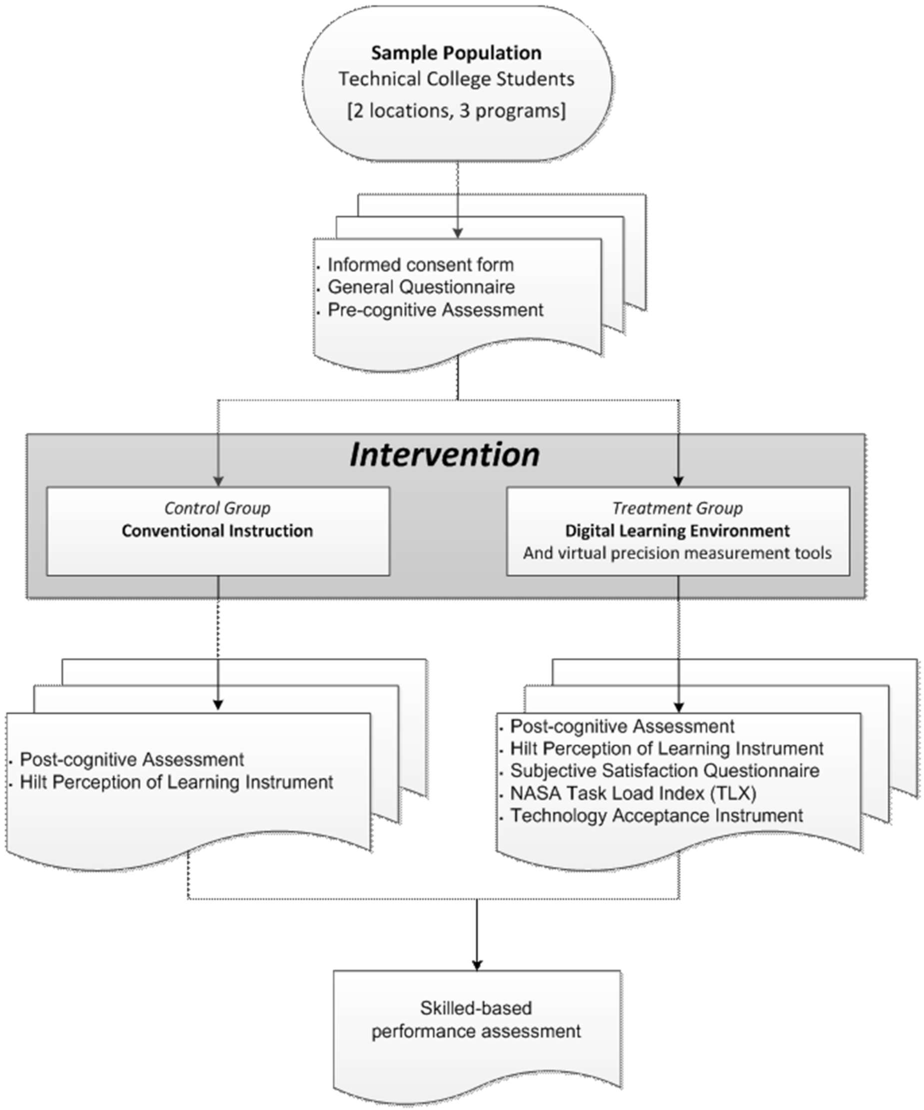


Figure 4.3. Experimental study flowchart

Performance Assessment Instruments: The pre- and post- cognitive assessments were only slightly modified based on results from the pilot study. The skilled-based assessment was also modified to reduce the length of the study. Four scenarios instead of six were completed by each participant. During the skilled-based assessment, participants had access to the following metric precision measuring instruments: one Vernier caliper (0-150mm), three outside micrometers (0-25mm, 25-50mm, and 50-75mm), two inside micrometers (5-30 mm and 50-75mm), and one depth micrometer (0-50mm). These can be seen in Figure 4.4.

Figure 4.4. Precision measuring instruments utilized during skilled-based assessment

Experimental Task

The study used a between-subjects experimental design. Participants were exposed to one of the two conditions to be investigated:

Group 1: Control condition – conventional learning method

Group 2: Treatment condition – digital learning integrated with visualization tools.

Procedure

The study was embedded into normal class instruction in all three programs. In for Trident Technical College, the participants of the automotive technology program were randomly divided into two areas where instruction was provided, either conventional or digital. Similarly, the participants of aircraft maintenance technology program and the avionics technology program were randomly divided. At Greenville Technical College, the participants of the automotive technology program were randomly divided into two sections. One section of the participants received the control condition, while another section of the section received the treatment. For a course that only had one section, the class was split into two groups with one group completing the lectures online and another group sitting through lectures given by an experience instructor. Students that were not eligible for the study, but were in the course, still received one of two treatments because the educational material was part of the course.

All participants were provided the consent form (Appendix V) and were asked to verify the information they submitted in the general questionnaire. In addition, the digital learning group was provided with instructions on how to log on to the web-based platform (Appendix W). All participants also completed the pre-cognitive assessment. After the instruction, all participants completed the post-cognitive assessment, as well as the perception of learning instrument. Finally, in a laboratory classroom, participants completed the skills-based assessment individually. At the completion of the study, participants received a $40 gift card.

For the treatment condition, participants were also asked to complete the subjective satisfaction questionnaire, the technology acceptance questionnaire, and the NASA TLX. After completing all instruments, all participants were asked to consent or decline participation on Phase II of the study using the Recruitment/Consent Form in Appendix X. The entire study took on average four and a half hours per participant to complete.

RESULTS

The demographic characteristics of all the participants in the study are presented in Table 4.1:

Table 4.1. Demographic characteristics (N=86)

Variable	N	%
Gender		
Male	80	93.0
Female	6	7.0
Race		
African American	12	14.0
American Indian/Alaska Native	3	3.5
Asian	1	1.2
Native Hawaiian or Other Pacific	1	1.2
White	65	75.6
Prefer not to answer	3	3.5
More than one	1	1.2
Ethnicity		
Hispanic or Latino	10	11.6
Not Hispanic nor Latino	76	88.4
Degree Program		
Automotive Technology	39	45.3
Aircraft Maintenance Technology	38	44.2
Avionics Maintenance Technology	9	10.5

Analysis

SPSS 21.0 was used to analyze the data on the dependent variables: normalized gains, total score of the skilled based assessment, and perception of learning instrument. A Shapiro-Wilk test for normality revealed that all of these variables did not fit a normal distribution; however, further investigation into the data was conducted. For the normalized gains, it was discovered that once one outlier was removed from the data, the Shapiro-Wilk test showed that the data followed a normal distribution with a $p = 0.246$. Additionally, after removing outliers from the data, a Shapiro-Wilk test for the Hilt overall perception of learning data and the Hilt learning construct data revealed normal distributions with p-values of 0.112 and 0.053 respectively. For the total score of the skilled based assessment, a two-step approach for transforming the data to normal was employed with successful results (Templeton, 2011). All other variables remained non-normal, thus Mann-Whitney tests were utilized to compare means. Results of the normality test and detailed data analysis are found in Appendix Y.

Performance Assessments

Pre- and post- cognitive assessments. The results of the pre- and post- cognitive assessments for the control and treatment group are shown in table 4.2.

Table 4.2. Pre- and post- cognitive assessments

	Control Group Mean (SD)	Digital Learning Group Mean (SD)
Total Score Pre-Cognitive Assessment	26.20 (8.13)	24.52 (6.96)
Percentage Score Pre-Cognitive Assessment	56.52% (17.68%)	53.30% (15.1%)
Total Score Post-Cognitive Assessment	33.24 (5.12)	31.88 (6.19)
Percent Score Post-Cognitive Assessment	72.26% (11.12%)	69.31% (13.46%)

Normalized Gains. To better compare the efficacy of the treatment, normalized gains were calculated using the following formula:

$$G = \frac{PostCog\% - PreCog\%}{100 - PreCog\%}, \quad (4.1)$$

where *G* is the normalized gains, *PostCog%* is the Post-Cognitive assessment score, and *PreCog%* is the pre-cognitive assessment score.

A one-tailed independent sample *t*-test indicated that the normalized gains for the convention learning group (M = 0.3087, SD = 0.039) and the digital learning group (M = 0.3559, SD = 0.032) showed no significant difference, $t(83) = -0.932$, $p = 0.177$. Figure 4.5 illustrates the bar graph of the mean normalized gains for cognitive assessment scores.

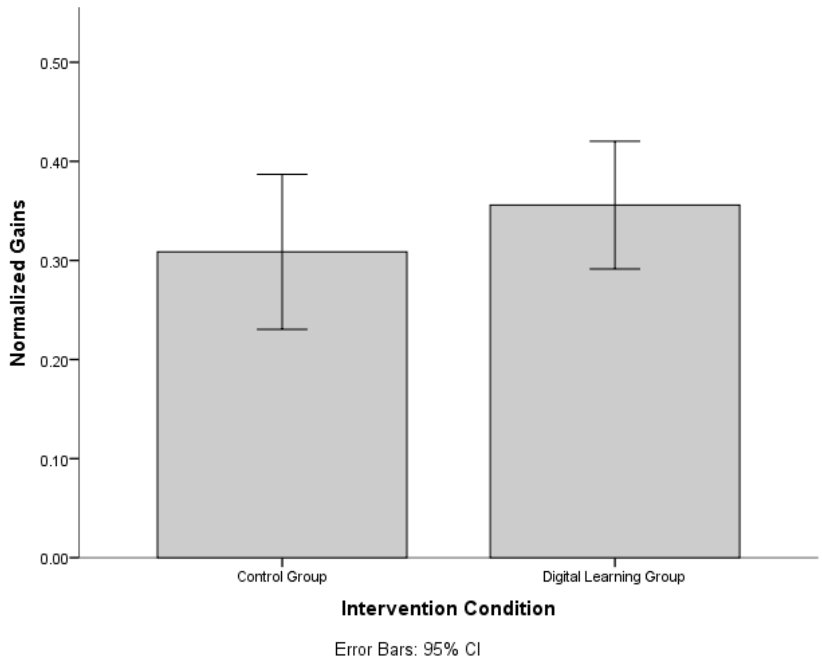


Figure 4.5. Bar graph of the normalized gains for conventional and digital learning groups.

Skilled-based assessment. Results of an independent sample *t*-test on the normalized skilled based assessment scores indicated no significant difference between the control group (M = 13.42, SD = 5.066) and digital learning group (M = 12.30, SD = 4.514), $t(82) = 1.069$, $p = 0.144$. Figure 4.6 illustrates the bar graph of the mean normalized total scores for the skilled-based assessment.

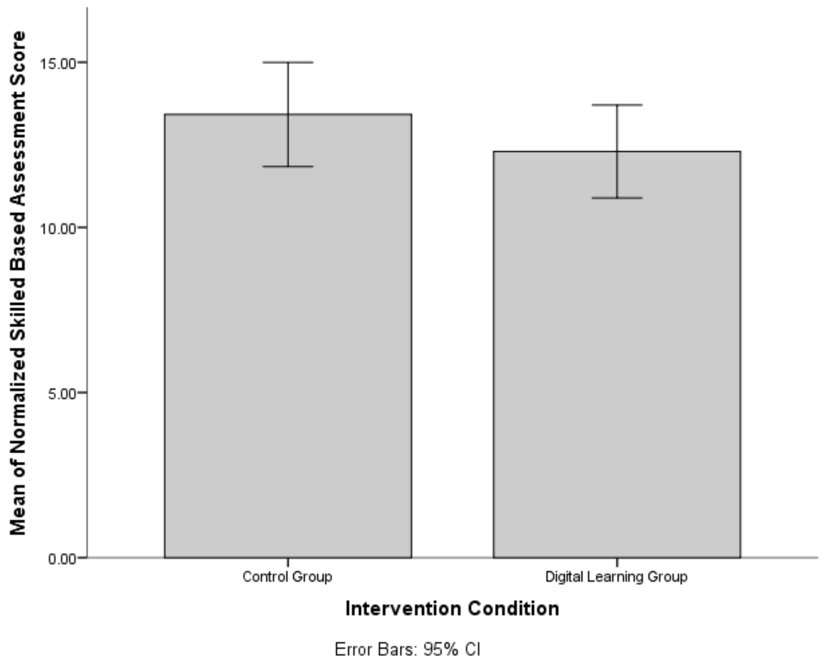


Figure 4.6. Bar graph of the mean normalized skilled-based assessment scores for the conventional and digital learning groups

Subjective assessments

Perception of learning. This measure was calculated by adding all the questions in the Hilt perception of learning instrument (Appendix U). A one-tailed independent sample *t*-test indicated that the overall perception of learning for the convention learning group (M = 29.68, SD = 3.851) and the digital learning group (M = 27.92, SD = 5.178) showed a significant difference, $t(81) = 1.768$, $p = 0.041$. Figure 4.7 shows the bar graph for the overall perception of learning scores.

To further investigate each construct in the Hilt perception of learning instrument – learning, communication of topic, and critical thinking – within the perception of learning instrument, one-tailed independent sample *t*-test for the learning construct and Mann-Whitney tests for the remaining dependent variables were also performed. In the case of the learning construct, a one-tailed independent sample *t*-test indicated no significant difference between the overall perception of learning for the convention learning group (M = 15.20, SD = 2.174) and the digital learning group (M = 14.26, SD = 2.917), $t(81) = 1.662$, $p = 0.051$

A Mann-Whitney test showed a significant difference between the two groups for the communication of topic construct. For the critical thinking construct, there was no significant difference between the two groups. In addition to the perception of learning constructs, two questions asked participants to rate from 1 to 5, where 1 is poor and 5 is great the lectures and the activities. A one-tailed Mann-Whitney test showed a significant difference between the mean ratings for lectures/videos and activities for both two groups. The findings of this instrument are summarized in Table 4.3 and 4.4. Figure 4.7 shows the bar graph for the overall perception of learning scores. Figure 4.8 shows the mean percentages of each of the perception of learning construct. Figures 4.9 and 4.10 show the histograms of the lecture/videos data and the activities data by intervention condition. Finally, Figure 4.11 illustrates the histogram for the visualizations data for the digital learning group.

Table 4.3. One-tailed independent sample t-test results

	Conventional Learning M(SD)	Digital Learning M(SD)	*t*(81)	p-value
Hilt Overall Perception of Learning	29.68 (3.851)	27.92 (5.178)	1.768	0.041*
Hilt Learning	15.20 (2.174)	14.26 (2.917),	1.662	0.051

* denotes significant difference at $p \leq 0.05$

Table 4.4. One-tailed Mann-Whitney results

	Conventional Learning Median	Digital Learning Median	*U*	p-value
Hilt Communication of topic	8.0	6.0	552.5	0.000*
Hilt Critical Thinking	7.0	7.0	817.5	0.174
Lectures/Videos	4.0	4.0	726.5	0.038*
Activities	4.0	4.0	628.5	0.004*
Visualizations	–	3.88 (1.067)	–	–

* denotes significant difference at $p \leq 0.05$

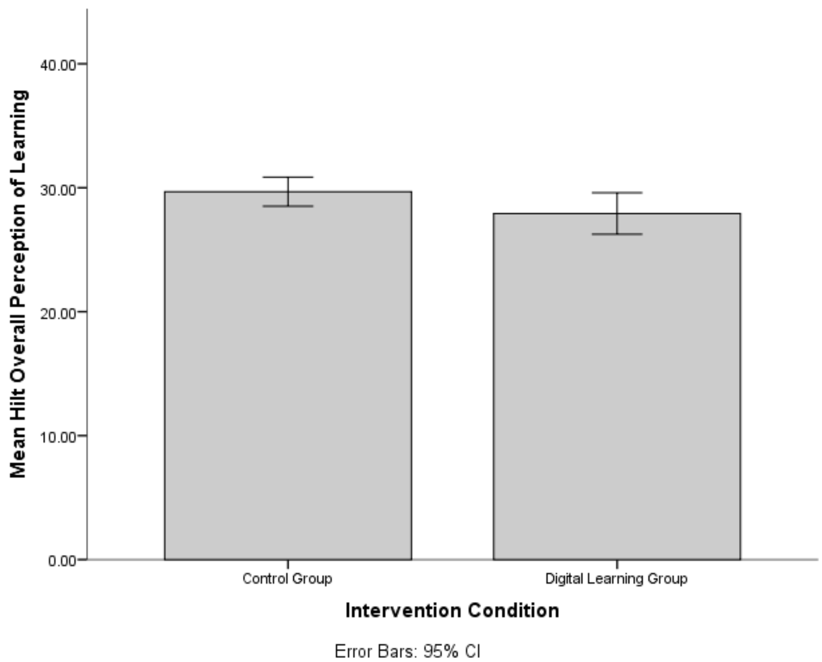


Figure 4.7. Bar graph for the Hilt overall perception of learning score

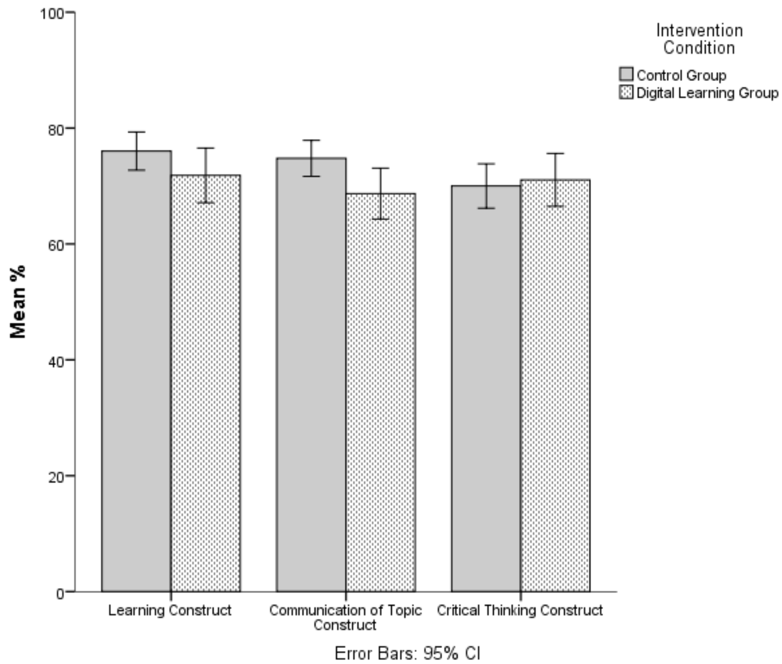
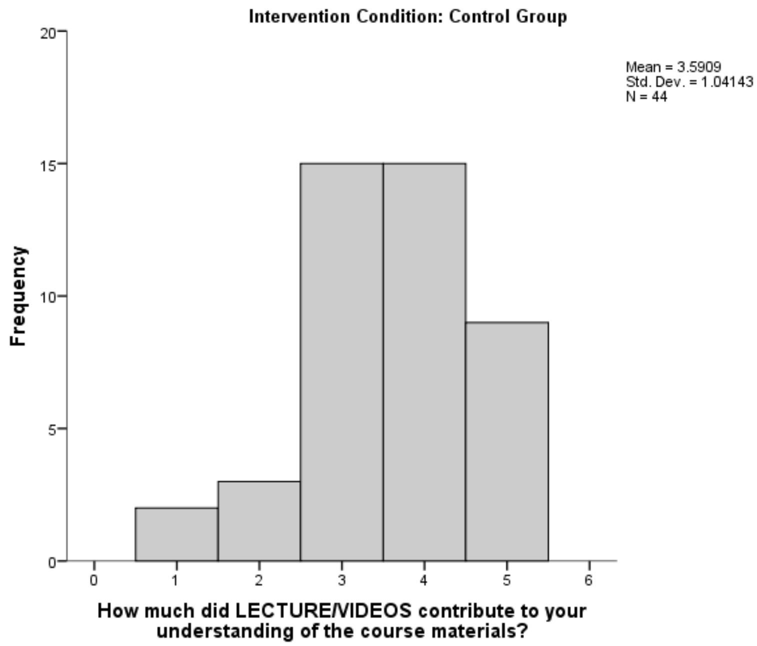


Figure 4.8. Bar graph of percentages for Hilt perception of learning constructs



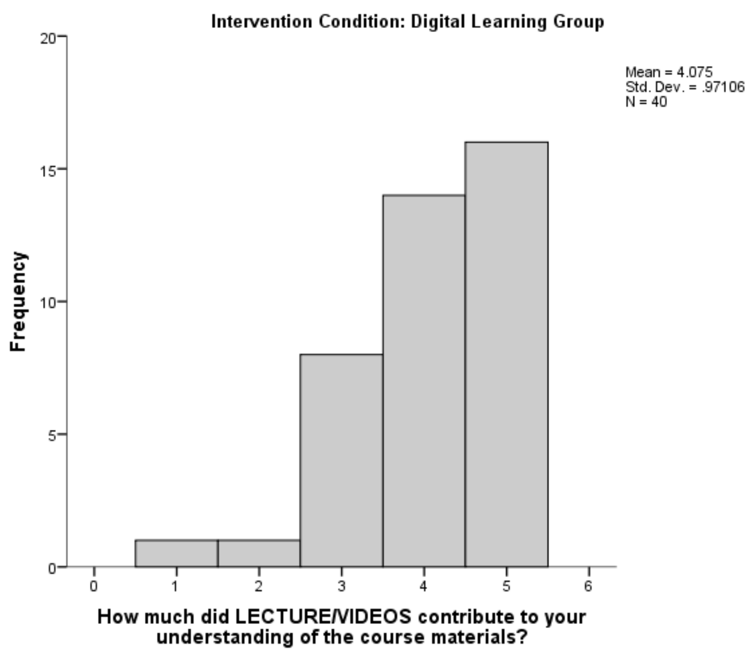


Figure 4.9. Histograms for the lecture/videos data for each intervention condition

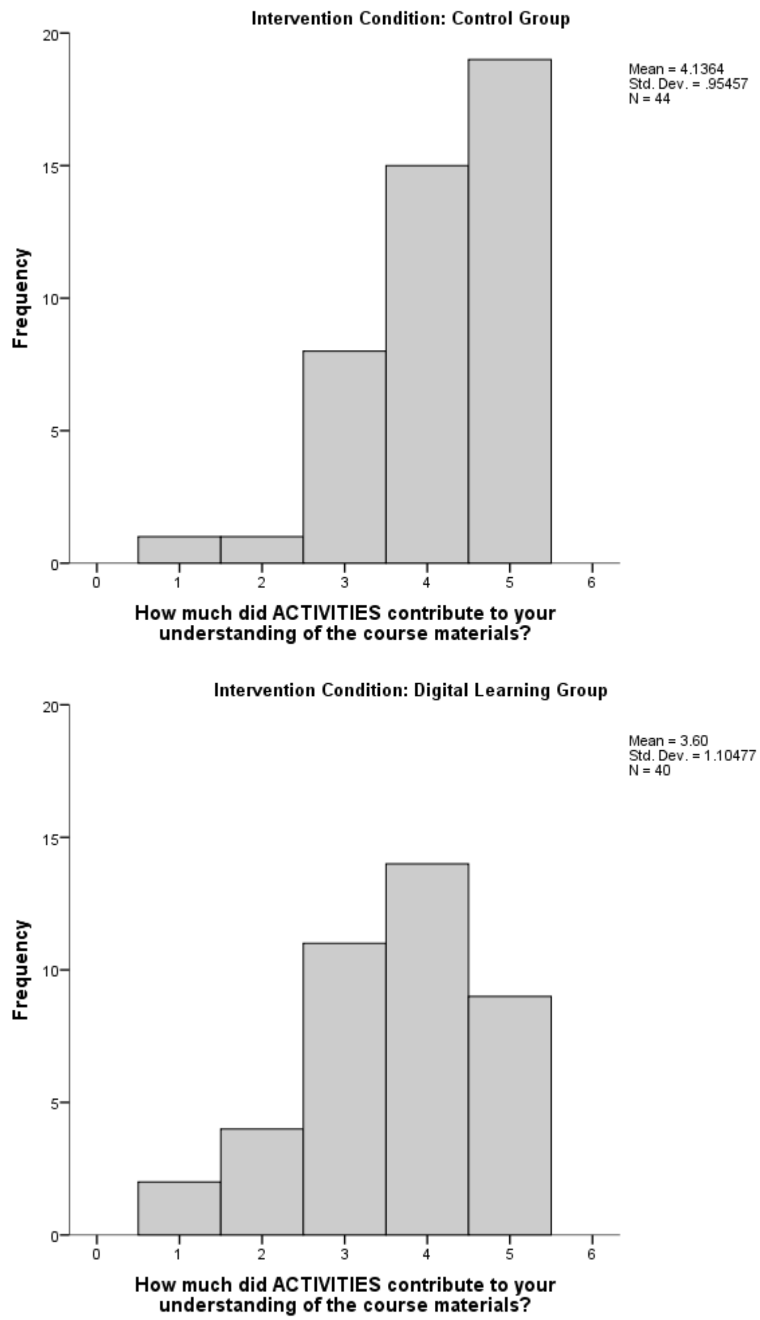


Figure 4.10. Histograms for the activities data for each intervention condition

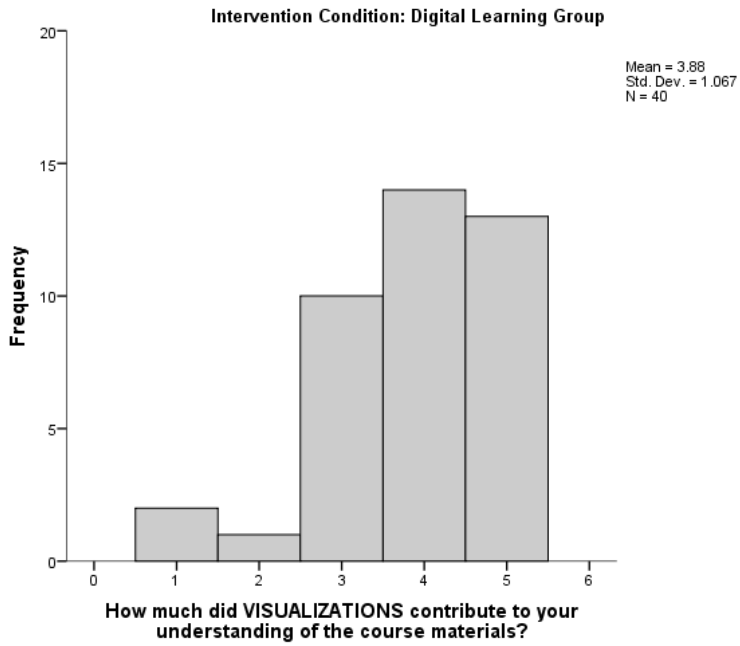


Figure 4.11. Histograms for the visualizations data for the digital learning condition

Subjective Satisfaction Questionnaire. This instrument was only completed by the digital learning group and was calculated by adding all the questions in the subjective satisfaction questionnaire (Appendix H). The measures for the internal constructs for system usability, information, and interface quality were calculated by adding eight, six, and three questions within the questionnaire, respectively. The digital learning group rated the total usability of the digital learning environment with a mean of 68.20 (SD = 16.37). The system usability subscale was given an average score of 26.60 (SD = 7.65). The information quality subscale was given an average score of 25.57 (SD = 4.96). And the interface quality subscale was given an average score of 9.80 (SD = 3.07). Figure 4.12 shows the average percentages of the subscales of usability.

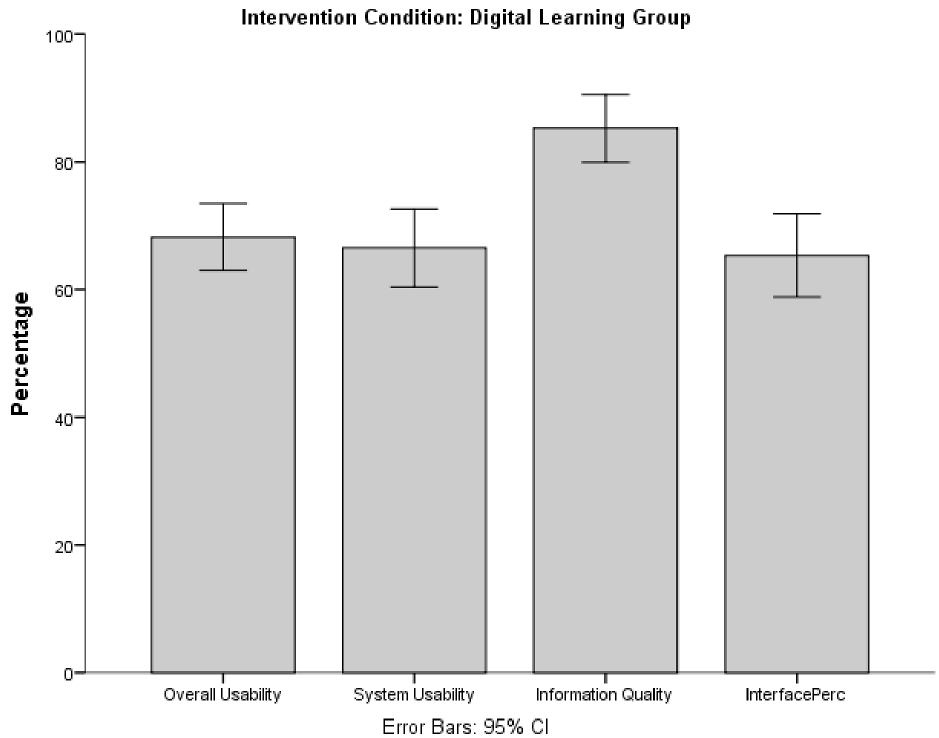


Figure 4.12. Average percentages of the subscales of usability

Technology Acceptance. Another instrument completed only by the digital learning group is the Technology Acceptance (Appendix I). The technology acceptance measures are calculated by adding the questions under each of the subscales. These include: perceived usefulness, perceived cognitive absorption, perceived ease-of-use, information quality, service quality, system quality, confirmation, satisfaction, and continuance intention. The digital learning group rated the perceived usefulness of the digital learning environment with an average score of 9.18 (SD = 3.08). They also rated the perceived cognitive absorption with an average score of 21.44 (SD = 6.52). Additionally, the digital learning group rated the digital learning environment for ease-of-use with an average score of 10.29 (SD = 3.40). Average scores were also reported for the remaining subscales: information quality (M = 31.65, SD = 6.62), service quality (M

= 24.76, SD = 4.64), system quality (M = 20.62, SD = 3.49), confirmation (M = 9.82, SD = 2.72), satisfaction (M = 9.68, SD = 3.24), and continuance intention (M = 9.09, SD = 3.19). Figure 4.13 illustrates the average percentages on the subscales of the technology acceptance instrument.

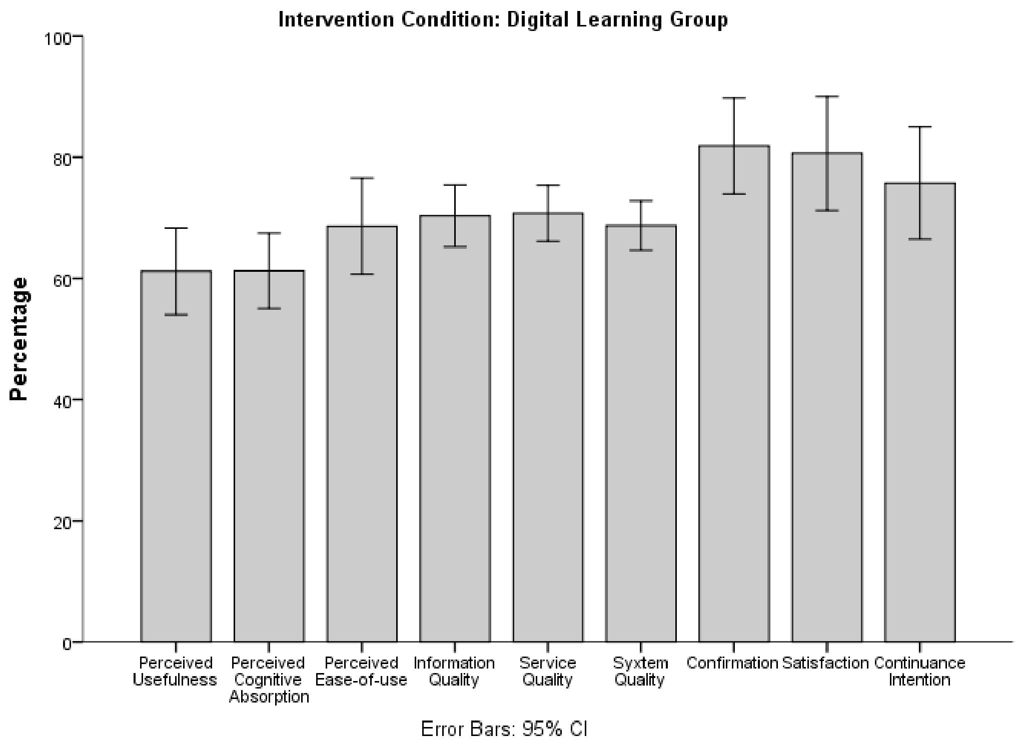


Figure 4.13. Average percentages of the subscales of the technology acceptance instrument.

Workload. The final instrument completed by the digital learning group was the NASA TLX which provides a workload score (Appendix J). The digital learning group rated the total workload experience of the digital learning environment with a mean of 39.84 (SD = 14.54). The mental demand subscale was given an average score of 46.58 (SD = 25.06). The physical demand subscale was given an average score of 15.00 (SD = 18.03). The temporal demand subscale was given an average score of 20.79 (SD =

24.31). The effort demand subscale was given an average score of 42.12 (SD = 27.46). The frustration demand subscale was given an average score of 52.55 (SD = 34.34). Lastly, the performance demand subscale was given an average score of 32.05 (SD = 22.03 Figure 4.14 illustrates the average percentages on each of the subscales.

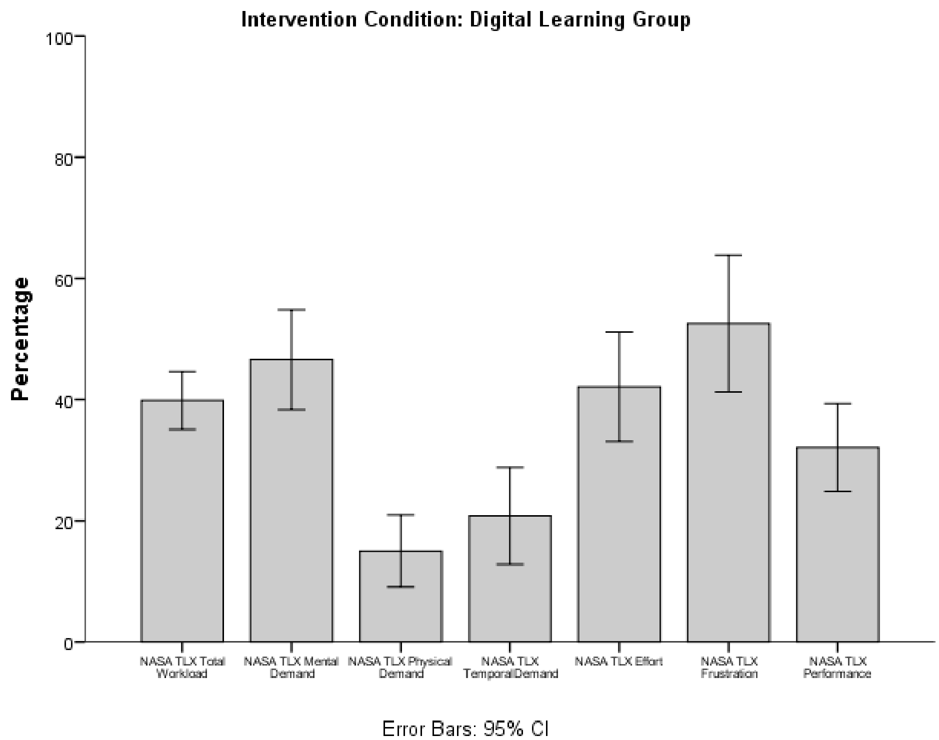


Figure 4.14. Average percentages of the subscales of workload

A summary of all subjective measures completed by the digital learning group can be found in Appendix Z.

A post hoc computation of achieved power was conducted on two dependent variables that showed significant difference between the two groups – the Hilt overall perception of learning score and the Hilt communication of topic construct score. In the case of the Hilt overall perception of learning score learning scores, a one-tailed test with an effect size of d = 0.3845 and an α = 0.05 revealed a power (1 – β) of 0.54. Similarly, for the Hilt communication of Topic construct, a one-tailed test with an effect size of d = 0.5996 and an α = 0.05 provided a power (1 – β) of 0.86. Appendix AA shows the results of this power analysis tests.

DISCUSSION

The results of this study failed to reject the first null hypothesis, which stated that the digital learning group will perform at least as well as the conventional learning group in normalized gains post treatment. This suggests that the digital learning environment acts equally as a scaffolding method in the zone of proximal development as conventional instruction for the cognitive assessment (Vygotsky, 1978). Figure 4.15 depicts the increase in developed capabilities and the shifting boundary of the zone of proximal development for the control and treatment condition. Participants in both groups are now able to complete more of the cognitive assessments. From Vygotsky's theory, we also conclude that these participants are now able to complete more tasks in the cognitive assessment with the help of an instructor or more experienced peer. It is not the intent of the study to measure the zone of proximal development. Instead, the focus is the shift and increase of the developed capabilities for each group.

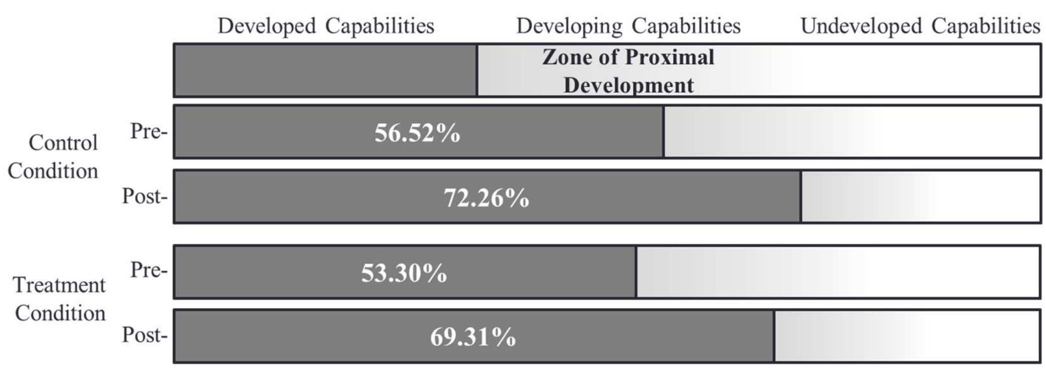


Figure 4.15. Depiction of developed capabilities for both groups pre- and post-intervention.

The results of this study also failed to reject the second hypothesis, which states "the digital learning group will perform as well as the conventional learning group in the skilled-based assessment." This result shows that the digital learning environment, and in particular the virtual reality tools, utilized in this study provide an appropriate scaffolding as the conventional instruction. As you may recall, in the conventional learning instruction, students had the opportunity to manipulate and use the measurement tools for a short period of time. In the digital learning environment, students were not able to manipulate the tools. However, they were able to manipulate the virtual tool for an indefinite period of time through the completion of 10 exercises per tool. Moreover, the conventional instruction provided the social interaction with the instructor and peers, whereas the digital learning instruction did not.

Constructivist theorist Glasersfeld (1922) described teaching as a social activity, but learning as a private activity and further described learning as happening "on the basis of failures and successes of its own actions." Thus, the digital learning environment utilized in this study, in particular the virtual reality tools, provide the opportunity for learning as a private activity as well as, the opportunity for successes and failures. For example, participants in the conventional learning environment had the opportunity to succeed and fail in a group setting when handling the metrology tool, as well as, answering instructor questions and responding to the activities. In contrast, the success or failure of participants in the digital learning environment was based solely on the feedback provided by the digital learning environment. In the virtual reality environment, participants had the opportunity to move, test, and explore the proprioceptive dynamics of the tools and begin to understand how they can successfully measure an object on an individual bases. Similarly, participants receive immediate feedback to whether they have correctly or incorrectly measured the object.

In online learning, the socioconstructivism view of learning and teaching is hardest to achieve. Socioconstructivism "proposes that the meaningful construction of knowledge occurs when a learner interacts with other learners" (Low 2003). This study is not an attempt to completely remove or replace social interaction from the learning. Instead, the ideal application of these results aims to provide flexibility to technical colleges by a showing that a portion of the curriculum can be provided in an online platform while maintaining desired student outcomes. As can be seen by Figure 4.11 and the results of the skilled-based assessment, neither group reached full mastery after one lesson in metrology and metrology tools. Thus, there is opportunity in a social setting to enable interaction with the instructor and other learners. This ideal situation is most commonly referred to as the flipped classroom. The flipped classroom is a pedagogical model in which lectures and homework are reversed. In the context of this study and technology programs, students would complete online lectures with the virtual reality tool, be tested through a cognitive assessments, and class time would be utilized to perform hands-on activities in a laboratory setting, along with discussion of the material covered in the lectures. Even though this pedagogical model has been touted as a way to engage millennial learners (Roehl, Reddy, and Shannon, 2013), research in technology programs like automotive, avionics, or aircraft maintenance technology programs was not found in the literature. The current study could pave the way for future research in the area with this target population.

The result of this study rejected the third hypothesis, which stated that “the digital learning group will score as least as the conventional learning group in the perception of learning measures. As presented in the results section, participants in the conventional learning group reported higher perception of learning in the overall measure, and in the communication of topic construct. These results can be explained by student’s perceptions of online learning. Rotellar and Cain (2016) reported that students who are most familiar with conventional instruction are initially resistant to the concepts of online classrooms which they see as too rigorous (Smith 2013). They also present resistance to move control of their learning from the instructor to themselves (Roach 2014). As reported in the general questionnaire, half of the students in this study had no previous experience with an online learning course. With these factors in mind as well as the added social interaction, it is not surprisingly that students in the digital learning group had a lower perception of learning than the conventional learning group, even though they performed just as well in both the cognitive and skilled-based assessments. For the learning and critical thinking constructs, the results failed to reject the null hypothesis, thus there was no significant difference between the two groups.

Interestingly, results also showed that there was significant difference between how students in the digital learning group (M = 4.075, SD = 0.9716) rated the videos compared to how the conventional learning group (M = 3.59, SD = 1.0414) rated the lectures with a higher mean of participants in favor of the digital learning group. For the activities, however, there was a significant difference between how students in the digital learning group (M = 3.60, SD = 1.105) rated the activities compared to how the conventional learning group (M = 4.14, SD = 0.9545) rated theirs in favor of the conventional learning group, despite the fact that they were the same. The main difference was that the conventional learning group answered the activities together, thus succeeding or failing and learning together; whereas the digital learning group answered these activities individually, thus succeeding or failing and learning individually. A recent study by Kurtz, Tsimerman, and Steiner-Lavi (2014), found that when student where given the opportunity to watch lectures of a flipped classroom when and where they wished, "most preferred to watch the videos at school and with their classmates – possibly to help each other marshal important peer support in the online learning process." It is possible that if participants in the digital learning group were given the opportunity to interact during activities, they may have rated these just as high as the conventional learning group For the subjective question "How much did virtual reality tools contribute to your understanding of the course materials?" the digital learning group gave virtual reality tools a mean of 3.88 (SD=1.067), where 1 was defined as very little and 5 was defined as very much. This mean is slightly lower than their videos score, but more than their activities score.

Following McArdle and Bertollotto's (2012) interpretation of the results of the subjective satisfaction questionnaire, the subscale for information quality scored a high level of satisfaction to the users with 85.23%. This is a similar result from the pilot study described in Chapter Three. Thus, it validates users find the content developed of high quality. Similar to the results of the pilot study, the overall usability, system usability, and interface quality provided a moderate level of satisfaction to users and very likely have contributed to other subjective scales like the workload measures. These results need further investigation to understand what has contributed most to the lower scores of the system usability and interface quality.

The technology acceptance subscales show promising results as well as, opportunity for improvement in the digital learning environment. The two highest scoring sub-scales were Confirmation and Satisfaction with 81.83% and 80.67% respectively. In the 70%-80% range, Continuance Intention (75.75%), Information Quality (70.33%), and Service Quality (70.74%). The lowest scoring sub-scales in the technology acceptance were Perceived Usefulness (61.20%), Perceived cognitive absorption (61.30%), Perceived Ease-of-use (68.60%), and System Quality (68.73%). Similar to the discussion of the perceived learning assessment, participants in the digital learning group reported a low perceived cognitive absorption. However, the cognitive assessment results show that both group had no difference in scores. Therefore, the implication for the digital learning environment may be to provide continuous feedback to support their perception of progress and learning.

To interpret the results of the workload subscales, the researcher defined 0 – 15 as low workload, 15 – 30 as moderate workload and 30 and above as high workload (Knapp and Hall, 1990). Additionally, a total workload score of 40 or above is considered high (Knapp and Hall, 1990). The scales the highly contributed to the workload demands of the participants included frustration (52.55%), mental demand (46.58%), effort (42.12%), and performance (32.05%). Temporal demand moderately contributed to the workload demands of the participants (20.79%). While physical demand contributed the least to the workload demands of the participants (15.00%). All subscale scores increased from the pilot study. Particularly with the subscales that scored above 30%, further investigation must be conducted to determine what factors in the digital learning environment are contributing the most to the workload demand: the web interface, the lectures, the activities, and/or the virtual reality tools.

The results of this second larger study have expanded the current body of knowledge in the field of online learning in technology programs at 2 year institutions. These results have shown that cognitive student gains are similar between both conventional instruction and digital learning with virtual reality tools. In addition, students are able to perform no differently in skilled-based assessments. Though the recommended sample size of 102 was not achieved, the achieved power of the study based on the Hilt communication of topic construct was desirable (0.86).

A limitation of this study is the inability to compare the subjective measures only given to the digital learning group. The findings of the subjective satisfaction survey, the technology questionnaire, and the workload assessment are informative, but provide very limited data to make changes that would impact the results. Another limitation of this study is the lack of peer learning that participants in the digital learning group were exposed to. A future research opportunity could be to compare performance on a skilled-based assessment of students that complete the assessment in small groups vs. those that complete them individually. Another future research opportunity that would enable the researcher to better compare and focus on areas of improvement in the subjective measures could be to have a third group of participants that the digital learning environment without the virtual reality tools. This would reveal the differences in cognitive gains between the two groups, while also helping determine whether the virtual reality tools are providing the most level of frustration (workload measure) or if the interface is to blame. In conclusion, this study provides an argument for incorporating aspects of online learning specifically in technology programs that are traditionally face-to-face instruction only and where online learning is seen as producing lesser student outcomes due to their larger need for hands-on instruction.

CHAPTER FIVE

COMPARATIVE TRANSFER OF KNOWLEDGE STUDY ON A COMPLEX METROLOGY TASK

"Tell me, and I'll forget. Show me, and I may remember. Involve me, and I'll understand"

- Chinese Proverb

Employers have been clamoring to higher education institutions for several years about the shortage of a skilled workforce (Theis, 2010; Shankel, 2010; Dastmozd, 2013). Lack of problem solving skills and critical thinking are among those described by many employers unable find the right people for the jobs that need to be filled. It is no longer enough to have a degree, but those seeking employment must be able to apply current and new knowledge to problems that are faced in a manufacturing plant. This is why transfer of knowledge is an important part of technician education. Knowledge transfer applies to a person's ability to access prior knowledge and utilize it to solve a problem. To understand knowledge transfer for this particular application, the researcher has selected a theoretical framework developed by Rebello et al. (2005) and adapted by Hutchison (2011). This transfer knowledge framework is depicted if Figure 5.1.

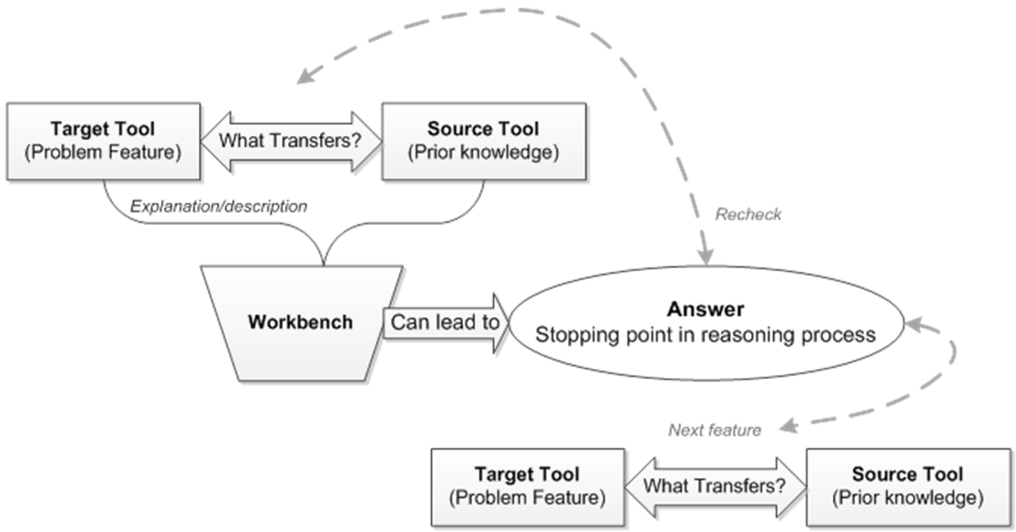


Figure 5.1. Transfer of knowledge framework (Rebello et al, 2005 and Hutchinson, 2011)

The framework consists of external inputs and tools (target tools and source tools) which are used in the workbench to make connections that can lead to answers. This answer can be a final outcome or conclusion, but it also may provide a step up to solving another part of the complex task. When a student reads the problem and observes the bits and pieces of the task, they may identify features or components that are relevant to the problem. These are coded as *target tools*. When a student activates or attempts to activate prior knowledge, these are coded as *source tools*. Source tool instances can also be co-coded as pre-existing from prior knowledge, life experiences, mental models, and such. When pre-existing tools originating from an authoritative source they are referred as *knowledge as propagated stuff*. Tools can also be dynamically constructed during the interview process. For example, a student may, through reasoning, may develop their own definition or mental model of based on external inputs or a previous question. This is known as *knowledge as fabricated stuff*. Instances in which the student connects the external inputs, target tools, and source tools are coded as *workbench*. In the workbench, mental processes like making connections, executing a known rule, reorganizing and restructuring knowledge, decision making, and analogical, inductive, and deductive reasoning can occur. *External inputs* can take the form of resources (lecture materials and other resources) or from the interviewer (protocol questions, follow-up, hints, cues, and clarification questions). The workbench can then lead to an *answer* which is a stopping point in reasoning. These can lead to another target tool, a request for more information from the researcher, or the student's inability to continue on to the next target tool.

Rebello et al (2005) describes three phases to this framework. Phase I involves the interviewer providing external inputs which describe the problem scenario. Priming, or the use of covert meta-messages which activate source tools or created tools, occurs during this first phase. During Phase II, the learner weighs the relevance of the target tools and problem inputs (including external inputs) to be used in the reasoning processes. In Phase II, long-term memory is activated which may lead to the learner utilizing their source tools (including knowledge as propagated stuff) or the learner may develop their own self constructed knowledge (knowledge as fabricated stuff).

The purpose of this study is to further compare the dynamic transfer of knowledge to a complex task between the conventional learning group and the digital learning group.

Research Hypotheses

From the results of the pilot study and the large-scale study, the researcher can safely estimate that, due to the results of post-cognitive and skilled-based assessments, the digital learning is as good as the conventional learning. The researcher was interested in knowing if this instruction can transfer to a complex task utilizing precision measuring instruments weeks after treatment. Yamnil & McLean (2001) emphasizes that "training is useless if it cannot be translated into performance".

Additionally, the researcher was interested in comparing the effect of instruction on the self-efficacy of the two groups. Self-efficacy is an individual's measure of personal mastery expectations which many theorize is the primary determinant in behavioral change (Sherer, Maddux, Mercandante, et al., 1982). To investigate self-efficacy, a problem-solving self-efficacy measure adapted from Bandura (2006) was collected pre- and post- task. Latham (1989) proposed that motivation must be considered as precursor and a product of training. Thus, the following hypotheses and research questions will also be explored and compared between groups. When accessing prior knowledge:

Hypothesis 1: The digital learning group will report their normalized gains in problem-solving self-efficacy at least as well as the conventional learning group.

Question 1: What originates from the treatment (conventional or digital)?

Question 2: What originates from the other authoritative sources such as a textbook or instructor (knowledge as propagated stuff)?

Question 3: What types of transfer occur during the complex task?

METHOD

Participants

All 86 participants that completed the study described in Chapter Four were invited to participate in the second phase of the study described in this chapter. Out of those that volunteered, seventeen were randomly selected from both groups: conventional learning and digital learning. Participants were scheduled to perform this phase of the study two to three weeks after the initial intervention was completed. These participants have already been screened to ensure that they are at least 18 years old, have a 20/20 vision either naturally or through the use of corrective lenses, have no auditory problem either naturally other through the use of corrective equipment, and do not experience any difficulty with motor function. Demographic information such as age, gender, and race was already collected using the general questionnaire.

Apparatus

Participants from both groups were asked to complete a complex problem (Appendix AB) which involved the outside measurement of the main journal on the cam crank and the inside measurement of two pistons. These are depicted is Figure 5.2. To measure these parts, participants had access to precision measurement tools: a Vernier caliper (0-150mm) and one outside micrometer (25-50mm). Participants also had access to a copy of the instructional material (book and PowerPoint slides), a notepad, a pen, a pencil and a four function calculator. Additionally, a Blue Yeti microphone and a laptop computer were utilized to capture the think-aloud process of the participants.

(a) (b)

Figure 5.2. (a) Cam crank and (b) pistons used in complex task

Independent variable

Similar to the previous studies, the independent variable for this study was the mode in which instruction was delivered: conventional learning or digital learning.

Quantitative Dependent Variables

Problem-solving self-efficacy. A problem-solving self-efficacy measure adapted from Bandura (2006) was collected pre- and post- task (Appendix AC). This instrument asked participants to "rate [their] degree of confidence by recording a number from 0 to 100" where 0 denotes that they cannot do the problems at all and 100 denotes that they are highly certain can do the problems. The average of these percentages was calculated pre- and post- complex task. Additionally, the normalized gains were calculated using these percentages.

Experimental Task

The study utilized a between-subjects experimental design. Participants were exposed to one of the two conditions to be investigated:

<u>Group 1:</u> Control condition – current instruction method

<u>Group 2:</u> Treatment condition – digital learning integrated with visualization tools.

A subset from the large scale study were randomly selected for the think-aloud interview two to three weeks from the initial treatment. Figure 5.3 shows the experimental study flow chart with the study described in this chapter highlighted in light blue.

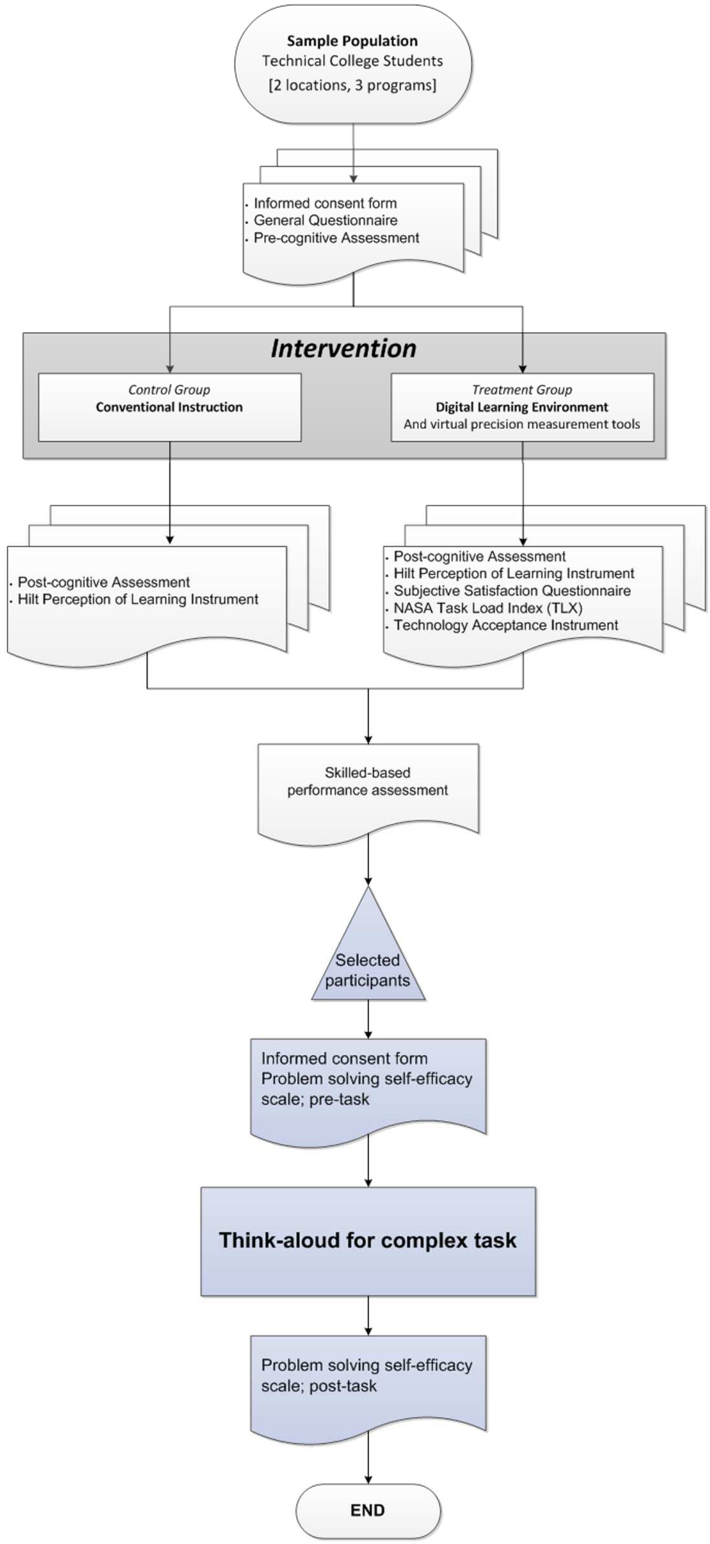


Figure 5.3. Experimental study flowchart

Procedure

The researcher randomly selected participants from the previous study and invited them to participate in this phase II. An email was sent to each participant individually explaining the process and understanding that they would be recorded. After agreement, participants were asked to return to the study location (Charleston, SC or Greenville, SC) and allow for a couple of hours. They were provided a copy of the informed consent form and asked to again verify the information provided in the general questionnaire. At this point, recording began. Each participant was welcomed to Phase II of the study. Each participant was then introduced to the problem-solving self-efficacy scale and asked to complete it pre-task and out loud. Afterwards, the participant was provided with the complex problem and asked to read the problem aloud. The researcher informed the participants of the metrology tools available for them to utilize, presented them with the resource materials, and informed them that they could ask for help if needed. Participants then completed the task. The researcher's role was to remind the participant to talk about their thinking process, as well as answer questions and provide support. Once the participant completed the task, or gave up on the task, they filled out the problem-solving self-efficacy scale again. At the completion of the study, participants received a $10 gift card.

Transfer of Knowledge Coding Structure

The researcher utilized QSR International's NVivo 11 qualitative analysis software to code and reviews the transcribed recordings of the think-aloud process. A framework code book was developed to aid in the coding of the interviews (Appendix

AD). Each transcription was first reviewed and coded by the researcher using NVivo. The researcher focused on coding external inputs, tools, workbench, and answers. A second coding and review, completed at a separate time, was done on paper and highlighted. The researcher reviewed any discrepancies between the two reviews and updated the NVivo codes. At this time, the researcher chose three exemplar interviews per group to code and review for a third time. For the control group, Jessica, Michael, and Matthew were selected. For the digital learning group, Daniel, Austin and Joseph were selected. Pseudonyms have been used. These exemplar interviews were chosen as they provided the best articulation of the mental processes occurring during the completion of the complex task. During the third review and coding of the six selected interviews, the researcher also focused on the types of transfer, activation, associations, and deductive reasoning occurring during the interview, but specifically in the workbench. Codes were added to the NVivo file documenting the above.

Through the review of the think-aloud interviews, the researcher added a code for problem-solving self-efficacy which could be described as negative, when the participant implied a negative view of their capabilities to perform the task; positive, when the participant implied a positive view of their capabilities to perform the task; and neutral, when the participant provided an opinion on their capabilities to perform the task what was neither negative nor positive.

RESULTS

The demographic characteristic of all the 17 participants in the study are presented in Table 5.1:

Table 5.1. Demographic characteristics (N=17)

Variable	N	%
Gender		
Male	14	82.4
Female	3	17.6
Race		
African American	1	5.9
American Indian/Alaska Native	1	5.9
Asian	0	0
Native Hawaiian or Other Pacific	0	0
White	13	76.5
Prefer not to answer	2	11.8
More than one	0	0
Ethnicity		
Hispanic or Latino	1	5.9
Not Hispanic nor Latino	16	94.1
Degree Program		
Automotive Technology	7	41.2
Aircraft Maintenance Technology	10	58.8

Problem-Solving Self-Efficacy

Analysis. SPSS 21.0 was used to analyze the data of the dependent variables: pre- and post-problem-solving self-efficacy scores and the average problem-solving self-efficacy normalized gains. A Shapiro-Wilk test for normality revealed that the post-problem-solving self-efficacy did not fit a normal distribution (p = 0.000), but the pre-problem-solving self-efficacy and problem-solving self-efficacy normalized gains did (p = 0.077 and p = 0.337, respectively). Thus, a Mann-Whitney test was conducted for the post- problem-solving self-efficacy variables and an independent sample t-test was used for the pre-problem-solving self-efficacy and normalized gains variables. Results of the normality test are found in Appendix AE.

Results. The results of the pre- and post- problem-solving self-efficacy scores for the control and digital learning group are shown in Table 5.2.

Table 5.2. Pre- and post- problem-solving self-efficacy scores

	Control Group M(SD)	Digital Learning Group M(SD)
Pre- problem-solving self-efficacy score	80.67% (15.81%)	83.54% (23.21%)
Post- problem-solving self-efficacy score	83.29% (10.99%)	82.14% (19.33%)

A one-tailed independent sample *t*-test indicated no significant difference (t= -0.355, p = 0.3635) between the problem-solving self-efficacy scores before the complex task was attempted/completed for the conventional learning group (M = 80.67%, SD = 5.27%) and digital learning group (M = 83.29%, SD = 4.49%). Similarly, no significant difference was found between the groups in the post- problem-solving self-efficacy scores (U= 30.00, p= 0.330). Figure 5.4 and 5.5 illustrate the bar graphs for the pre- and post- problem-solving self-efficacy scores. Also shown are the problem-solving self-efficacy scores for the selected participants of the think-aloud interviews.

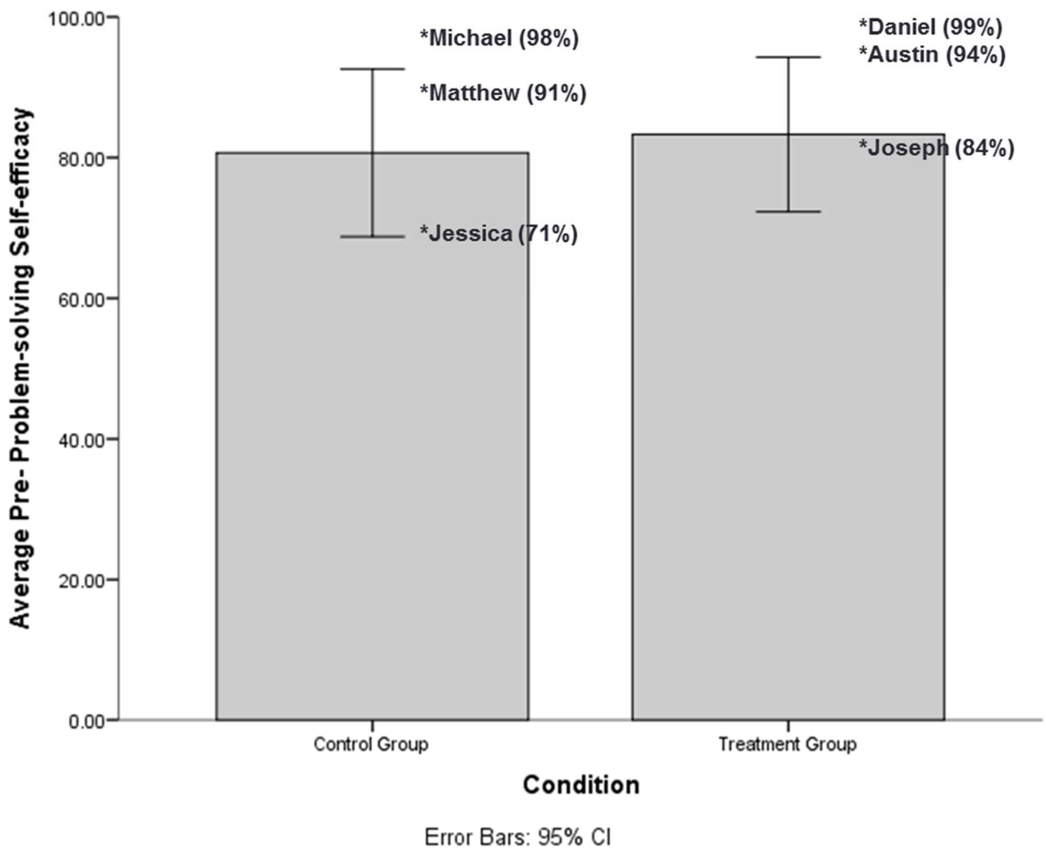


Figure 5.4. Bar graph for the pre-problem-solving self-efficacy scores with selected participants identified.

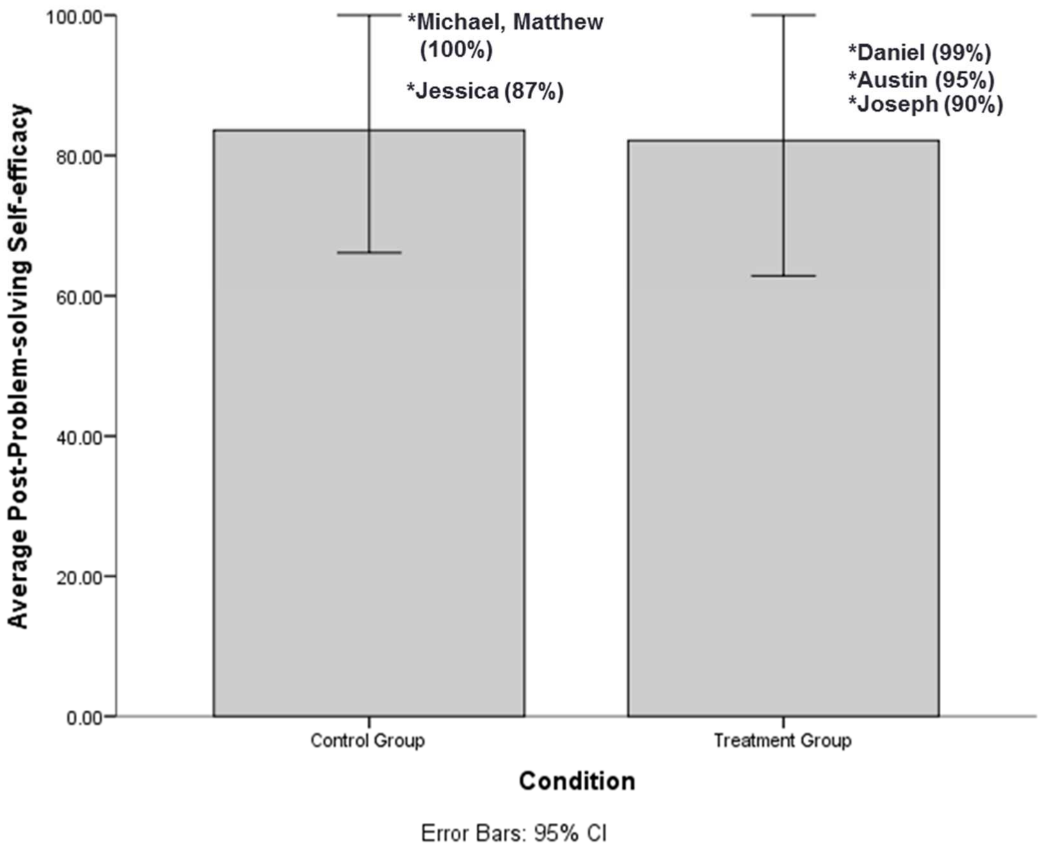


Figure 5.5. Bar graph for the post-problem-solving self-efficacy scores with selected participants identified.

Normalized Gains. To better understand whether going through the complex task had any comparable effect between the two groups, normalized gains were calculated using the following formula:

$$G = \frac{PostCog\% - PreCog\%}{100 - PreCog\%}, \tag{5.1}$$

where *G* is the normalized gains, *PostCog%* is the post problem-solving self-efficacy score, and *PreCog%* is the pre problem-solving self-efficacy score.

The normalized gains for the problem-solving self-efficacy were determined to fit a normal distribution by Shapiro-Wilk to test for normality (p= 0.337). A one-tailed independent sample *t*-test of that the mean normalized gains for the conventional learning group (M = 0.379, SD= 0.583) and digital learning group (M = 0.081, SD = 0.512) showed no significant difference, $t(15) = 1.088$, $p = 0.149$. Average normalized gains for both groups were positive which tells us that the groups did not lose problem-solving self-efficacy after completing the task. Though not significantly different, the conventional learning group did have a higher average normalize gains. Figure 5.6 illustrates the bar graph of the normalized gains. Figure 5.6 also shows that the 95% confidence interval for the normalized gains for the control group remains mostly positive between -0.038 and 0.795. Whereas, the 95% confidence interval for the digital learning group had a lower bound of -0.392 and an upper bound of 0.554.

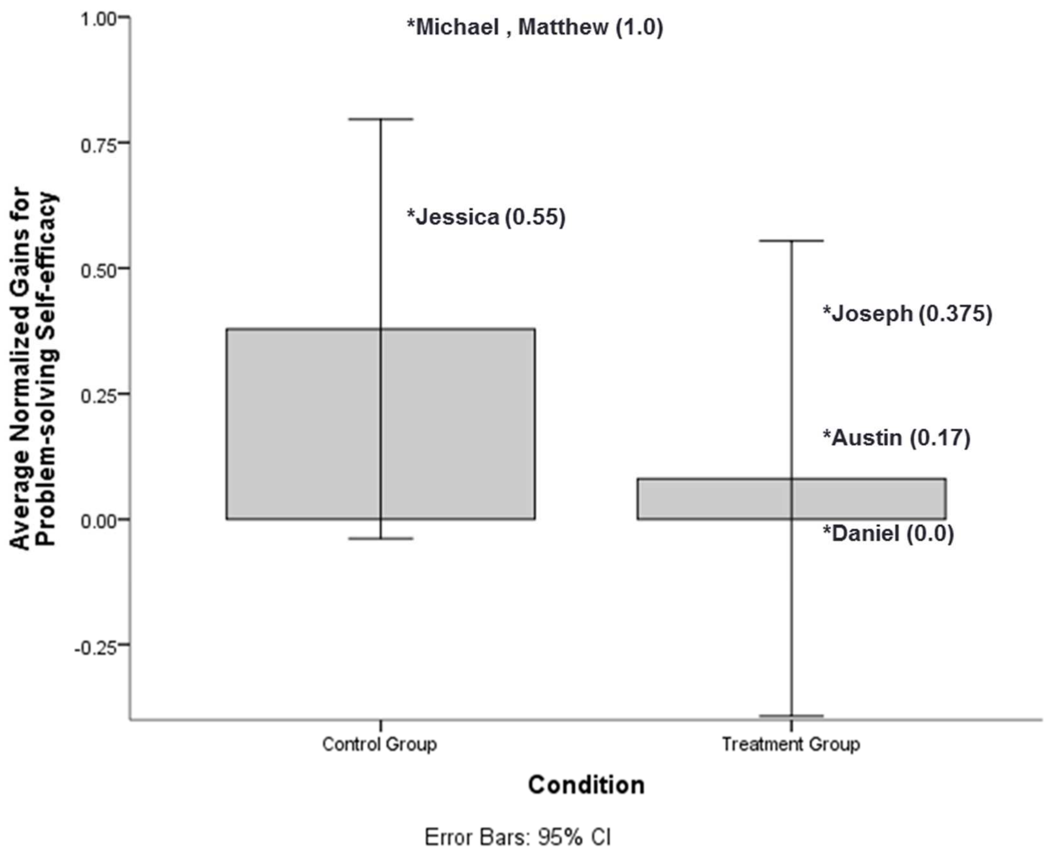


Figure 5.6. Bar graph of the mean normalized gains for problem-solving self-efficacy with selected participants identified.

Qualitative Findings

The following section outlines the qualitative findings of the think-aloud interviews and explores the tools, mental processes in the workbench, and scaffolded and spontaneous transfer observed. The section also presents two themes: metric versus English measuring system and the attitudes towards the digital learning environment.

Tools. Participants from both groups had instances of target tools and source tools. Rebello et al. (2005) defines target tools as features of the problem that the student identifies as useful in the execution of the problem. A source tool, on the other hand, is pre-existing knowledge or experiences that the student retrieves from memory to solve the problem (Rebello et al., 2005).

Participants identified the main journal of the cam crank, the pistons, and the difference between the two as target tools of the problem. Some identified specifically the outside diameter of the main journal and inside diameter of the pistons as target tools. For example, Michael from the conventional learning group identified all three target tools right after reading the problem: “So, I need to figure out the diameter of this [main journal] and the diameter of the piston. And check for clearance of 0.25 millimeters.” Daniel from the digital learning group also identified all three target tools, but did so in a series of steps: “First, I am going to measure the cam crank.” He completed the measurement and then said commented: “Next, I am going to measure the inside diameter of the connecting rods.” Daniel did not specifically identify the clearance as the target tool, but did use it when determining the answer as to which piston would fit best.

Source tools, however, were not as easily drawn from the interviews as the target tools. They appear to be used in the workbench, but only two true instances of source tools were recorded from the same participant, Matthew. Matthew from the conventional learning group said “As I recall on these things, you take a micrometer reading at 90 degrees out and see what your micrometer reading is and to see if its true first.” Matthew also shared an anecdote about being exposed to measurement tools, rebuilding of motorcycle engines, and tolerances. This excerpt can be found in Appendix AF.

The workbench. According to Redish (2003) and Rebello et al. (2005), the workbench utilizes external inputs and tools in the mental processes. These processes include: executing a known rule or procedure, associations or connections between tools, assimilation, accommodation, analogical, inductive and deductive reasoning, and decision making. Thus, the participant interviews from both groups revealed instances of several of these mental processes.

Several participants from both groups articulated and executed known procedures when utilizing the tools. These known procedures included: lining up the zero on the main scale with a number on the Vernier scale, locking the tool to ensure the measurement wouldn't move when ready to read, and splitting the difference when a measurement read between two numbers.

Participants also articulated associations or connections between tools. These came in the form of associating the target tools (cam crank and pistons) with the measuring tools. For example, all participants utilized the inside jaws of the Vernier calipers to measure the inside diameter of the pistons. Similarly, all participants utilized either the outside jaws of the Vernier caliper or the outside micrometer to measure the main journal. Also implied in both these scenarios is the decision making process that participants took when choosing the tool they would utilize to measure the cam crank and pistons. Another association that was common among both groups was the subtraction of the measurement of the main journal from the measurements obtained from each piston to check with the clearance.

Though not as common as the previous two mental processes, the interviews also revealed instances of deductive reasoning. One of these instances is from Jessica, a participant from the conventional learning group. When referring to the solution of the problem, she said “I’ve got to figure out which one of these [pistons] won’t fit properly.” Deductive reasoning and decision making also play a role in developing an answer for this complex problem. Joseph, from the digital learning group, selected piston one as the piston that would best fit the main journal of the cam crank. When prompted by the researcher why the second piston would not work, Joseph replied that “it would be too small.”

Scaffolded and spontaneous transfer. Rebello et al. (2005) defined dynamic transfer as the “creation of associations between target tools read out from the external inputs and source tools activated from long term memory.” Scaffolded transfer occurs when transfer is “facilitated by direct and conscious inputs of the interviewer, which would prompt the student to dynamically create associations” (Rebello et al., 2005). Spontaneous transfer, on the other hand, occurs without external inputs. In the participant interviews, the researcher was able to observe instances of both scaffolded and spontaneous transfer. Two instances of scaffolded transfer, one in each group, involved the use of the instructional materials to guide participants to a solution. Another instance of scaffolded transfer came from Austin from the digital learning group. In this case, the researcher provided external inputs and guided Austin on how to read a metric micrometer when measuring the main journal. The external inputs included reminding him that he was measuring in metric, not in the English system and that the micrometer would only measure between 25 and 50 mm. These two external inputs were enough for Austin to correctly measure the main journal. For Michael from the conventional learning group, scaffolded transfer occurred in an exchange with the researcher shared below.

> **RESEARCHER**: So you're saying that this piston that measures 45.85 millimeters can fit around the main journal that measures 45?
>
> **MICHAEL**: Oh, I guess not, when you put it like that. Okay. Yeah, that's wrong them. So it's too small, so let's do the other one. Kind of funny when you doing eve think about stuff like that… alright.

The instances of spontaneous transfer often occurred in the workbench where participants are actively making connections between the tools. A participant, Matthew from the conventional learning group, expressed an instance of spontaneous transfer when he acknowledged having never measured the inside of pistons. In the workbench, he was able to connect his source tools of measuring inside measurements and transfer that knowledge to this new situation of measuring the inside of the pistons. Matthew had another instance of spontaneous transfer after he had measurements for all three components: the main journal and the two pistons. He had initially said that either piston would work and meet the clearance of 0.25 mm. After a few more seconds of think aloud discussion he realized that only one of the pistons would work as only one has a larger inside diameter than that main journal.

Metric versus English measurement system. When conducting and reviewing the interviews, the researcher noticed a few participants either struggling with or providing negative comments about utilizing the metric system for completing the complex problem versus using the English system. Joseph, from the digital learning group, would have preferred an inch micrometer because he is most familiar with the English system as opposed to the metric system. Additionally, Austin also from the digital learning group expressed negative feelings to utilizing metric rather than the English system. Matthew from the conventional learning group did not suggest wanting to use one measurement system over another, but rather had to "recall" how to utilize the metric measurement system and tool. However, it is important to note that automotive technology programs, to which both Austin and Joseph belong, must teach both the English and Metric measuring system because students will encounter vehicles with specifications and tolerance in both systems. In some cases, vehicles have parts whose specs are in one measurement system, and other parts that are in another measurement system, thus they must nimbly switch from one to another. These are clear differences expressed by the digital learning group. Matthew, on the other hand, is enrolled in the aircraft maintenance program and is primarily required to read English system tools.

The digital learning environment. Two participants, Daniel and Austin, from the digital learning environment provided feedback about the instruction in the think-aloud interviews. Daniel articulated that he thought "the online [materials] helped, but I would not be this confident if I had not done the practice in class like we did." This notion is consistent with LaBay & Comm's (2011) findings that students perceived less learning when utilizing online environments, as well as our findings from the perception of learning results from Chapter Four which showed a statistical difference between the two groups in favor of traditional instruction.

Additionally, Austin expressed that the digital learning instruction "prepared me, but … the teaching really hit home in the classroom." Utilizing Vygotsky's Zone of Proximal Development (Vygotsky's 1978) as a framework this comment validates the notion that digital learning instruction increased the developed capabilities, shifting boundaries with appropriate instruction, and moved the zone of proximal development to a level that could then help the instructor continue to expand on the developed capabilities of these students to a higher level of mastery.

DISCUSSION

Problem-Solving Self-Efficacy

The results of the problem-solving self-efficacy scores show no statistical difference in the problem-solving self-efficacy before the complex task was completed when comparing the control group and the digital learning group. Similarly, the test of the normalized gains of the problem-solving self-efficacy measures for the control group and the digital learning group showed no statistical difference. At this time no any generalizations due the small sample size (N=17) in this study. Investigating problem-solving self-efficacy is important when comparing these two groups. From research around math self-efficacy and performance, we find multiple studies suggesting that students with high self-efficacy not only outperform students with low self-efficacy, but they also persisted longer in working through problems that were initially incorrect (Collins 1982; Siegel, Galassi, and Ware 1985). Pajares and Miller (1994) found that a "student's judgment about their capability to solve math problems were more predictive of their ability to solve those problems" compared to math self-concept, math anxiety, and perceived usefulness of math. In the context of this study, it is encouraging that both groups reported an average problem-solving self-efficacy score before and after the complex metrology task above 80%. If results are validated with a future study, it suggests that student's self-efficacy is not hindered by the use of the digital learning platform. More closely related to our study, Hung, Huang, and Hwang (2014) compared the self-efficacy scores of three groups: digital game-based learning group, an e-learning group, and a traditional instruction group. They found significantly higher self-efficacy scores in the digital game-based learning group and the e-learning group compared to the traditional instruction group.

The researcher recommends that another study be conducted with a larger sample size in order to draw better conclusions. It is important to keep in mind that the participants in this study also received instruction and hands on training from the time they completed the large scale study described in Chapter Four to the time they completed Phase II. Therefore, the problem-solving self-efficacy instrument could be administered at various stages of the study. For example, the problem-solving self-efficacy instrument could be provided after the intervention condition, after the skilled based assessment, a week after the intervention condition, two weeks after the intervention condition, before the complex task and after completing the complex task. This could present a clearer picture of the growth and/or decline of the participants' problem-solving self-efficacy throughout the life of the study in order to pinpoint when an intervention is needed and if something in the classroom is causing a growth or decline.

Qualitative Data

The think-aloud interviews provided an authentic view of the mental processes and struggles during the application of metrology instruction on a complex metrology task for participants in technology programs. The following section discusses the results of these implications to instruction, curriculum development and scaffolding throughout.

The instances of scaffolded transfer in the think-aloud interviews revealed an opportunity for students to reinforce previous instruction. There are three types of scaffolding, as classified by Holton and Clarke (2006). These are expert scaffolding, reciprocal scaffolding, and self-scaffolding. Increasing the opportunities for students to experience reciprocal scaffolding with peers and expert scaffolding with instructors could better cement learning processes. According to Bacon, et al. (1999), students who find group activities more interesting than conventional learning have shown better academic performance and motivation. We have previously described self-scaffolding as spontaneous transfer. We encountered cases of self-scaffolding or spontaneous transfer in the think aloud interviews. For example, Michael worked through the problem, caught himself making mistakes and corrected them almost immediately. Thus, utilizing complex tasks in an individual or in group to reinforce learning could be helpful especially for hands-on learning and can provide a means of reciprocal scaffolding.

Another opportunity for improved or more focused instruction was revealed with participant's struggles and comments between utilizing the metric and English systems of measurement. These struggles are of course not unique to the participants in our study and have contributed to losses in the past. The most notable example is NASA's loss of a $125 million Mars orbiter when a Lockheed Martin engineering team used English units while the NASA team was utilizing the metric system (Lloyd, 1999). Instruction and curricula could focus on the similarities and differenced when measuring with metric tools versus English system tools. Jaworski (1985a,b) proposed a general model of measurement showed in Figure 5.7. This model shows that the general approach to measurement involves planning, organization and execution of measurement. The model places the measuring system in between the mathematical model of the object (length, weight, mass, etc.) and the parameters (i.e., measurement) of the object. Thus the measuring system is integral in the execution of the measurement.

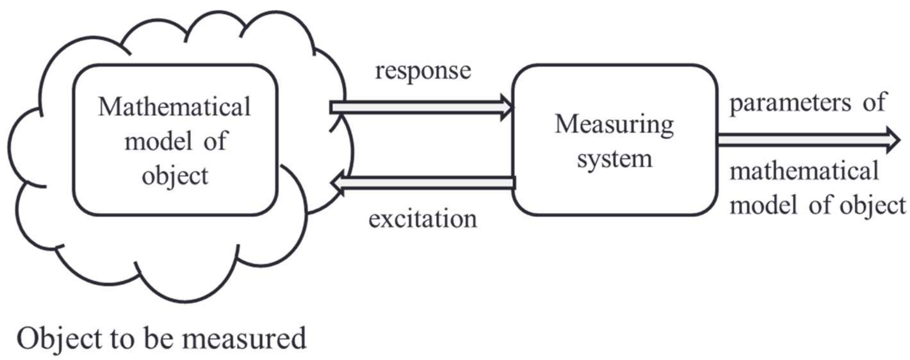


Figure 5.7. General model of measurement (Jaworski, 1986a,b)

The findings of the think-aloud interviews may hint at a deficiency in the instructions in providing nimbleness for participants to move easily between measuring systems and its tools. In addition, participants seemed to prefer to measure in the English system, thus exploring the reasons why this is the case could also provide better insight into what was found in the interviews. One possible explanation is that they may have had more exposure to the English system post instruction. However, since all participants live in the United States, they have had more exposure in their lifetime to the English system compared to the metric system. The study could also have been performed differently by providing participants with both metric and English system tools and had participants decide which measurement system they preferred to use to complete the complex task.

A significant finding from the think-aloud interviews were Daniel and Austin's attitudes towards the digital learning materials. This is especially important if technical colleges would want to move into a flipped classroom model. The digital learning environment needs to provide participants with confidence in the activities and in particular the virtual reality components. Integrating better and more frequent feedback loops in the digital learning environment can instill more confidence in participants. Students tend to ask for more synchronous feedback when working alone (Gillet et al., 2003) and would benefit from this feedback as they navigate through the digital learning environment.

Setting expectation for students could also improve their perceptions of the digital learning environment. From Daniel and Austin's comments, we can imply that they expected to achieve a much higher level of mastery after the instruction. Instruction provided in the digital learning environment was meant to be a starting point for student to gain basic understanding of metrology and the basic measurement tools. Further instruction and hands on activities were meant to provider further mastery of the study area.

Problem-Solving Self-Efficacy: Comparing Quantitative and Qualitative Data

When completing the pre- and post- problem-solving self-efficacy instrument, some participants shared positive, negative and neutral comments about their confidence in completing metrology problems. This section aims to explore how the quantitative data compares with their expressed confidence and the mental processes in the workbench. In general, of the six selected interviews, participants from the digital learning group reported lower gains than those from the conventional learning group.

Interestingly, five out of the six selected think-aloud participants increased problem-solving self-efficacy scores. Daniel from the digital learning group was the only participant whose self-efficacy scores stayed the same (99%). The most interesting finding was for Jessica from the conventional learning group. She reported the lowest pre- and post- self-efficacy score, 71% and 87%, respectively; and exhibited the least gains from the conventional learning group. During the think aloud, she provided a neutral comments "I have the ability. I could do it, but I make mistakes." However, she did not struggle when completing the complex task and only required one external input of validation that she was on the right track. During her workbench processes, she exhibited use of target tools, associations, and quickly and without hesitation provided correct answers to the problem. In contrast, Joseph from the digital learning group began with a pre-problem solving self-efficacy of 84%, struggled throughout the complex task with various instances of scaffolded transfer. He reported a self-efficacy score post complex task of 90%. Joseph backed his confidence pre-task by commenting "I normally don't get low grades like that" and after completing the task by saying "Well, now I can do it. I was just confused." Matthew and Michael, both from the conventional learning group, provided unsure comments that about solving metrology problems. Michael said "I'm going to have to brush up on that one again" and Matthew said "I haven't done that much of this. But let's see here." They both reported self-efficacy scores above 90% (98% and 91%, respectively). Both provided average self-efficacy scores post-task of

100%. Afterwards, they both provided positive comments about their confidence in solving metrology problems. Both Michael and Matthew exhibited dynamic and spontaneous transfer in their think-aloud interviews and required external inputs to solve problems. These findings do not show correlation between a higher self-efficacy score and higher mental processes occurring in the workbench. A possible reason for this is that participants were asked to fill out the problem-solving self-efficacy instrument when thinking of any and all metrology problems. Each participant may have had a different mental model of what these problems entail. Participants might not have had the same experiences with metrology problems. Thus, it would have been best to define a reference problem when they were asked to fill out the instrument. This problem could have been one from the previous study or the complex task itself.

Implications for Instruction

The implications for instruction in the technical colleges and in particular technology programs are varied. Instructors could utilize online learning to focus more on hand-on learning tasks than in traditional lectures, thus moving optimizing the movement of the Zone of Proximal Development when students have some developed capabilities and are not starting from zero. This form of instruction is usually described as a flipped classroom. Toivola and Silfverberg (2014) describe the flipped classroom as moving the student towards a more learner-centered approach where the student's self-regulation increases, while the teacher's controls decreases. Because learners are more in control of their learning, Toivola and Silfverberg continue, students are able to continue their learning in the classroom at a level that best fits their zone of proximal development.

A future research opportunity could be to compare self-efficacy, performance and think aloud interviews when the complex metrology task is completed in small groups (2-3 students) vs. to those that are completed individually. Additionally, having additional points of contact throughout the study would be helpful in understanding the types of scaffolding activities conducted in the classroom that are helping students gain (or lose) self-efficacy in solving metrology problems. In conclusion, this study provides an argument for incorporating aspects of online learning specifically in technology programs that are traditionally face-to-face instruction only and where online learning is seen as producing lesser student outcome due to their larger need for hands-on instruction.

CHAPTER SIX

CONCLUSION

Two-year technical and community colleges serve their communities by providing educational opportunities in the form of certificates or two year degree programs. Industries seek these students because they are a highly skilled workforce that they need to fill their sought after jobs quickly. However, technical and community colleges are not able to fill the demand that industries have for these jobs. Expansion of the physical infrastructure for these programs is costly and not quick enough for industries. Thus, online and hybrid education programs are often seen as a solution. The constraint with technology programs, however, is that they heavily rely on hands-on training of tools and equipment. This dissertation compared the effects on performance and knowledge transfer of traditional classroom lectures in technology programs versus online lectures and visualization tools, henceforth referred to as digital learning, for a specific topic: metrology and linear precision measuring instruments. The theoretical framework utilized throughout this dissertation is Vygotsky's Zone of Proximal Development (Vygotsky, 1978).

The first pilot study compared the effects on performance specifically between these two groups. The results found that there was a statistically significant difference in the gains made by the groups in favor of the digital learning. No significant differences were detected for the skilled-based assessment or perception of learning instrument. This suggested that, when it came to the hands-on skills, the digital learning instruction prepared participant at least as well as the traditional face-to-face instruction.

Additionally, the groups did not perceive their learning any differently from each other. The pilot study results were limited by the small sample size of the population (N=28).

Next, a large-scale investigation utilizing a slightly adapted experimental procedure and educational interventions from the pilot study was conducted. In this study, a total of 86 participants were involved. The results of this study failed to reject the null hypotheses for the cognitive and psychomotor assessments. These result show the digital learning environment in this study provides the appropriate scaffolding at least as well as the conventional instruction. However, for this study, the digital learning group had statistically significant lower scores than the conventional learning group when it came to their perception of learning. This could potentially influence self-efficacy about the topic and could deter students from utilizing the online tools (LaBay & Comm 2011).

The final investigation was an extension of the large-scale study and focused on the transfer of knowledge that occurs from the learning intervention and during the completion of a complex metrology task. Results found no significant difference between the groups for the pre-, post, and normalized problem-solving self-efficacy scores.

A transfer of knowledge theoretical framework developed by Rebello et al. (2005) and adapted by Hutchinson (2011) was used to analyze the think aloud interviews recorded while participants completed the complex task. The analysis identified instances of the use of tools, mainly target tools or problem features. Source tools were not as evident in the think aloud interviews, but were implied in the mental processes of the workbench. Furthermore, instances of scaffolded and spontaneous transfer were documented. Two themes also emerged from these interviews. The first was the confusion and frustration of participants having to utilize the metric measuring tools versus the English measuring tools. It appears that some participants possess a better ability to switch from metric to English and vice versa with ease, while others struggled with the task. The second theme identified in the interviews was perception from students that the digital learning environment did not provide them with their desired level of mastery. Comments, however, showed that they felt best prepared after hands on activities and further reinforcement of the tools in the classroom.

Limitations and Future Work

The studies in this dissertation have inherent limitations. In the first study, the researcher has already identified sample size as a limiting factor. Another limitation of this study was that the population of students originated from entry level mathematics courses. These participant's degree majors varied immensely and did not accurately portray our true target population.

A limitation for both the first and second study was that the NASA TLX workload instrument was only administered to the digital learning group. This was identified as a missed opportunity to compare both groups' total workload when experiencing the different instructions which could have led to better understanding on where to focus improvements in the overall instruction and in particular the digital learning. Additionally, comparison references were found for both the NASA TLX and Subjective Satisfaction instrument result. However, comparison references were not found for the technology acceptance instrument.

In the second study, another limitation of is the unknown effect that virtual reality tools have on the participant's performance in the digital learning instruction. Thus, future work could divide participants into three groups: conventional learning, digital learning with virtual reality tools, and digital learning without virtual reality tools. This can help better inform of the effect that utilizing the virtual reality tools has on the cognitive assessment, the skilled based assessment and the perception of learning instrument. Additionally, a statistical comparison could be made between the digital learning groups to explore how the virtual reality tools affect, positively or negatively, the subscales of usability, the technology acceptance constructs, and the workload measures. A final limitation for both the pilot study and the large scale study involve the completion of the usability and the technology acceptance instruments. These are both subjective, self-reported measures that are not as concrete as the performance based measures. They provide the research team with baseline information on what to improve in the digital learning environment.

In the final study, sample size (N=17) was also a limitation for the pre- and post-problem-solving self-efficacy scores. Utilizing the problem-solving self-efficacy instrument itself is a limitation as it is a self-reported measure where students may not have the same mental model of metrology problems when completing the instrument. In terms of the transfer of knowledge interviews, the qualitative data failed to reveal clearly what knowledge was transferred from the instruction or from previous experiences. A final limitation of this study is the fact that students continued learning and utilizing linear measuring instruments in the classroom. Thus, the effects on problem-solving self-efficacy and the transfer of knowledge cannot be solely attributed to the intervention condition. This was evident with student requesting other instruments than those the materials utilized.

Implications for Instruction

Even with the limitations described in the previous section, there are various lessons that can be gained from this work that can be applied to instruction in the classroom. First, students are able to gain knowledge through online learning platforms and virtual reality tools and are able to perform at least as well in psychomotor assessments compared to traditional face-to-face instruction. However, instructors and students must understand that completing the digital learning material will not guarantee full mastery of the topic and tools. As evident from Daniel's comment in which he says "the online [materials] helped, but I would not be this confident if I had not done the practice in class like we did." Therefore, instructors should not shy away from online learning platforms in order to provide instruction, whether it introduces a topic to students or it is used for remedial purposes. This could have various advantages. Instructors can utilize the time they spent lecturing to a more hands-on, problem-based instruction during class time. Technical and community colleges can also better utilize their current resources and bricks-and-mortar to maximize the number of sections that they can host at one time, thus increasing enrollment and more nimbly meeting industry demands. A recent market trend report stated that flipped classrooms are expected to "grow at a compound annual growth rate of 35% between 2016 and 2020" and cited three factors contributing to this growth: (1) leveraging devices and infrastructure, (2) availability of online content, and (3) student retention (Chang 2016). Additionally, the use of complex problems in both individual and group settings can help instructors gauge what students know and don't know about the topic depending on the amount of assistance and the types questions they receive. Then, they can provide either individualized instruction on small items or recommend remedial instruction in the online format.

This dissertation focused on the instructional materials for metrology instruments and was able to show that students that received instruction on this topic through a digital learning platform with virtual reality tools were able to perform as well as those that received instruction in a traditional face-to-face classroom setting. Though the topic was narrow, the investigation was in depth. Thus, further study is recommended with other technology related topics and this dissertation can serve as an illustration on how to adequately compare these two instructional methods.

CHAPTER SEVEN

EXTENSION OF RESEARCH

The research presented in this work provided an in depth look at one domain equivalent to just a few classes in a technology program. Thus, expansion of this research is necessary. This chapter addresses methodological changes, expansion to other domains, expansion into other technologies, diversity in population, and the generalizability of this work.

Methodological

For future research, there are various recommendations and expansions that are suggested. First, to investigate the effect of the virtual reality components on the learning outcomes, it is recommended that a third group be added whose treatment is only the recorded lectures. Conversely, this third group could still be exposed to the virtual reality tools, but less so than the digital learning group was for this study. For example, a digital learning group could be required to complete five scenarios for each instrument, whereas another digital learning group is required to complete ten. Additionally, other technologies like augmented reality or immersive virtual reality that provide similar tool interactions could also be compared against the virtual reality tools.

For the qualitative study address in Chapter Five, it is recommended that more focus be placed on working with the technical instructors to better understand the type of reinforcement that occurs in the classroom post treatment. Adding a few checkpoints with a subset of students could also provide insight on the types of instruction between treatment and complex task that helped or hindered learning. Also, a more complex task or more proving questions from the researcher revealed more information about the student's source tools, their mental processes and their attitudes towards the two measurement systems and the digital learning environment. In addition to modifying the complex task, future work could compare think aloud interviews between individuals and small groups of two to three participants. This expansion could reveal instances of the various types of scaffolding: expert scaffolding, reciprocal scaffolding, and self-scaffolding (Holton and Clarke, 2006) and which ones are more effective to lead to transfer. Comparing the types of scaffolding that can occur in individual vs group setting can reveal which is best suited for completion of complex task for students pursuing technology degrees or certificates.

Expansion to other domains

The framework presented in this research could also be expanded into other novel domains. The expansion into other technology and engineering fields is easily foreseen; especially in areas where tools and materials can be cost prohibited. On the other hand, this research and the use of these technologies can be expanded into domains like trauma medicine, surgery, and bomb disarming were practitioners would have the opportunity to test their knowledge and skill under high stress, life and death situations. In addition, they could explore through play the "what-if" scenarios that would otherwise be life threatening in the real world.

Expansion with other technologies

With constant advancements in technology and lower costs of equipment, the expansion of this research to other domains with new technologies is not hard to envision. For example, the effects on learning outcomes of embedding interactive augmented reality models into textbooks, lectures, or laboratories could be explored. Additionally, virtual reality headsets that utilize smart phones could be used to immerse students in educational experiences including interactive lectures, virtual reality tools, or immersive activities.

Comparing technologies is one aspect that can be explored. More interesting, however, is to better understand the balance between technology and social interaction – in classroom hands-on problem solving, peer-to-peer learning, and instructor led education/facilitation. At which point does technology move from advancing learning outcomes and to negatively affecting learning and transfer of knowledge? Moreover, specific modalities may be more beneficial to some students versus others due to various factors like individual differences, individual preferences (online vs. face-to-face), gender, and the type of problem.

Diversity in target population

The studies presented in this dissertation targeted students in three technology programs: Automotive Technology, Aircraft Maintenance Technology, and Avionics Maintenance Technology. This was purposeful as the researcher wanted to specifically test students who find the topic, metrology, useful in their degree of study. However, this limited the diversity in the population that was studied. Table 4.1 shows that 93.0% of participants in the large scale study were male, 75.6% were white, and only 11.6% were Hispanic or Latino. The researcher was therefore not able to test for gender, race, or ethnic differences in the study. Thus, an expansion of this research could increase the diversity of the target population and aim to explore differences in learning outcomes, perception of learning, and problem-solving self-efficacy between females and males, between races, and/or between ethnicities.

Generalizability

The findings of this work serve as a basis of generalizability for the study's domain to the target population. These findings are easily replicated with students from the Automotive, Aircraft Maintenance, and Avionics Maintenance Technology programs. It is recommended that this model is utilized to develop generalizations across other 2-year technology programs like Computer Numerical Control (CNC), Engineering Design, Machine Tool, and Mechatronics Technology programs to name a few.

The 2-year technology population is quite unique and very different from traditional undergraduate engineering and science programs. It was both challenging and rewarding to work with them on this endeavor. Many of the participants have had one or more careers before joining the programs. Others were only months out of high school. This population diversity brought varied perspectives on this work. Therefore, it is highly recommended that generalizations from this research not be made for groups outside the 2-year technology programs.

APPENDICES

APPENDIX A

Recruitment Email

Dear <First_Name> <Last_Name>,

With the collaboration of Greenville Technical College, the Center for Workforce Development is looking for participants for a research study. You are receiving this email because you are a student enrolled in MAT 155 at Greenville Technical College and are considered to be in the target population for the study. Your email address was obtained through the Mathematics Department at GTC.

The research study will focus on the effects of digital resources on student learning. If you take part in this study, you would will receive instruction on basic measuring instruments and then complete a series of surveys and questionnaire about the platforms and the learning you received. The study will take approximately 3 hours of your time. To be able to take part in this study, you must be at least 18 years old and enrolled in MAT 155 at GTC. For your time, you will receive a **$25 Wal-Mart gift card**.

If you are interested in participating in this study please register by completing this short survey at https://www.surveymonkey.com/s/GTCresearchstudy. If you have any questions about the study, please contact Melissa Zelaya at zelaya@clemson.edu or call (843)730-5065.

Thank you for your consideration!

--

MELISSA ISABEL ZELAYA | *Program Manager*
Clemson University | Center for Workforce Development

APPENDIX B

Pilot Study's General Questionnaire

Participant #: ___________________ (*This will be filled out by the test administrator*)

DEMOGRAPHICS

Age: ________________________________

Gender: ☐ Male ☐ Female ☐ I prefer not to answer

Race: ☐ African American ☐ American Indian or Alaska Native
☐ Asian ☐ Native Hawaiian or Other Pacific Islander
☐ White ☐ I prefer not to answer

Ethnicity: ☐ Hispanic or Latino ☐ Not Hispanic nor Latino

What degree(s) are you currently seeking? ___________________________________

PREVIOUS EXPERIENCE

Have you ever used a machinist's or metric scale?

☐ Yes ☐ No

If you answered yes, what do you consider is your level of mastery?

1	2	3	4	5
Low Mastery		Medium Mastery		High Mastery

Have you ever used a Vernier caliper?

☐ Yes ☐ No

If you answered yes, what do you consider is your level of mastery?

1	2	3	4	5
Low Mastery		Medium Mastery		High Mastery

Have you ever used an inside, outside or depth micrometer?

☐ Yes ☐ No

If you answered yes, what do you consider is your level of mastery?

1	2	3	4	5
Low Mastery		Medium Mastery		High Mastery

Have you ever taken an online course?

☐ Yes ☐ No

Have you ever utilized a digital tool that mimics a workshop or laboratory setting?

☐ Yes ☐ No

If you answered yes, what was your level of satisfaction while utilizing this digital tool?

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

OTHER

Do you experience difficulty understanding soft or whispered speech?

☐ Yes ☐ No ☐ Sometimes

Do you have normal vision (20/20) either naturally or by the use of corrective lenses?

☐ Yes ☐ No

Do you experience difficulty with motor functions?

☐ Yes ☐ No ☐ Sometimes

APPENDIX C

Ineligibility Email

Dear <First_Name> <Last_Name>,

Thank you for your interest in our research study! Unfortunately, we are not able to select you to participate based on your level of mastery of basic measuring instruments.

We will be conducting research studies on other topics including electricity, quality, safety, manufacturing process, among others in the coming months. If you would like to be part of a future research study, we would gladly add you to our mailing list.

To learn more about our work, please visit our website at www.clemson.edu/cucwd. To receive our quarterly newsletters, sign up here!

If you have any other questions, please contact Melissa Zelaya at zelaya@clemson.edu or call (843)730-5065.

Thank you for your interest and your time!

Melissa

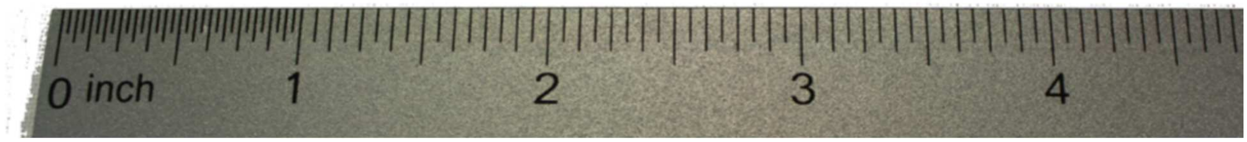
--
MELISSA ISABEL ZELAYA | *Program Manager*
Clemson University | Center for Workforce Development

APPENDIX D

Pilot Study's Pre-cognitive Assessment

Participant #: ___________________ (*This will be filled out by the test administrator*)

1. Using the rule below, determine (a) the measuring system being used (b) the unit of measurement and (c) the number of fractional divisions, or graduations, per unit of measurement.

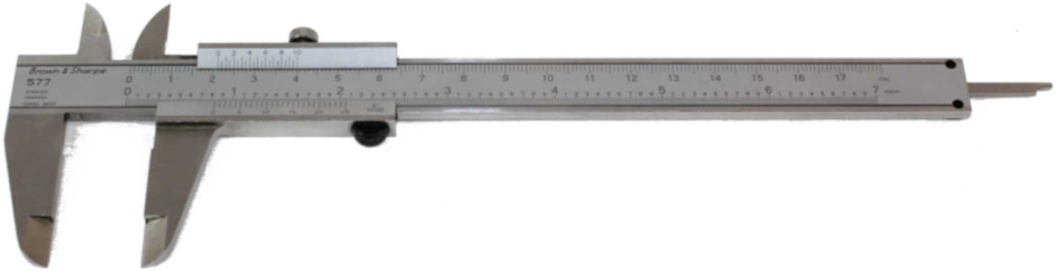


(a) ______________________________________ **(Cognition: Knowledge)**

(b) ______________________________________ **(Cognition: Knowledge)**

(c) ______________________________________ **(Cognition: Knowledge)**

2. For the following (a) identify the measuring instrument, and (b) Explain step-by-step the process that you would follow when measuring object A using this instrument.



(a) ______________________________________ **(Cognition: Knowledge)**

(b) ______________________________________ **(Cognition: Application)**

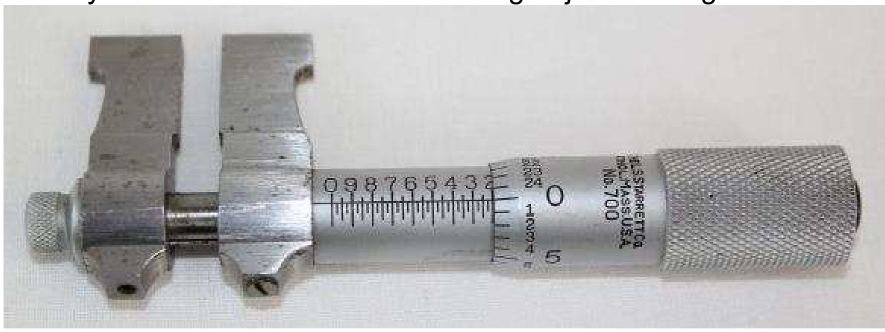
____

____

____

____

3. For the following (a) identify the measuring instrument, and (b) Explain step-by-step the process that you would follow when measuring object A using this instrument.



(a) **(Cognition: Knowledge)**

(b) **(Cognition: Application)**

4. Reflect on your personal and work experiences and describe one scenario in which you used or could have used measuring instruments to assist on a task or project.

(Cognition: Application)

5. For the following measurements (a) convert them to inches (b) convert them to centimeter and (c) arrange the measurements from smallest to largest.

(Cognition: Knowledge and Comprehension)

Conversion table
1 inch = 2.54 cm 1 cm = 0.3937 inches

2.54 cm	3.5 in	1.7 in	6.15 cm	1.0 cm

(a) Convert all measurements to inches

______________ ______________ ______________ ______________ ______________

(b) Convert all measurements to centimeters

______________ ______________ ______________ ______________ ______________

(c) Arrange measurements from smallest to largest in the units of measurement you prefer

______________ ______________ ______________ ______________ ______________

smallest *largest*

6. In the space provided, (a) describe the function of the locking screw on the Vernier caliper (b) explain why the locking screw is important (c) explain how the reading could be affected if this feature is not used.

(Cognition: Comprehension, Analysis, Evaluation)

(a) ____

____

____

(b) ____

____

____

(c) ____

____

____

____

7. Imagine you saw a colleague grabbing a 3 – 4 in. inside micrometer to measure the inside feature of a part whose specifications are 2.5 – 2.7 in. In the space provided, (a) describe the issues you expect your colleague to encounter, and (b) discuss how you would explain to your colleague why this micrometer is not appropriate to use to measure object A.

(Cognition: Synthesis and Application)

(a) ____

____

____

____

____

____

(b) ____

____

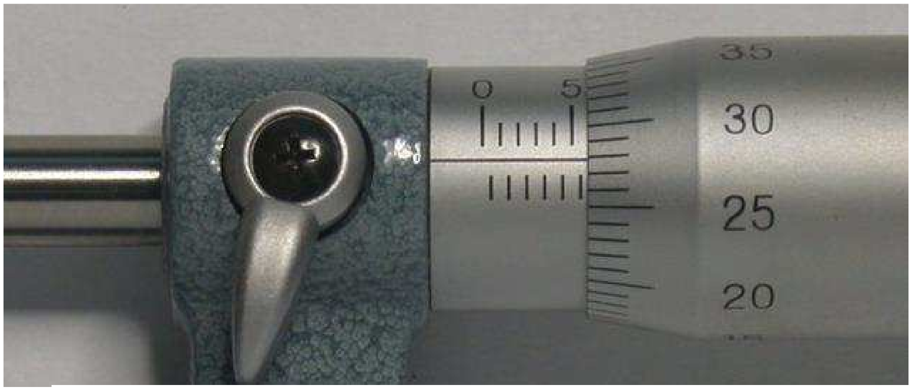
____

____

____

____

8. The specifications of the thickness of a part is 5.50 – 5.80 mm. Given the measurement below, determine if the part meets specifications.

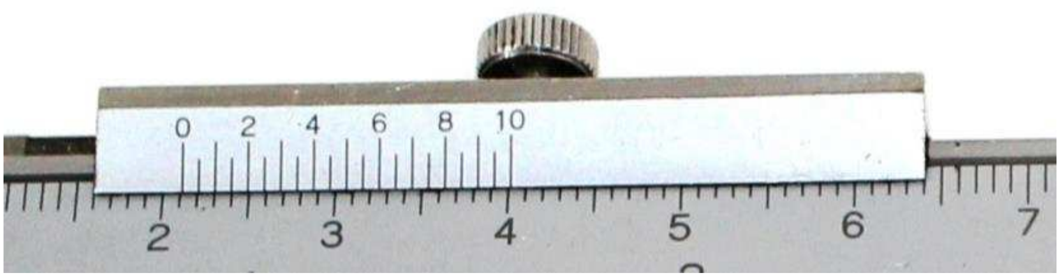


Metric Micrometer by Glenn McKechnie CC BY SA 3.0

(a) Measurement ______________________ **(Cognition: Comprehension)**

(b) Does part meet specifications? ______________________ **(Cognition: Evaluation)**
If not, by how many mm is
the part out of spec ______________________ **(Cognition: Synthesis)**

9. The specifications of the thickness of a part is 2.000 – 2.100 cm. Given the measurement below, determine if the part meets specifications.



(a) Measurement ______________________ **(Cognition: Comprehension)**

(b) Does part meet specifications? ______________________ **(Cognition: Evaluation)**
If not, by how many mm is
the part out of spec ______________________ **(Cognition: Synthesis)**

10. Analyze the following specifications:

a) The specifications of the inside diameter of a cylinder are 3.175 – 3.555 mm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one micron (0.001 mm)? **(Cognition: Evaluation)**

---

b) The specifications of the inside diameter of a cylinder are 3.175 – 3.555 in. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one thousandths of an inch (0.001 in)? **(Cognition: Evaluation)**

---

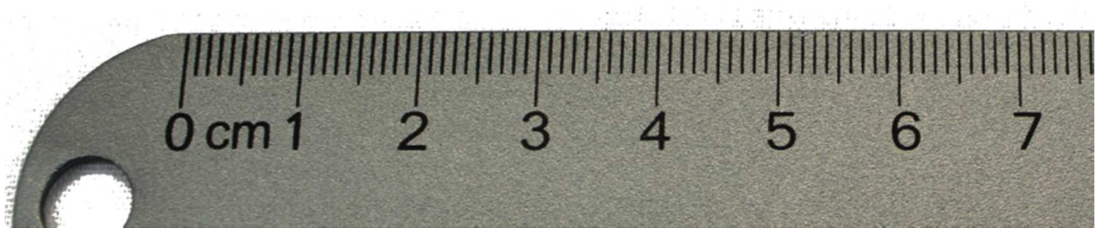
c) The specifications of the inside diameter of a cylinder are 3.1 – 3.5 cm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one tenths of a centimeter (0.1 cm)? **(Cognition: Evaluation)**

APPENDIX E

Pilot Study's Post-cognitive Assessment

Participant #: ___________________ (*This will be filled out by the test administrator*)

1. Using the rule below, determine (a) the measuring system being used (b) the unit of measurement and (c) the number of fractional divisions, or graduations, per unit of measurement.



(a) ____ **(Cognition: Knowledge)**

(b) ____ **(Cognition: Knowledge)**

(c) ____ **(Cognition: Knowledge)**

2. For the following (a) identify the measuring instrument, and (b) Explain step-by-step the process that you would follow when measuring object A using this instrument.

(a) ____ **(Cognition: Knowledge)**

(b) ____ **(Cognition: Application)**

____

____

____

____

3. For the following (a) identify the measuring instrument, and (b) Explain step-by-step the process that you would follow when measuring object A using this instrument.

(a) ______________________________ **(Cognition: Knowledge)**

(b) ______________________________ **(Cognition: Application)**

4. Reflect on your personal and work experiences and describe one scenario in which you used or could have used measuring instruments to assist on a task or project.

(Cognition: Application)

5. For the following measurements (a) convert them to inches (b) convert them to centimeter and (c) arrange the measurements from smallest to largest.

(Cognition: Knowledge and Comprehension)

Conversion table
1 inch = 2.54 cm 1 cm = 0.3937 inches

2.5 in   2.54 cm   5.57 cm   4.2 in   1.0 in

(a) Convert all measurements to inches

________ ________ ________ ________ ________

(b) Convert all measurements to centimeters

________ ________ ________ ________ ________

(c) Arrange measurements from smallest to largest in the units of measurement you prefer

________ ________ ________ ________ ________

smallest *largest*

6. In the space provided, (a) describe the function of the locknut on the micrometer (b) explain why the locknut is important (c) explain how the reading could be affected if this feature is not used.

(Cognition: Comprehension, Analysis, Evaluation)

(a) ____

(b) ____

(c) ____

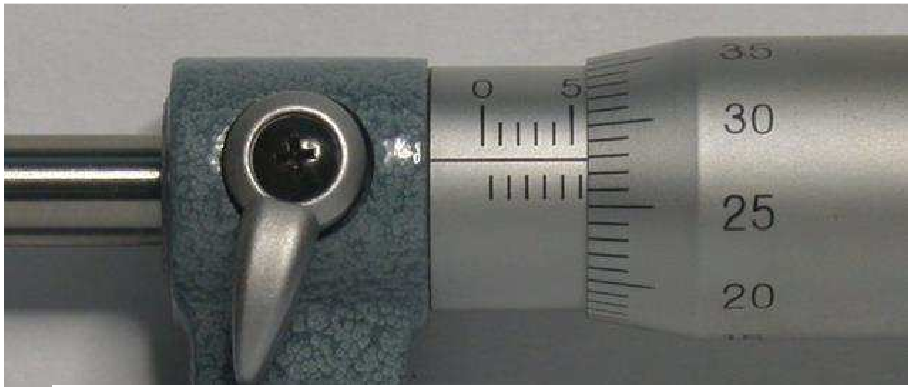
7. Imagine you saw a colleague grabbing a 0 – 1 in. outside micrometer to measure the length of a part whose specifications are 1.5 – 1.7 in. In the space provided, (a) describe the issues you expect your colleague to encounter, and (b) discuss how you would explain to your colleague why this micrometer is not appropriate to use to measure object A.

(Cognition: Synthesis and Application)

(a) ____

(b) ____

8. The specifications of the thickness of a part is 5.00 – 5.50 mm. Given the measurement below, determine if the part meets specifications.

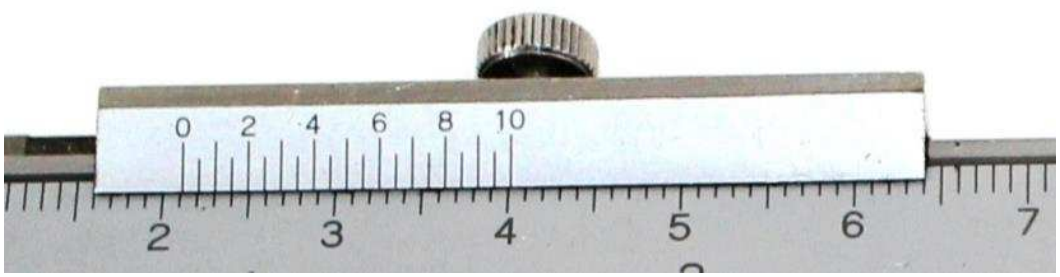


Metric Micrometer by Glenn McKechnie CC BY SA 3.0

(a) Measurement ______________________ **(Cognition: Comprehension)**

(b) Does part meet specifications? ______________________ **(Cognition: Evaluation)**
If not, by how many mm is
the part out of spec ______________________ **(Cognition: Synthesis)**

9. The specifications of the thickness of a part is 2.000 – 2.150 cm. Given the measurement below, determine if the part meets specifications.



(a) Measurement ______________________ **(Cognition: Comprehension)**

(b) Does part meet specifications? ______________________ **(Cognition: Evaluation)**
If not, by how many mm is
the part out of spec ______________________ **(Cognition: Synthesis)**

10. Analyze the following specifications:

a) The specifications of the inside diameter of a cylinder are 1.455 – 1.555 mm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one micron (0.001 mm)? **(Cognition: Evaluation)**

---

b) The specifications of the inside diameter of a cylinder are 1.455 – 1.555 in. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one thousandths of an inch (0.001 in)? **(Cognition: Evaluation)**

---

c) The specifications of the inside diameter of a cylinder are 1.4 – 1.5 cm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one tenths of a centimeter (0.1 cm)? **(Cognition: Evaluation)**

APPENDIX F

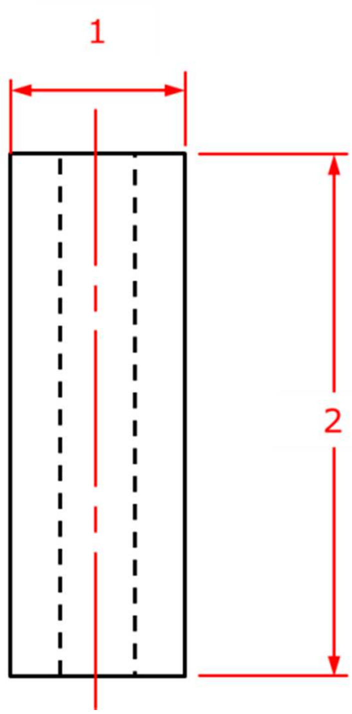
Pilot Study’s Skilled-based Performance Assessment

Participant #: ___________________ (*This will be filled out by the test administrator*)

Scenario 1

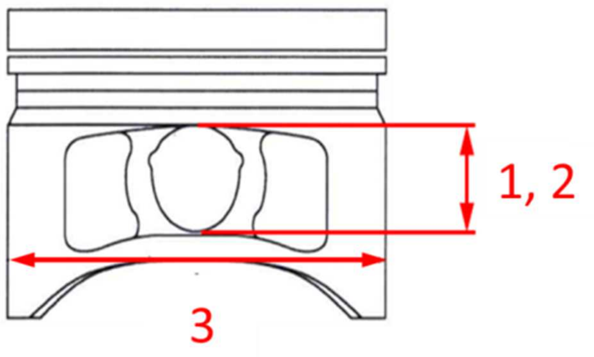
For each of the following items, record the measurements highlighted in the drawings.

a) Wrist pin



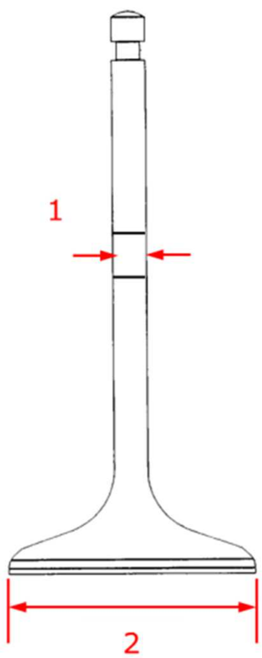
#	Measurement
1.	
2.	

b) Piston



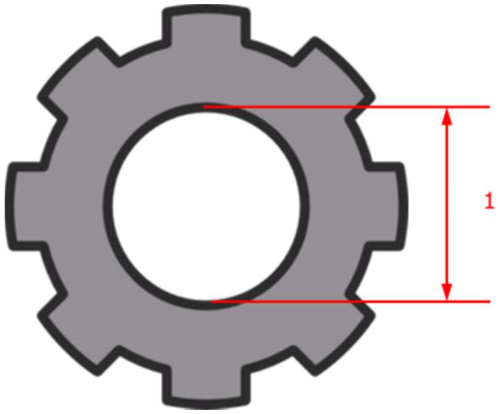
#	Measurement
1.	
2.	
3.	

c) Valve



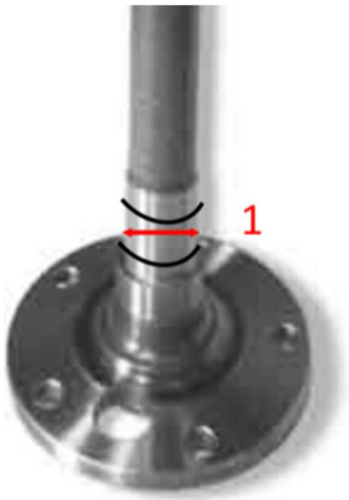
#	Measurement
1.	
2.	

d) Gear



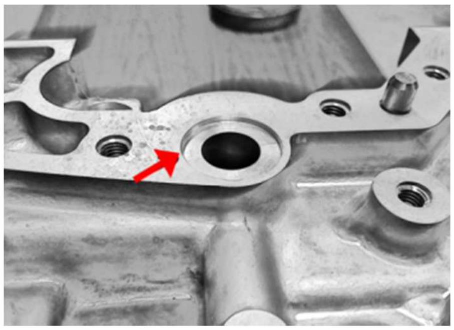
#	Measurement
1.	

e) Rear Axel Shaft



#	Measurement
1.	

f) Engine block (depth measurement)



#	Measurement
1.	

Scenario 2
In an engine, the intake valve allow a fuel/ and air mix to enter the combustion chamber. Then, the exhaust valve allows the spent mixture to exit the engine. Wear on the steam of these valves can cause these processes to malfunction. This is wear is called **valve stem wear.**

a) Measure the valve at the two marked locations shown in figure 1

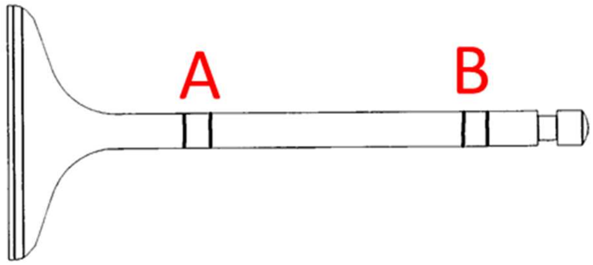


Figure 1. Marked Valve Locations

A. ____________________________________

B. ____________________________________

b) What is the valve stem wear?

Show your work:

c) Locate the specifications of the valve stem. Record specifications below.

____

d) Would it be safe to use this valve on a vehicle?

☐ Yes ☐ No

Explain your answer.

____

____

____

____

Scenario 3

A **brake drum** is a broad, very short cylinder attached to a wheel against which the brake shoes press in. The brake drum should be as perfectly round as possible. When the brake drum is not a perfect circle, it is said to be **out of round**. Out of roundness is the difference between the highest and lowest diameter measurements.

a) Measure the brake drum at locations A, B, C and D. Record your measurement below.

A. ____________________ B. ____________________

C. ____________________ D. ____________________

b) Based on your answers from a), is the break drum out of round?

☐ Yes ☐ No

If so, what is the out of round measurement?

Show your work:

c) Locate the specifications of the brake drum out of round on your sheet and record it below

____

d) Would it be safe to use this brake drum on a vehicle?

☐ Yes ☐ No

Explain your answer.

____

____

____

____

____

Scenario 4

The **brake rotor thickness variation** is the variation in the thickness of the rotor when it is measures at several places around its circumference. It is the difference between the highest and lowest thickness measurements. The rotor needs to be measured to the ten thousands of an inch (0.0001 in) or to the thousands of a millimeter (0.001mm).

a) Measure the brake rotor thickness at four places. Be sure that each measurement is evenly spaced around the rotor at approximately ¼ inch from the outer edge. Record your measurements below.

1. ______________________ 2. ______________________

3. ______________________ 4. ______________________

b) Calculate the brake rotor thickness variation:

Show your work:

Brake rotor thickness variation: ______________________

c) Locate the specifications of the brake rotor thickness variation on your sheet and record it below

____

d) Would it be safe to use this rotor on a vehicle?

☐ Yes ☐ No

Explain your answer.

____

____

____

____

____

Scenario 5

A customer comes in with an in line 4-cylinder engine car complaining of knocking. As a technician, you know that the clearance between the pistons and the cylinders can produce this type of noise. The **clearance** is the space between each piston and cylinder. Figure 1 shows the location (A) where you should make your measurement on the piston.

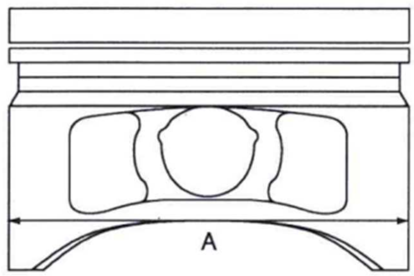


Figure 1. Piston measurement

a) Calculate the clearance for one of the cylinders:

Show your work:

Clearance: ______________________________

b) Locate the specifications of the clearance on your sheet and record it below.

____

c) Would it be safe to use this engine on a vehicle?

☐ Yes ☐ No

Explain your answer.

____

____

____

____

Scenario 6

Main journal #1 on this cam crank was machined down to remove defects. From the two pistons that are laid out on the table, determine which one fits the newly machined down journal based on the piston to journal clearance.

Conversion Table

Conversion table
1 inch = 2.54 cm
1 cm = 0.3937 inches
1 cm = 10 mm

Specifications Table

	Specifications	
Item	**millimeters**	**Inches**
Valve Stem Wear		
Brake Drum Out of round		
Thickness variation		
Piston to cylinder bore clearance		
Piston to journal clearance		

APPENDIX G

Pilot Study's Perception of Learning Instrument

Based on: Adapted from: Hiltz, S.R. Learning in a Virtual Classroom, Volume 1 of "A Virtual Classroom on EIES: Final Evaluation Report," New Jersey Institute of Technology, Newark, NJ, 1988

Participant #: ___________________ (*This will be filled out by the test administrator*)

Instructions: Please rate the usability of the system. Try to respond to every item.

1. I became more interested in the subject.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

2. I learned a great deal of factual material.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

3. I gained a good understanding of basic concepts.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

4. I learned to identify central issues in this field.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

5. I developed the ability to communicate clearly about this subject.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

6. My skill in critical thinking was increased.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

7. My ability to integrate facts and develop generalizations about this subject improved.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

8. I was forced to think for myself.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Overall, how much did each of the following contribute to your understanding of the course materials?

	Very little				Very much
9. Lectures	1	2	3	4	5
10. Videos	1	2	3	4	5
11. Activities	1	2	3	4	5
12. Visualizations	1	2	3	4	5

APPENDIX H

Subjective Satisfaction Questionnaire

Based on: Lewis, J. R. (1995) IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use. *International Journal of Human-Computer Interaction 7:1*, 57-78.

Participant #: ___________________ (*This will be filled out by the test administrator*)

Instructions: Please rate the usability of the system. Try to respond to every item.

1. Overall, I am satisfied with how easy it is to use this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

2. It was simple to use this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

3. I can effectively complete my mission using this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

4. I am able to complete my mission quickly using this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

5. I am able to efficiently complete my mission using this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

6. I feel comfortable using this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

7. It was easy to learn to use this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

8. I believe I became productive quickly using this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

9. The system gives error messages that clearly tell me how to fix problems.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

10. Whenever I make a mistake using this system, I recover easily and quickly.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

11. The information (help, on-screen messages, tool-tips, etc.) provided is clear.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

12. It is easy to find the information I need.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

13. The information provided for the system is easy to understand.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

14. The information is effective in helping me complete the tasks and scenarios.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

15. The organization of information on the system screens is clear.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

16. The interface of this system is pleasant.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

17. I like using the interface of this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

18. This system has all the functions and capabilities I expect it to have.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

19. Overall, I am satisfied with this system.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

20. I am confident about the results I produced.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

APPENDIX I

Technology Acceptance Instrument

Based on: Davis Jr, F. D. (1986). *A technology acceptance model for empirically testing new end-user information systems: Theory and results* (Doctoral dissertation, Massachusetts Institute of Technology).

Participant #: ___________________ (*This will be filled out by the test administrator*)

Perceived usefulness

1. Using the digital learning environment can improve my learning performance.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

2. Using the digital learning environment can increase my learning effectiveness.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

3. I find the digital learning environment to be useful to me.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Perceived cognitive absorption.

4. I find the digital learning environment to be useful to me.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

5. Time flies when I am using the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

6. Most times when I get on to the digital learning environment, I end up spending more time than I had planned.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

7. When I am using the digital learning environment I am able to block out most other distractions.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

8. While using the digital learning environment, I am absorbed in what I am doing.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

9. I have fun interacting with the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

10. I enjoy using the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Perceived ease-of-use.

11. Learning to operate the digital learning environment is easy for me.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

12. It is easy for me to become skillful at using the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

13. My interaction with the digital learning environment is clear and understandable.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Information quality

14. The digital learning environment provides relevant information for my learning or professional goals.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

15. The digital learning environment **does not** provide easy-to-understand information*.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

16. The output information from the digital learning environment is **not** clear*.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

17. The digital learning environment presents the information in an appropriate format.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

18. The information content in the digital learning environment is very good.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

19. The information from the digital learning environment is up-to-date enough for my purposes.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

20. The completeness of output information that the digital learning environment delivers is **not** sufficient for my purposes*.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

21. The reliability of output information from the digital learning environment is high.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

22. The digital learning environment provides the information I need in time.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Service quality

23. The digital learning environment has a modern looking interface.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

24. The digital learning environment has visually appealing materials.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

25. The digital learning environment provides the right solution to my request.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

26. The digital learning environment gives me prompt service.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

27. The digital learning environment does not give me individual attention*.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

28. The digital learning environment has a good interface to communicate my needs.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

29. The digital learning environment **does not** have convenient operating hours*.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

System quality

30. There are too many number of steps per task in the digital learning environment*.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

31. Steps to complete a task in the digital learning environment follow a logic sequence.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

32. Performing an operation in the digital learning environment always leads to a predicted result.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

33. The organization of information on the digital learning environment screens is clear.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

34. The digital learning environment has natural and predictable screen changes.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

35. The digital learning environment responds quickly during the busiest hours of the day.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Confirmation

36. My experience with using the digital learning environment was better than I expected.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

37. The service level provided by the digital learning environment was better than I expected.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

38. Overall, most of my expectations from using the digital learning environment were confirmed.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Satisfaction

39. I am satisfied with the performance of the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

40. I am pleased with the experience of using the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

41. My decision to use the digital learning environment was a wise one.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Continuance Intention

42. I would use the digital learning environment on a regular basis in the future.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

43. I would strongly recommend others to use the digital learning environment.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

44. I would frequently use the digital learning environment in the future.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

APPENDIX J

NASA Task Load Index (TLX)

Based on:

Participant #: ___________________ (*This will be filled out by the test administrator*)

Task Questionnaire – Part 1
Click on each scale at the point that best indicates your experience of the task

Mental Demand — How mentally demanding was the task?

Low — High

Physical Demand — How physically demanding was the task?

Low — High

Temporal Demand — How hurried or rushed was the pace of the task?

Low — High

Performance — How successful were you in accomplishing what you were asked to do?

Good — Poor

Effort — How hard did you have to work to accomplish your level of performance?

Low — High

Frustration — How insecure, discouraged, irritated, stressed and annoyed were you?

Low — High

Task Questionnaire – Part 2

On each of the following 15 screens, click on the scale title that represents the more important contributor to workload for the task.

Click on the factor that represents the more important contribution to workload for the task.

Frustration	or	Mental Demand

Click on the factor that represents the more important contribution to workload for the task.

Temporal Demand	or	Frustration

Click on the factor that represents the more important contribution to workload for the task.

Effort	or	Performance

Click on the factor that represents the more important contribution to workload for the task.

Temporal Demand	or	Mental demand

Click on the factor that represents the more important contribution to workload for the task.

Temporal Demand	or	Effort

Click on the factor that represents the more important contribution to workload for the task.

Mental	or	Physical Demand

Click on the factor that represents the more important contribution to workload for the task.

Effort	or	Physical Demand

Click on the factor that represents the more important contribution to workload for the task.

Mental Demand	or	Effort

Click on the factor that represents the more important contribution to workload for the task.

Physical Demand	or	Frustration

Click on the factor that represents the more important contribution to workload for the task.

Performance	or	Frustration

Click on the factor that represents the more important contribution to workload for the task.

Physical Demand	or	Performance

Click on the factor that represents the more important contribution to workload for the task.

Performance	or	Temporal Demand

Click on the factor that represents the more important contribution to workload for the task.

Performance	or	Mental Demand

Click on the factor that represents the more important contribution to workload for the task.

Physical Demand	or	Temporal Demand

Click on the factor that represents the more important contribution to workload for the task.

Frustration	or	Effort

APPENDIX K

Mapping of Pre- and Post- Cognitive Assessment Questions to Bloom's Taxonomy Cognitive Domain

Question	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Q1 Using the rule below, determine\						
(a) the measuring system being used	X					
(b) the unit of measurement and	X					
(c) the number of fractional divisions, or graduations, per unit of measurement.	X					
Q2 For the following						
(a) identify the measuring instrument, and	X					
(b) Explain step-by-step the process that you would follow when measuring object A using this instrument.						
Q3 For the following						
(a) identify the measuring instrument	X					
(b) Explain step-by-step the process that you would follow when measuring object A using this instrument.			X			
Q4 Reflect on your personal and work experiences and describe one scenario in which you used or could have used measuring instruments to assist on a task or project.			X			
Q5 For the following measurements						
(a) convert them to inches		X				
(b) convert them to centimeter and		X				
(c) arrange the measurements from smallest to largest.		X				
Q6 In the space provided,						
(a) describe the function of the locking screw on the Vernier caliper		X				

Question	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
(b) explain why the locking screw is important				X		
(c) explain how the reading could be affected if this feature is not used.						X
Q7 Imagine you saw a colleague grabbing a 3 – 4 in. inside micrometer to measure the inside feature of a part whose specifications are 2.5 – 2.7 in. In the space provided,						
(a) describe the issues you expect your colleague to encounter, and					X	
(b) discuss how you would explain to your colleague why this micrometer is not appropriate to use to measure object A.			X			
Q8 The specifications of the thickness of a part is 5.50 – 5.80 mm. Given the measurement below, determine if the part meets specifications.						
(a) Measurement		X				
(b1) Does part meet specifications?						X
(b2) if not by how much is the part out of spec					X	
Q9 The specifications of the thickness of a part is 2.000 – 2.100 cm. Given the measurement below, determine if the part meets specifications.						
(a) Measurement		X				
(b1) Does part meet specifications?						X
(b2) if not by how much is the part out of spec					X	
Q10(a) The specifications of the inside diameter of a cylinder are 3.175 – 3.555 mm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one micron (0.001 mm)?						X

Question	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Q10(b) The specifications of the inside diameter of a cylinder are 3.175 – 3.555 in. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one thousandths of an inch (0.001 in)?						X
Q10(c)The specifications of the inside diameter of a cylinder are 3.1 – 3.5 cm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one tenths of a centimeter (0.1 cm)?						X
Total	5	6	3	1	3	6

APPENDIX L

Mapping of the Skilled-Based Performance Assessment Questions to Bloom's Taxonomy Psychomotor Domain

Question	Perception	Set	Guided Response	Mechanism	Complex Overt Response	Adaptation	Origination
Scenario 1							
For each of the following items, record the measurements as highlighted in the drawings							
(a) Wrist pin				X			
(b) Piston				X			
(c) Valve				X			
(d) Gear				X			
(e) Rear axel shaft				X			
(f) Engine block				X			
Scenario 2							
In an engine, the intake valve allow a fuel/ and air mix to enter the combustion chamber. Then, the exhaust valve allows the spent mixture to exit the engine. Wear on the steam of these valves can cause these processes to malfunction. This is wear is called valve stem wear.							
(a) Measure the valve at the two marked locations as shown in figure 1				X			
(b) What is the valve stem wear?			X				
(c) Locate the specifications of the valve stem. Record specifications below.			X				
(d) Would it be safe to use this valve on a vehicle?						X	

Question	Perception	Set	Guided Response	Mechanism	Complex Overt Response	Adaptation	Origination
Scenario 3 A brake drum is a broad, very short cylinder attached to a wheel against which the brake shoes press in. The brake drum should be as perfectly round as possible. When the brake drum is not a perfect circle, it is said to be out of round. Out of roundness is the difference between the highest and lowest diameter measurements.							
(a) Measure the brake drum at locations A, B, C and D. Record your measurement below.				X			
(b) Based on your answers from a), is the break drum out of round?			X				
(c) Locate the specifications of the brake drum out of round on your sheet and record it below			X				
(d) Would it be safe to use this brake drum on a vehicle						X	
Scenario 4 The brake rotor thickness variation is the variation in the thickness of the rotor when it is measures at several places around its circumference. It is the difference between the highest and lowest thickness measurements. The rotor needs to be measured to the ten thousands of an inch (0.0001 in) or to the thousands of a millimeter (0.001mm).							

Question	Perception	Set	Guided Response	Mechanism	Complex Overt Response	Adaptation	Origination
(a) Measure the brake rotor thickness at four places. Be sure that each measurement is evenly spaced around the rotor at approximately ¼ inch from the outer edge. Record your measurements below.				X			
(b) Calculate the brake rotor thickness variation:			X				
(c) Locate the specifications of the brake rotor thickness variation on your sheet and record it below			X				
(d) Would it be safe to use this rotor on a vehicle?						X	
Scenario 5 A customer comes in with an in line 4-cylinder engine car complaining of knocking. As a technician, you know that the clearance between the pistons and the cylinders can produce this type of noise. The clearance is the space between each piston and cylinder. Figure 1 shows the location (A) where you should make your measurement on the piston.							
(a) Calculate the clearance for one of the cylinders:						X	
(b) Locate the specifications of the clearance on your sheet and record it below.			X				
(c) Would it be safe to use this engine on a vehicle?			X				

Question	Perception	Set	Guided Response	Mechanism	Complex Overt Response	Adaptation	Origination
Scenario 6							
Main journal #1 on this cam crank was machined down to remove defects. From the two pistons that are laid out on the table, determine which one fits the newly machined down journal based on the piston to journal clearance.							
(a) piston 1 measurement				X			
(b) piston 2 measurement				X			
(c) correct selection of piston						X	
Total	-	-	8	12	-	5	-

APPENDIX M

Inform Consent Form

Information about Being in a Research Study
Clemson University

An Investigation on the effects of digital learning integrated with visualization tools on learning outcomes

Description of the Study and Your Part in It

You are invited to participate in a research study conducted by Dr. Anand Gramopadhye, Melissa Zelaya, Kapil Chalil Madathil, Jeffrey Bertrand, Virginia Hall and Alana Powers. This research project is funded by the NSF Advanced Technical Education program to investigate the use of digital learning integrated with interactive virtual reality systems to educate aviation and automotive students at partnering technical colleges in South Carolina. In this study we will be evaluating the effects of the role of digital learning, and specifically the use of visualization tools, to improve learning outcomes. In addition, this study will evaluate constructs such as ease-of-use, technology acceptance and perception of learning associated with digital learning. There is limited research related to the use of simulation technology in teaching key skills necessary for manufacturing and maintenance in the aviation and automotive industry. The digital learning environment technology is a simulation with virtual characters and entities like a serious game, using which users can learn technical skills such as precision measurements for inspection and maintenance, electrical circuitry and team building skills. We believe that this interactive virtual reality simulation could be a good method for this purpose and potentially replace or complement the currently used methods of education in cognitive and psychomotor skills for the aviation and automotive industry.

The researchers will be happy to answer any questions for you. Your participation will involve:

1. Providing on demographics and previous experience
2. The completion of the Kolb's learning styles inventory
3. The completion of a technology acceptance survey
4. The completion of instruction on a specific topic
5. The submission of a written cognitive and psychomotor assessment
6. The completion of a user satisfaction and task load survey.

7. Audio recorders will be used.

The amount of time of your participation will be approximately 180 minutes or less.

Risks and Discomforts

There are no known major risks associated with this research. Resting periods will be provided. If you experience any discomfort, you may discontinue participation at any time without penalty. Another minor risk is that your assigned participant code may become connected to your responses. However, your assigned participant code will not provide details of your identity.

Possible Benefits

The benefits of this research are that you will be able to experience participation in a research study and have the opportunity to interact with virtual entities and characters in a computer generated environment. You will also be given the opportunity to be a part of a study that will help contribute to the broader questions of the use of virtual reality to educate users in critical technical skills in aviation and automotive manufacturing and inspection. The results of this research may have an impact on how people use interactive virtual environments for education.

Incentives

For your participation, you will be given a $25 Wal-Mart gift card.

Protection of Privacy and Confidentiality

We will not collect any identifying information in the study instruments. The usability data provided will be stored safely in a locked cabinet for at least three years. No usability response data will reside online or on any of the workstations, we will take every precaution to print the data and store it in a locked cabinet. We will do everything we can to protect your privacy and confidentiality. We will not tell anybody outside of the research team that you were in this study or any particular information that we collect about you. Audio recordings from this study will be destroyed after three years.

We might be required to share the information we collect from you with the Clemson University Office of Research Compliance, and the federal Office for Human Research Protections, National Science Foundation, and Florence-Darlington Technical College . If this happens, the information would only be used to find out if we ran this study properly and protected your rights in the study.

Choosing to Be in the Study

You do not have to be in this study. You may choose not to take part and you may choose to stop taking part at any time. You will not be punished in any way if you decide not to be in the study or to stop taking part in the study.

You may choose to stop taking part in this study after today. If you do, we will remove your information from the study. However, if we have already completed our research analysis, we will not be able to remove your information from the study.If you choose to stop taking part in this study, the information you have already provided will be used in a confidential manner.

Contact Information

If you have any questions or concerns about this study or if any problems arise, please contact Dr. Anand Gramopadhye at Clemson University at 864-656-5540 or via email at agramop@clemson.edu or Melissa Zelaya at (843)730-5065 or via email at zelaya@clemson.edu.

If you have any questions or concerns about your rights in this research study, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-6460 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC's toll-free number, 866-297-3071.

APPENDIX N

Test of Normality for Dependent Variables for Pilot Study

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
NormalizedGains	.161	28	.061	.941	28	.116
Total Score Skill-Based Performance Assessment	.122	28	.200*	.945	28	.150
Hilt Learning	.156	28	.080	.942	28	.128
Hilt Communicate Topic	.176	28	.026	.955	28	.271
Hilt Critical Thinking	.181	28	.020	.949	28	.188
Hilt Overall perception of Learning	.123	28	.200*	.974	28	.700
How much did LECTURES contribute to your understanding of the course materials?	.227	28	.001	.835	28	.000
How much did VIDEOS contribute to your understanding of the course materials?	.196	28	.007	.845	28	.001
How much did ACTIVITIES contribute to your understanding of the course materials?	.308	28	.000	.782	28	.000

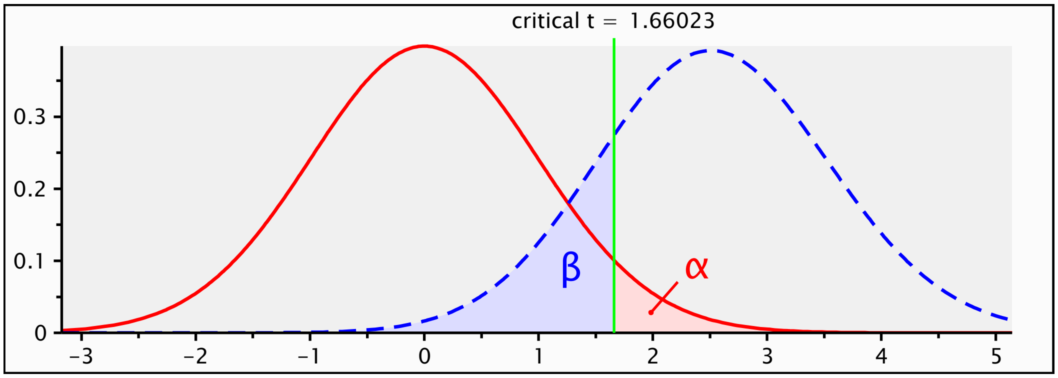
APPENDIX O

Pilot Study's Summary of Results of Subjective Data from Digital Learning Group

Subjective Measures	Mean (SE)	Max	%
Usability Total	73.38 (13.65)	100	73.38
System Usability	29.00 (8.08)	40	72.50
Information	25.15 (5.64)	30	83.83
Interface Quality	11.23 (2.31)	15	74.87
Technology Acceptance			
Perceived Usefulness	12.77 (1.74)	15	85.13
Perceived Cognitive Absorption	26.62 (3.52)	35	76.06
Perceived Ease-of-Use	12.69 (1.75)	15	84.60
Information Quality	35.31 (6.99)	45	78.47
Service Quality	27.23 (6.17)	35	77.80
System Quality	23.31 (2.50)	30	77.70
Confirmation	11.38 (2.75)	12	75.87
Satisfaction	11.85 (2.44)	12	79.00
Continuance Intention	12.08 (2.36)	12	80.53
NASA TLX Total Workload	49.84(24.94)	100	49.84
Mental Demand	18.33(11.28)	100	18.33
Physical Demand	1.46 (2.60)	100	1.46
Temporal Demand	5.56 (6.20)	100	5.56
Performance	7.13 (5.67)	100	7.13
Effort	11.92 (6.06)	100	11.92
Frustration	8.90 (13.85)	100	8.90

APPENDIX P

A Priori Power of Analysis test



t tests – Means: Difference between two independent means (two groups)		
Analysis:	A priori: Compute required sample size	
Input:	Tail(s)	= One
	Effect size d	= 0.5
	α err prob	= 0.05
	Power (1−β err prob)	= 0.8
	Allocation ratio N2/N1	= 1
Output:	Noncentrality parameter δ	= 2.5248762
	Critical t	= 1.6602343
	Df	= 100
	Sample size group 1	= 51
	Sample size group 2	= 51
	Total sample size	= 102
	Actual power	= 0.8058986

APPENDIX Q

LARGE SCALE STUDY'S GENERAL QUESTIONNAIRE

Participant #: ____________________ (*This will be filled out by the test administrator*)

DEMOGRAPHICS

Age: ________________________

Gender: ☐ Male ☐ Female ☐ I prefer not to answer

Race: ☐ African American ☐ American Indian or Alaska Native

☐ Asian ☐ Native Hawaiian or Other Pacific Islander

☐ White ☐ I prefer not to answer

Ethnicity: ☐ Hispanic or Latino ☐ Not Hispanic nor Latino

What degree(s) are you currently seeking? ________________________

PREVIOUS EXPERIENCE

Have you ever used a machinist's or metric scale?

☐ Yes ☐ No

If you answered yes, what do you consider is your level of mastery?

1	2	3	4	5
Low Mastery		Medium Mastery		High Mastery

Have you ever used a Vernier caliper?

☐ Yes ☐ No

If you answered yes, what do you consider is your level of mastery?

1	2	3	4	5
Low Mastery		Medium Mastery		High Mastery

Have you ever used an inside, outside or depth micrometer?

☐ Yes ☐ No

If you answered yes, what do you consider is your level of mastery?

1	2	3	4	5
Low Mastery		Medium Mastery		High Mastery

Have you ever taken an online course?

☐ Yes ☐ No

Have you ever utilized software that mimics a tool, workshop, or laboratory setting? (i.e., Tooling U)

☐ Yes ☐ No

If you answered yes, what was your level of satisfaction while utilizing this digital tool?

1	2	3	4	5
Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied

OTHER

Do you experience difficulty understanding soft or whispered speech?

☐ Yes ☐ No ☐ Sometimes

Do you have normal vision (20/20) either naturally or by the use of corrective lenses?

☐ Yes ☐ No

Do you experience difficulty with motor functions?

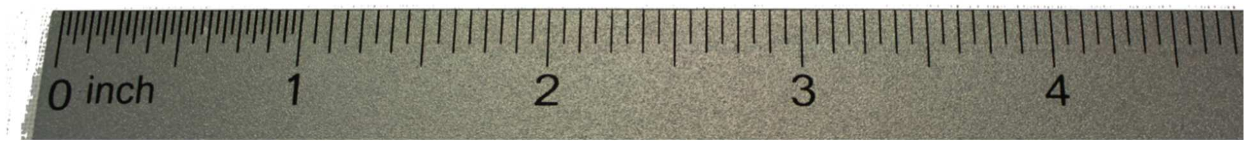
☐ Yes ☐ No ☐ Sometimes

APPENDIX R

LARGE SCALE STUDY'S PRE-COGNITIVE ASSESSMENT

Participant #: ______________________ (*This will be filled out by the test administrator*)

1. Using the rule below, determine (a) the measuring system being used (b) the unit of measurement and (c) the number of fractional divisions, or graduations, per unit of measurement.

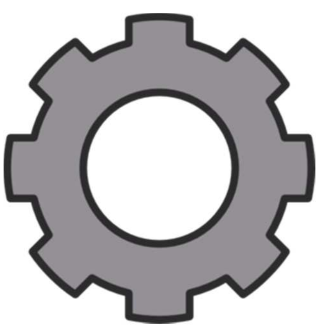


(a) ____

(b) ____

(c) ____

2. For the following (a) identify the measuring instrument, and (b) explain step-by-step the process that you would follow when measuring the object below using this instrument.



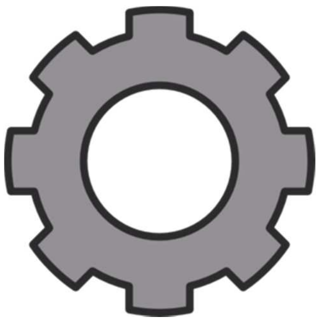
(a) ____

(b) ____

____

____

3. For the following (a) identify the measuring instrument, and (b) explain step-by-step the process that you would follow when measuring the object below using this instrument.



(a) ____

(b) ____

____

____

____

____

4. Reflect on your personal and work experiences and describe one scenario in which you used or could have used measuring instruments to assist on a task or project.

____

____

____

____

____

____

5. For the following measurements (a) convert them to inches (b) convert them to centimeter and (c) arrange the measurements from smallest to largest.

Conversion table
1 inch = 2.54 cm 1 cm = 0.3937 inches

2.54 cm   3.5 in   1.7 in   6.15 cm   1.0 cm

(d) Convert all measurements to inches

__________ __________ __________ __________ __________

(e) Convert all measurements to centimeters

__________ __________ __________ __________ __________

(f) Arrange measurements from smallest to largest in the units of measurement you prefer

__________ __________ __________ __________ __________

smallest *largest*

6. In the space provided, (a) describe the function of the locking screw on the Vernier caliper (b) explain why the locking screw is important (c) explain how the reading could be affected if this feature is not used.

(a)

(b)

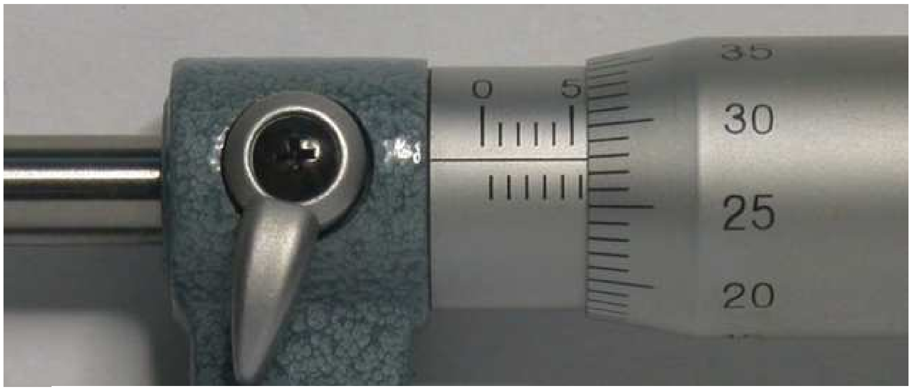
(c)

7. Imagine you saw a colleague grabbing a 3 – 4 in. inside micrometer to measure the inside feature of a part whose specifications are 2.5 – 2.7 in. In the space provided, (a) describe the issues you expect your colleague to encounter, and (b) discuss how you would explain to your colleague why this micrometer is not appropriate to use to measure this inside feature.

(a)

(b)

8. The specifications of the thickness of a part is 5.50 – 5.80 mm. Given the measurement below, determine if the part meets specifications.



Metric Micrometer by Glenn McKechnie CC BY SA 3.0

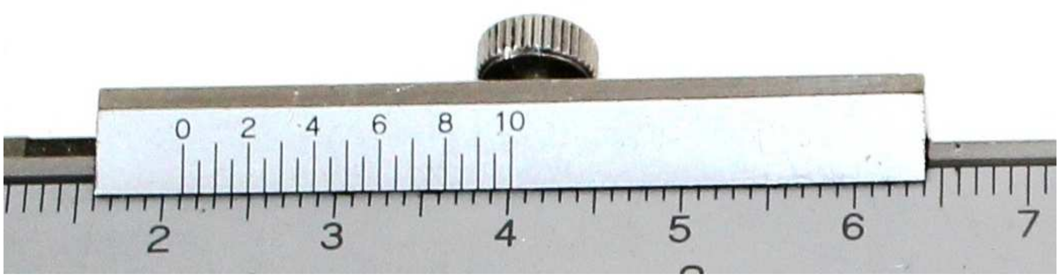
(a) Measurement

(b) Does part meet specifications?

If not, by how many mm is

the part out of spec

9. The specifications of the thickness of a part is 2.000 – 2.100 cm. Given the measurement below, determine if the part meets specifications.



(a) Measurement

(b) Does part meet specifications?

If not, by how many mm is

the part out of spec

10. Analyze the following specifications:

a) The specifications of the inside diameter of a cylinder are 3.175 – 3.555 mm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one micron (0.001 mm)?

(a) Metric scale

(b) Vernier caliper

(c) Inside micrometer

(d) Inside Vernier micrometer

b) The specifications of the inside diameter of a cylinder are 3.175 – 3.555 in. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one thousandths of an inch (0.001 in)?

(a) Machinist scale

(b) Vernier caliper

(c) Inside micrometer

(d) Inside Vernier micrometer

c) The specifications of the inside diameter of a cylinder are 3.1 – 3.5 cm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one tenths of a centimeter (0.1 cm)?

(a) Metric scale

(b) Vernier caliper

(c) Inside micrometer

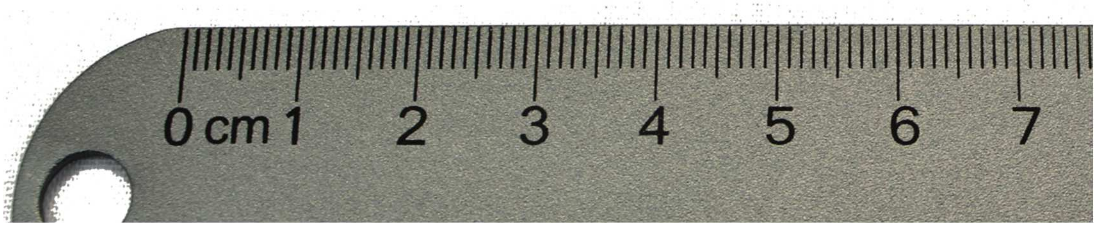
(d) Inside Vernier micrometer

APPENDIX S

LARGE SCALE STUDY'S POST-COGNITIVE ASSESSMENT

Participant #: ______________________ (*This will be filled out by the test administrator*)

1. Using the rule below, determine (a) the measuring system being used (b) the unit of measurement and (c) the number of fractional divisions, or graduations, per unit of measurement.

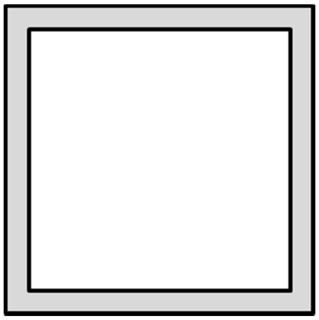


(a) ____

(b) ____

(c) ____

2. For the following (a) identify the measuring instrument, and (b) explain step-by-step the process that you would follow when measuring the object below using this instrument.

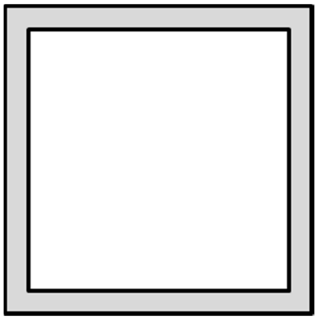


(a) ____

(b) ____

3. For the following (a) identify the measuring instrument, and (b) explain step-by-step

the process that you would follow when measuring the object below using this instrument.



(a) ____

(b) ____

____

____

____

____

4. Reflect on your personal and work experiences and describe one scenario in which you used or could have used measuring instruments to assist on a task or project.

____

____

____

____

____

____

5. For the following measurements (a) convert them to inches (b) convert them to centimeter and (c) arrange the measurements from smallest to largest.

Conversion table
1 inch = 2.54 cm
1 cm = 0.3937 inches

2.5 in 2.54 cm 5.57 cm 4.2 in 1.0 in

(g) Convert all measurements to inches

_____________ _____________ _____________ _____________ _____________

(h) Convert all measurements to centimeters

_____________ _____________ _____________ _____________ _____________

(i) Arrange measurements from smallest to largest in the units of measurement you prefer

_____________ _____________ _____________ _____________ _____________

smallest *largest*

6. In the space provided, (a) describe the function of the locknut on the micrometer (b) explain why the locknut is important (c) explain how the reading could be affected if this feature is not used.

(a)

(b)

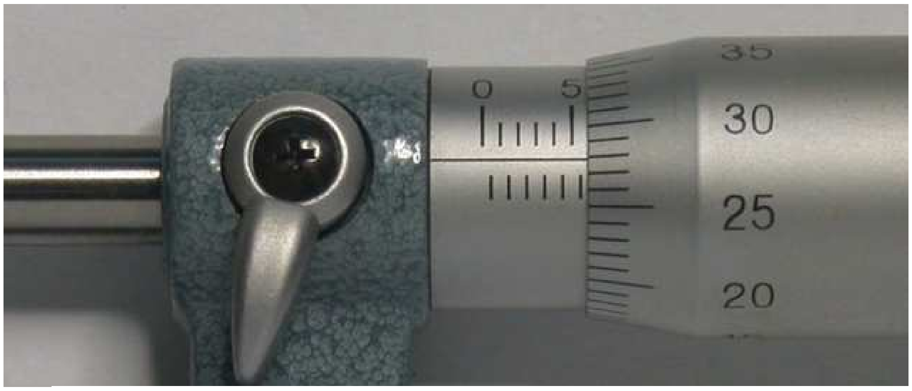
(c)

7. Imagine you saw a colleague grabbing a 0 – 1 in. outside micrometer to measure the length of a part whose specifications are 1.5 – 1.7 in. In the space provided, (a) describe the issues you expect your colleague to encounter, and (b) discuss how you would explain to your colleague why this micrometer is not appropriate to use to measure the length of the part.

(a)

(b)

8. The specifications of the thickness of a part is 5.00 – 5.50 mm. Given the measurement below, determine if the part meets specifications.



Metric Micrometer by Glenn McKechnie CC BY SA 3.0

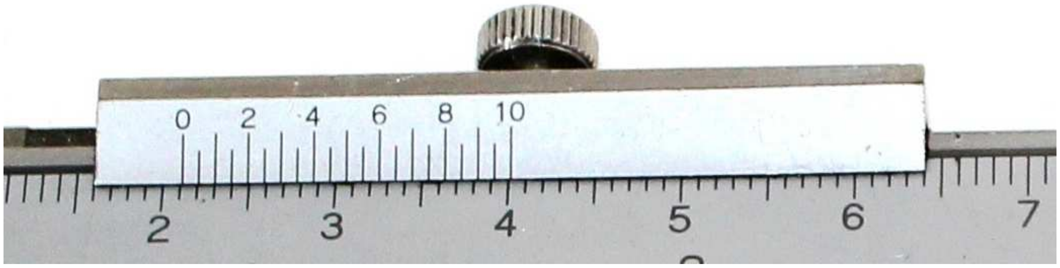
(a) Measurement ______________

(b) Does part meet specifications? ______________

If not, by how many mm is

the part out of spec ______________

9. The specifications of the thickness of a part is 2.000 – 2.150 cm. Given the measurement below, determine if the part meets specifications.



(a) Measurement ______________

(b) Does part meet specifications? ______________

If not, by how many mm is

the part out of spec ______________

10. Analyze the following specifications:

a) The specifications of the inside diameter of a cylinder are 1.455 – 1.555 mm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one micron (0.001 mm)?

(a) Metric scale

(b) Vernier caliper

(c) Inside micrometer

(d) Inside Vernier micrometer

b) The specifications of the inside diameter of a cylinder are 1.455 – 1.555 in. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one thousandths of an inch (0.001 in)?

(a) Metric scale

(b) Vernier caliper

(c) Inside micrometer

(d) Inside Vernier micrometer

c) The specifications of the inside diameter of a cylinder are 1.4 – 1.5 cm. Which measuring instrument(s) can be used to measure the diameter of the cylinder accurately up to one tenths of a centimeter (0.1 cm)?

(a) Metric scale

(b) Vernier caliper

(c) Inside micrometer

(d) Inside Vernier micrometer

APPENDIX T

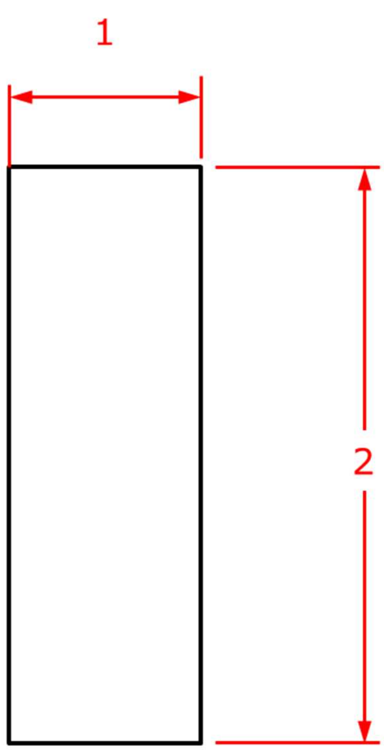
LARGE SCALE STUDY'S SKILL-BASED PERFORMANCE ASSESSMENT

Participant #: ______________________ (*This will be filled out by the test administrator*)

<u>Scenario 1</u>

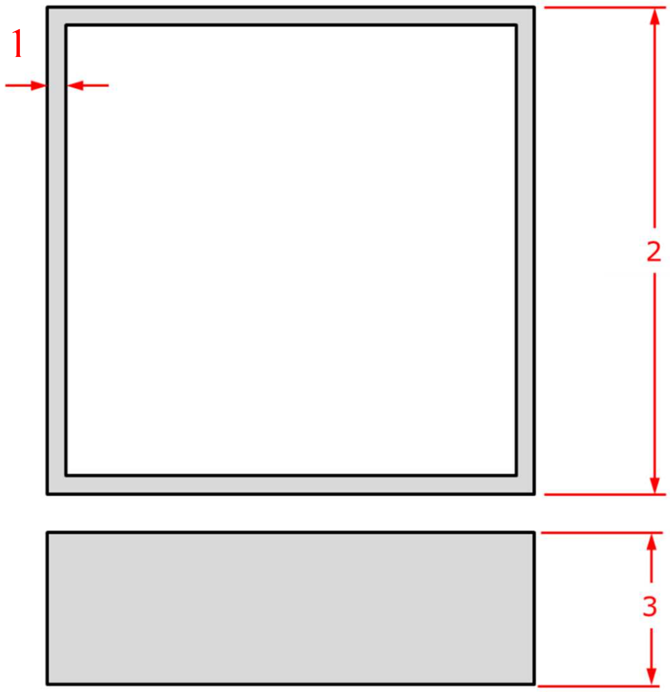
For each of the following items, record the measurements highlighted in the drawing and circle the instrument you used to record the measurement.

g) Cylinder



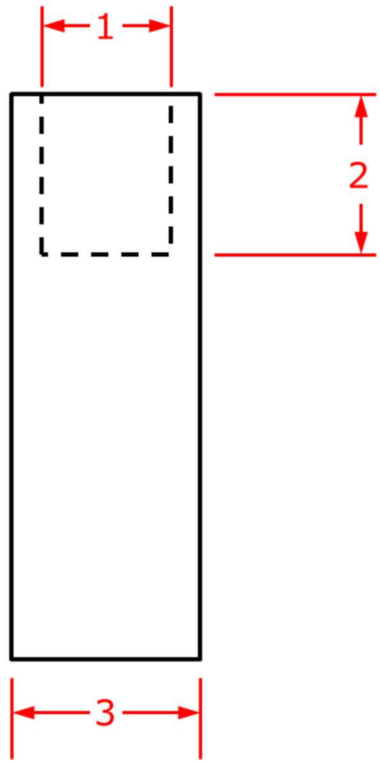
#	Measurement	
1.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer
2.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer

h) Square



#	Measurement	
1.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer
2.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer
3.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer

i) Cylinder with hole



#	Measurement	
1.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer
2.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer
3.		
	Vernier caliper	Outside micrometer
	Inside micrometer	Depth micrometer

Scenario 2

In an engine, the intake valve allow a fuel/ and air mix to enter the combustion chamber. Then, the exhaust valve allows the spent mixture to exit the engine. Wear on the steam of these valves can cause these processes to malfunction. The difference of measurement along the stem of the valve is called **valve stem wear**.

e) Measure the valve at the two marked locations shown in figure 1

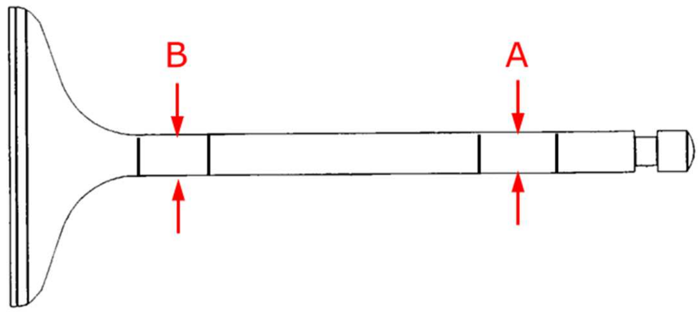


Figure 1. Marked Valve Locations

B. ______________________________

B. ______________________________

f) What is the valve stem wear?

Show your work:

g) If the maximum value for the valve stem wear for this engine is 0.25 mm, would it be safe to use this valve on a vehicle?

☐ Yes ☐ No

Explain your answer.

____

____

Scenario 3

The **brake rotor thickness variation** is the variation in the thickness of the rotor when it is measures at several places around its circumference. It is the difference between the highest and lowest thickness measurements.

e) Measure the brake rotor at four places. Be sure that each measurement is evenly spaced around the rotor at approximately ¼ inch from the outer edge. Record your measurements below.

5.	6.
7.	8.

f) Calculate the brake rotor thickness variation:

Show your work:

Brake rotor thickness variation: ____________________

g) If the maximum value for the brake rotor thickness variation is 0.25 mm, would it be safe to use this rotor on a vehicle?

☐ Yes ☐ No

Explain your answer.

APPENDIX U

LARGE SCALE STUDY'S PERCEPTION OF LEARNING INSTRUMENT

Adapted from: Hiltz, S.R. Learning in a Virtual Classroom, Volume 1 of "A Virtual Classroom on EIES: Final Evaluation Report," New Jersey Institute of Technology, Newark, NJ, 1988

Participant #: ______________________ (*This will be filled out by the test administrator*)

Instructions: Please rate the usability of the system. Try to respond to every item.

13. I became more interested in the subject.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

14. I learned a great deal of factual material.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

15. I gained a good understanding of basic concepts.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

16. I learned to identify central issues in this field.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

17. I developed the ability to communicate clearly about this subject.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

18. My skill in critical thinking was increased.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

19. My ability to integrate facts and develop generalizations about this subject improved.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

20. I was forced to think for myself.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Overall, how much did each of the following contribute to your understanding of the course materials?

	Very little				Very much
21. Lectures	1	2	3	4	5
22. Activities	1	2	3	4	5
23. Visualizations	1	2	3	4	5

APPENDIX V

Large Scale Study's Inform Consent form

INFORMATION ABOUT BEING IN A RESEARCH STUDY
CLEMSON UNIVERSITY

An Investigation on the effects of digital learning integrated with visualization tools on learning outcomes

Description of the Study and Your Part in It

You are invited to participate in a research study conducted by Dr. Anand Gramopadhye, Melissa Zelaya, Kapil Chalil Madathil, and Jeffrey Bertrand. This research project is funded by the NSF Advanced Technical Education program to investigate the use of digital learning integrated with interactive virtual reality systems to educate aviation and automotive students at partnering technical colleges in South Carolina. In this study we will be evaluating the effects of the role of digital learning, and specifically the use of visualization tools, to improve learning outcomes. In addition, this study will evaluate constructs such as ease-of-use, technology acceptance and perception of learning associated with digital learning. There is limited research related to the use of simulation technology in teaching key skills necessary for manufacturing and maintenance in the aviation and automotive industry. The digital learning environment technology is a simulation with virtual characters and entities like a serious game, using which users can learn technical skills such as precision measurements for inspection and maintenance, electrical circuitry and team building skills. We believe that this interactive virtual reality simulation could be a good method for this purpose and potentially replace or complement the currently used methods of education in cognitive and psychomotor skills for the aviation and automotive industry.

The researchers will be happy to answer any questions for you. Your participation will involve:

8. Providing on demographics and previous experience
9. The completion of the Kolb's learning styles inventory
10. The completion of a technology acceptance survey
11. The completion of instruction on a specific topic
12. The submission of a written cognitive and psychomotor assessment
13. The completion of a user satisfaction and talk load survey.
14. Audio and video recorders will be used.

15. Photographs may be taken following written consent.

The amount of time of your participation will be approximately 180 minutes or less.

Risks and Discomforts

There are no known major risks associated with this research. Resting periods will be provided. If you experience any discomfort, you may discontinue participation at any time without penalty. There is a minor risk that your assigned participant code may become connected to your responses. However, your assigned participant code will not provide details of your identity.

Possible Benefits

The benefits of this research are that you will be able to experience participation in a research study and have the opportunity to interact with virtual entities and characters in a computer generated environment. You will also be given the opportunity to be a part of a study that will help contribute to the broader questions of the use of virtual reality to educate users in critical technical skills in aviation and automotive manufacturing and inspection. The results of this research may have an impact on how people use interactive virtual environments for education.

Incentives

For your participation in Phase I, you will be given a $10 Wal-Mart gift card. If you agree to participate in Phase II, you will be given an additional $10 Wal-Mart gift card.

Protection of Privacy and Confidentiality

We will not collect any identifying information in the instruments. The usability data provided in will be stored safely in a locked cabinet for at least three years. No usability response data will reside online or on any of the workstations, we will take every precaution to print the data and store it in a locked cabinet. We will do everything we can to protect your privacy and confidentiality. We will not tell anybody outside of the research team that you were in this study or what information we collected about you in particular. Video and audio recordings from this study will be destroyed after three years.

Choosing to Be in the Study

You do not have to be in this study. You may choose not to take part and you may choose to stop taking part at any time. You will not be punished in any way if you decide not to be in the study or to stop taking part in the study.

Contact Information

If you have any questions or concerns about this study or if any problems arise, please contact Dr. Anand Gramopadhye at Clemson University at 864-656-5540 or via email at agramop@clemson.edu or Melissa Zelaya at (843)730-5065 or via email at zelaya@clemson.edu.

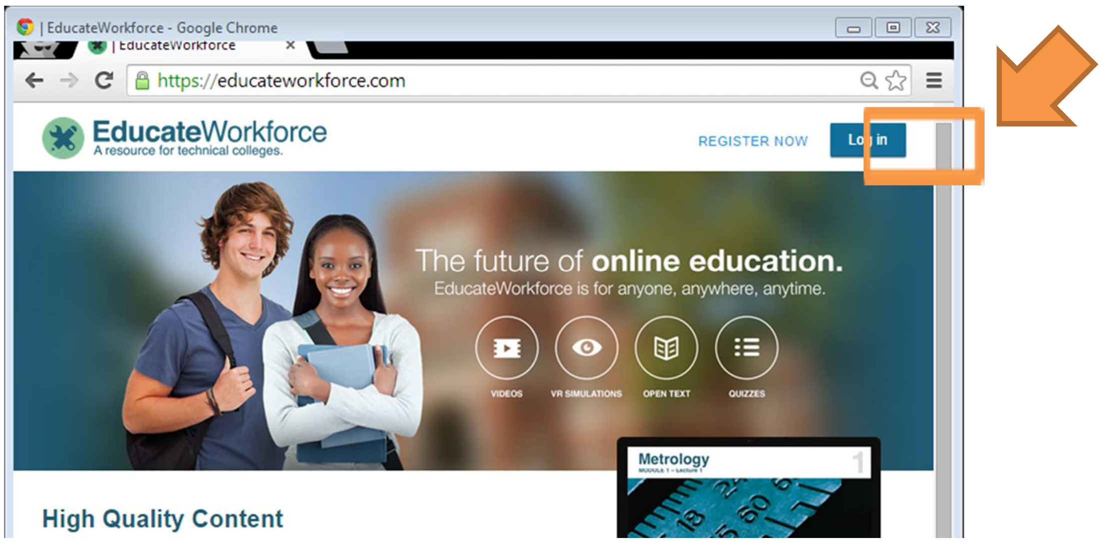
If you have any questions or concerns about your rights in this research study, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-6460 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC's toll-free number, 866-297-3071.

APPENDIX W

Large Scale Study's Instructions for Web Log-in

You have been selected to be part of online learning group.

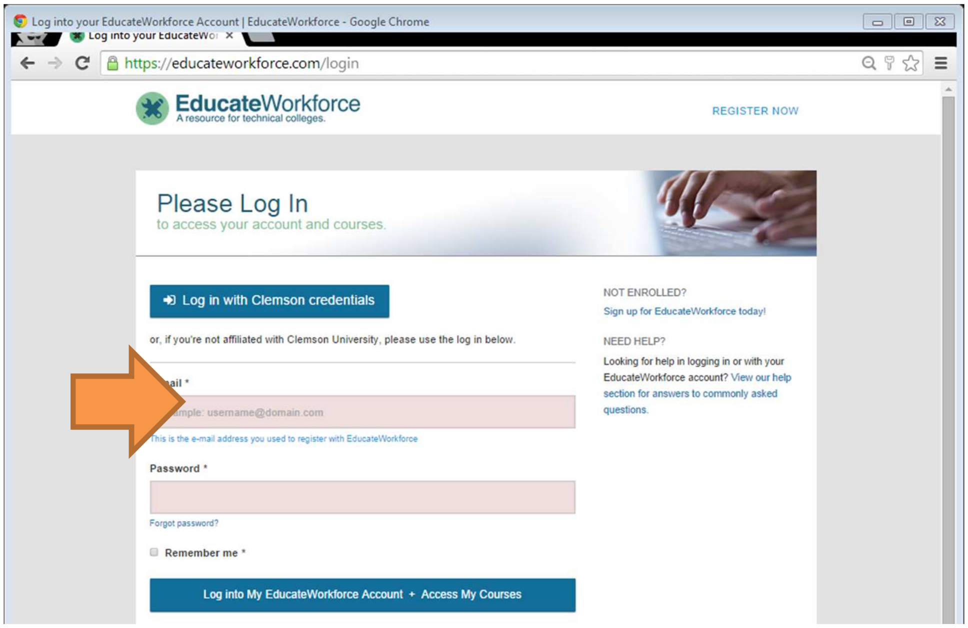
1) To start the study, please use Google Chrome and go to www.educateworkforce.com and click on the Log In button on the home page.



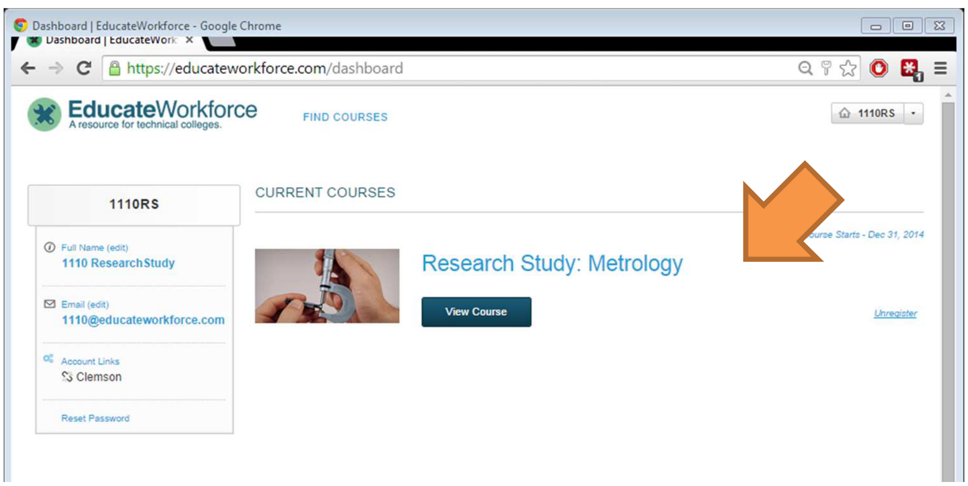
2) To log in, use the following user email and password:

Email: 1050@educateworkforce.com

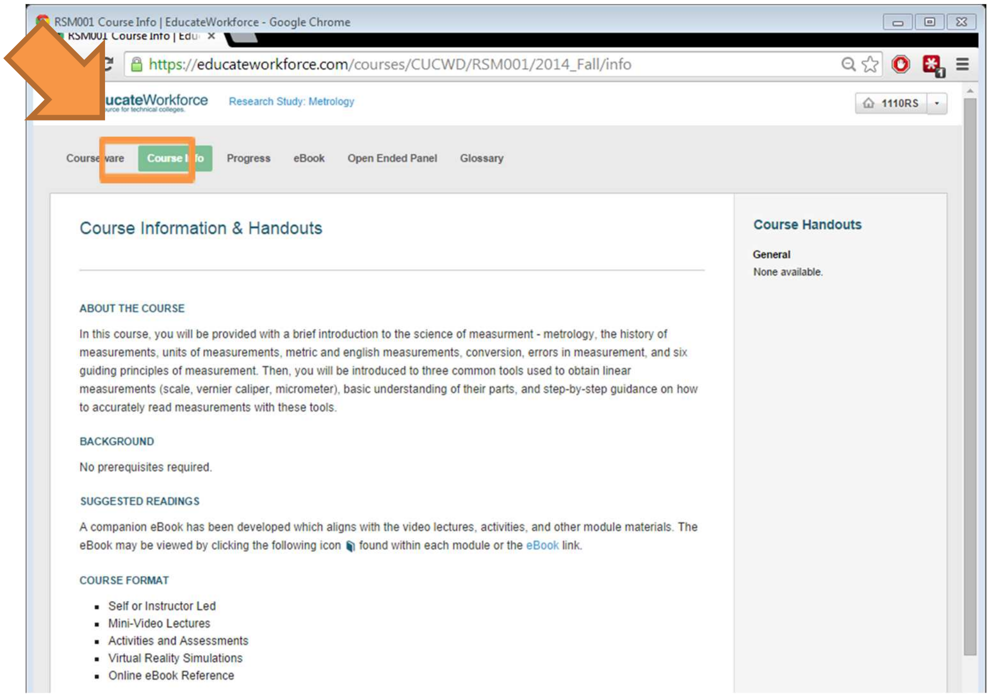
Password: rsm001



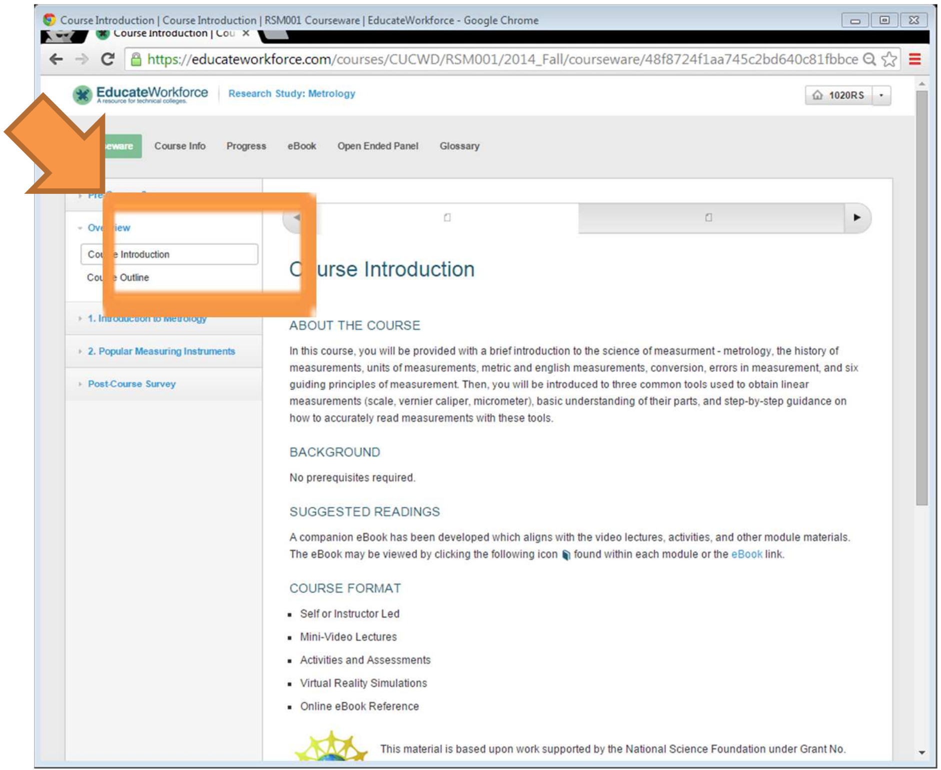
3) Click on the course located on your dashboard: Research Study Metrology.



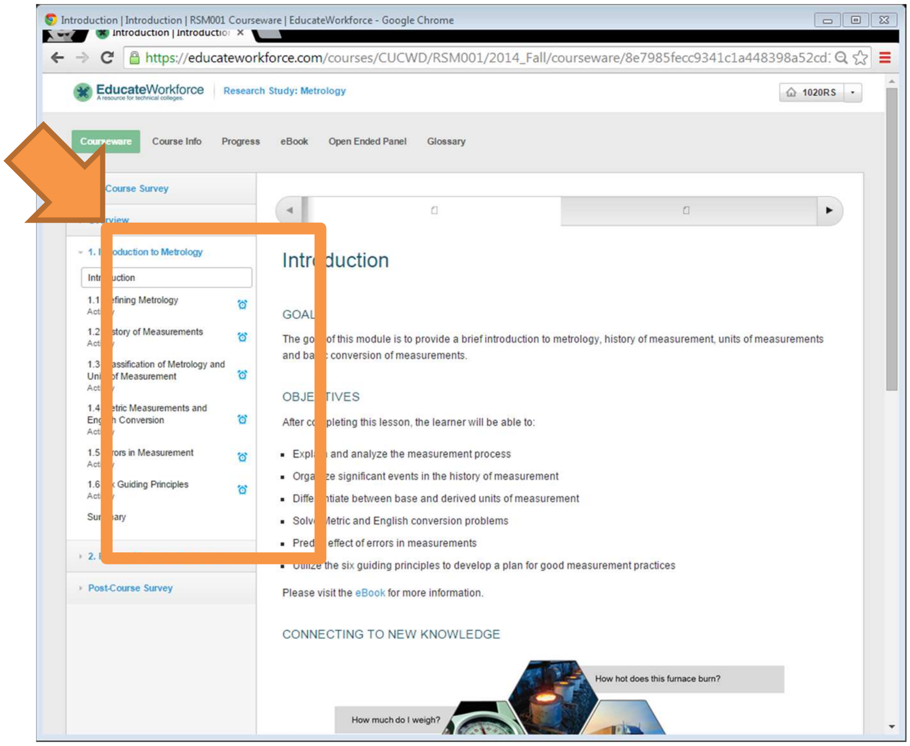
4) Read the course information page. Then click on the Courseware link on the top left of the webpage as highlighted below.


RSM001 Course Info | EducateWorkforce - Google Chrome
https://educateworkforce.com/courses/CUCWD/RSM001/2014_Fall/info
Research Study: Metrology
1110RS
Progress
eBook
Open Ended Panel
Glossary
Course Information & Handouts
ABOUT THE COURSE
In this course, you will be provided with a brief introduction to the science of measurment - metrology, the history of measurements, units of measurements, metric and english measurements, conversion, errors in measurement, and six guiding principles of measurement. Then, you will be introduced to three common tools used to obtain linear measurements (scale, vernier caliper, micrometer), basic understanding of their parts, and step-by-step guidance on how to accurately read measurements with these tools.
BACKGROUND
No prerequisites required.
SUGGESTED READINGS
A companion eBook has been developed which aligns with the video lectures, activities, and other module materials. The eBook may be viewed by clicking the following icon found within each module or the eBook link.
COURSE FORMAT
Self or Instructor Led
Mini-Video Lectures
Activities and Assessments
Virtual Reality Simulations
Online eBook Reference
Course Handouts
General
None available.

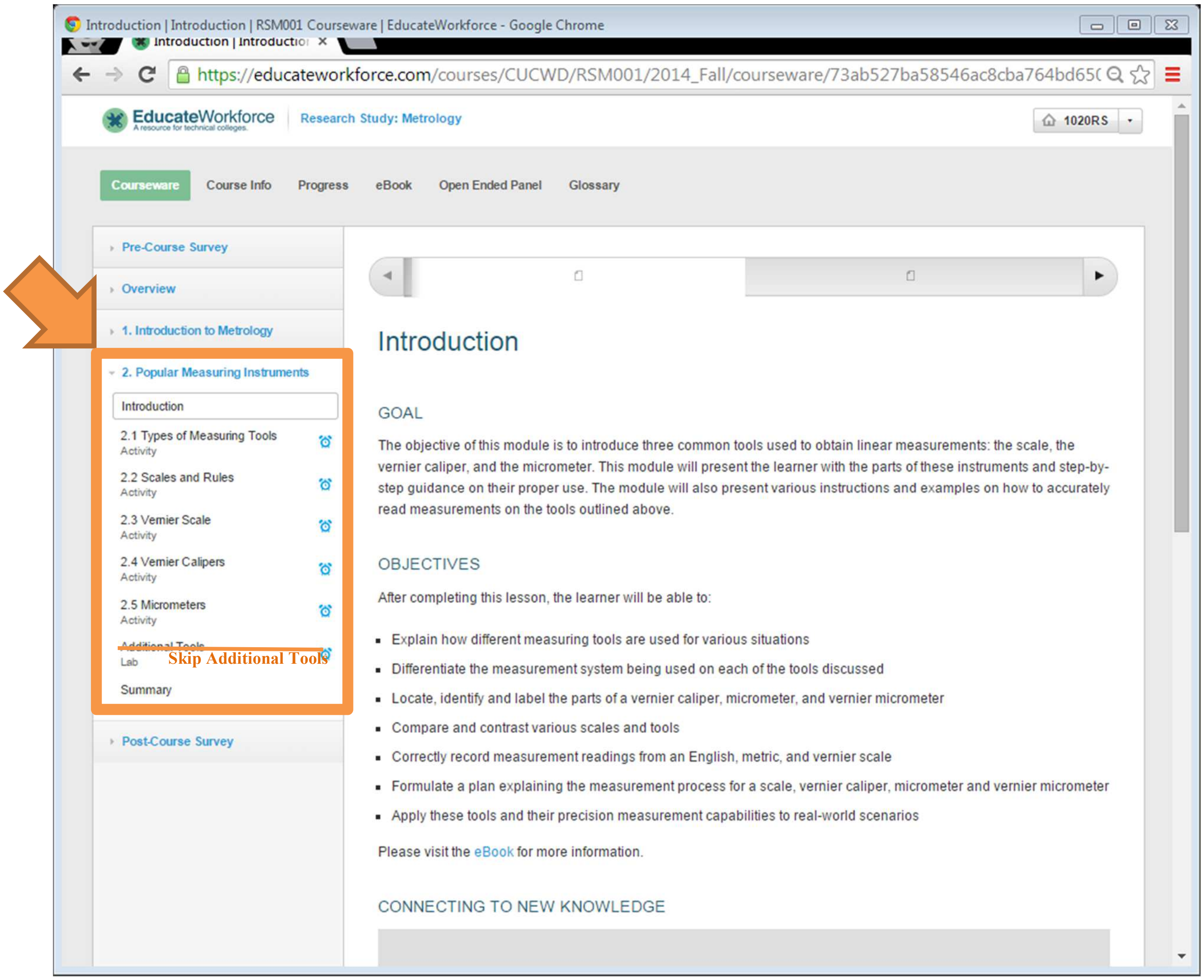
5) Review Course Introduction & Course Outline.



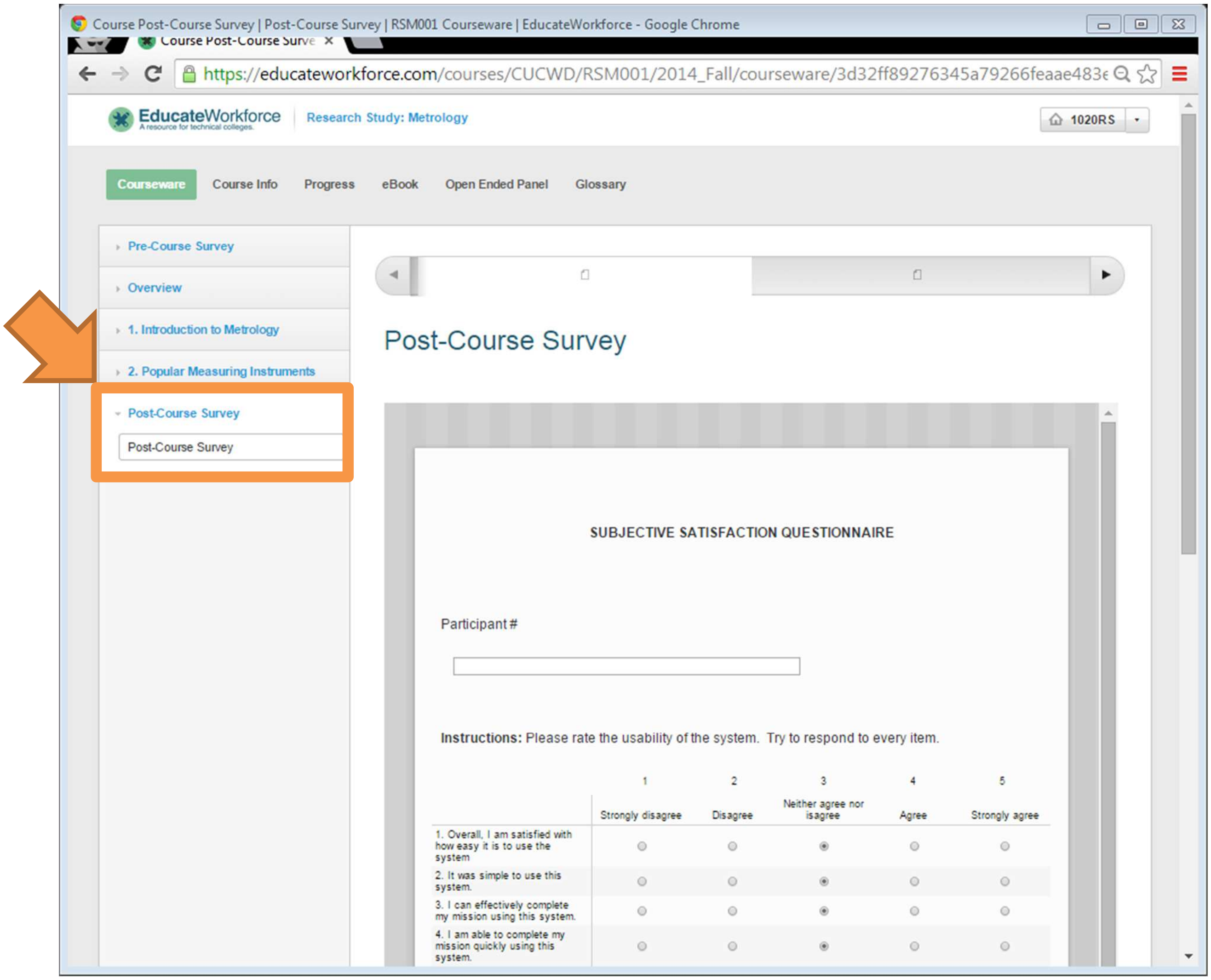
6) Click on Introduction to Metrology and complete all lectures and activities of the module.


Introduction | Introduction | RSM001 Courseware | EducateWorkforce - Google Chrome
https://educateworkforce.com/courses/CUCWD/RSM001/2014_Fall/courseware/8e7985fecc9341c1a448398a52cd
EducateWorkforce
Research Study: Metrology
Courseware
Course Info
Progress
eBook
Open Ended Panel
Glossary
Post-Course Survey
Introduction
The goal of this module is to provide a brief introduction to metrology, history of measurement, units of measurements and basic conversion of measurements.
Utilize the six guiding principles to develop a plan for good measurement practices
Please visit the eBook for more information.
CONNECTING TO NEW KNOWLEDGE
How hot does this furnace burn?
How much do I weigh?

7) Click on Introduction to Metrology and complete all lectures, activities, and virtual reality components of the module.



8) Complete the Post-Course Survey



Please ensure that you have completed ALL of the Post Course Survey.

There are various pages to this survey.

APPENDIX X

RECRUITMENT/CONSENT FORM PHASE II

You have now completed Phase I of this research study! You may now choose to participate in Phase II of the study. We will randomly select participants to come back and complete a complex task regarding the use of measuring instruments utilized during Phase I.

During Phase II, participants will be asked to complete a task and be interviewed while they think-aloud through their process of completing this task. This activity will last no longer than 1 hour. You will receive an additional $10 Wal-mart gift card for your time.

Please indicate whether you want to be contacted regarding Phase II

____ I, ____
(participant name)

would like participate in Phase II of this research study and I give permission to the researcher to contact me regarding this matter.

____ I, ____
(participant name)

do not want to participate in Phase II of this research study.

____ ________________
Your Signature *Date*

____ ________________
Email *Telephone number*

APPENDIX Y

Test of Normality for Dependent Variables for Large Scale Study

Tests of Normality

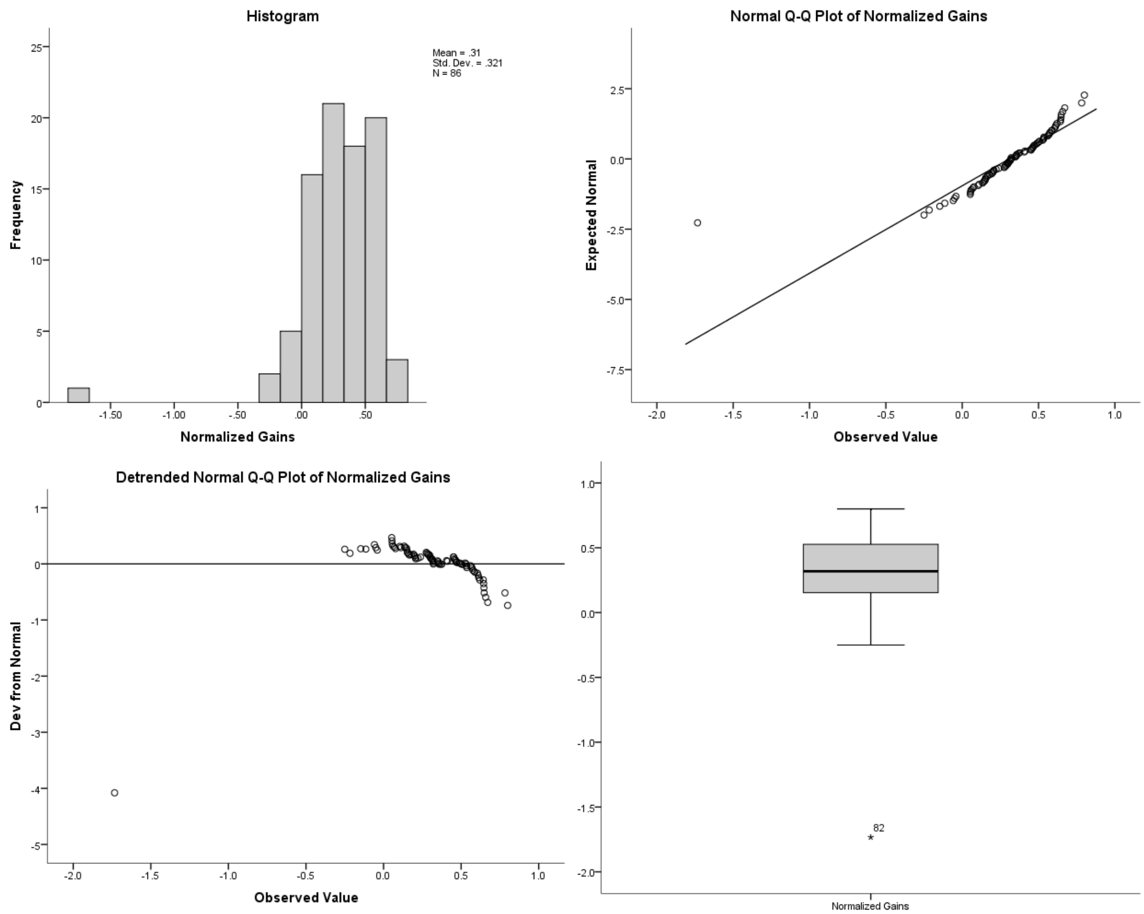
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Normalized Gains	.121	86	.003	.779	86	.000
Total Score Skilled-Based Assessment	.107	86	.016	.956	86	.005
Hilt Overall Perception of Learning	.148	86	.000	.838	86	.000
Hilt Learning Construct	.160	86	.000	.862	86	.000
Hilt Communication of Topic Construct	.191	86	.000	.839	86	.000
Hilt Critical Thinking Construct	.212	86	.000	.866	86	.000
How much did LECTURE/VIDEOS contribute to your understanding of the course materials?	.218	86	.000	.850	86	.000
How much did ACTIVITIES contribute to your understanding of the course materials?	.232	86	.000	.841	86	.000

a. Lilliefors Significance Correction

Further Investigation: Normalized gains

Tests of Normality

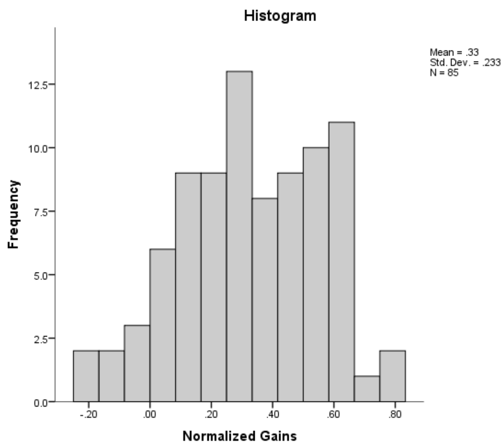
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Normalized Gains	.121	86	.003	.779	86	.000

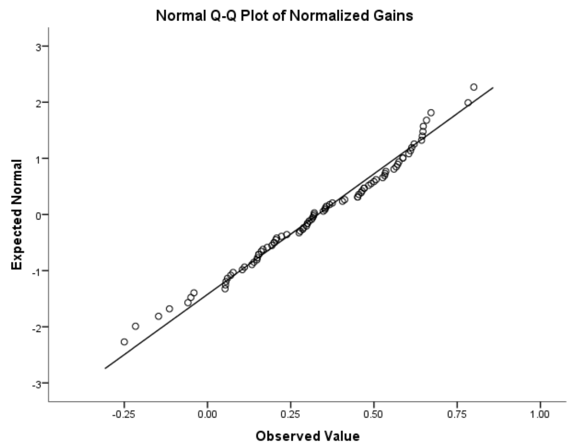


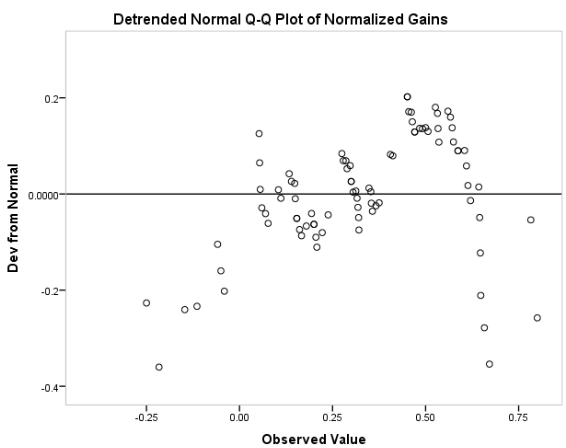
Outlier 82 was removed from the data and a Shapiro-Wilk test redone. Below are those results.

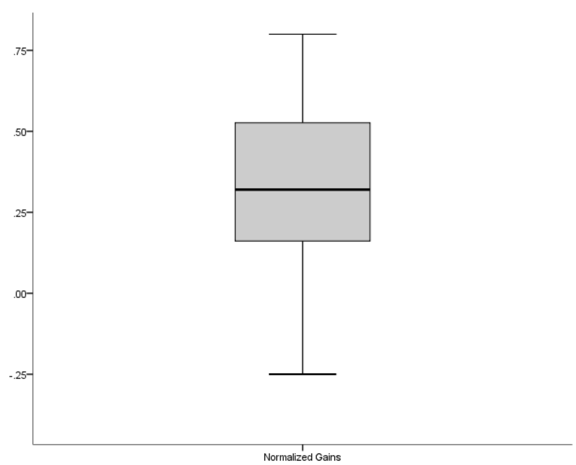
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Normalized Gains	.084	85	.199	.981	85	.246







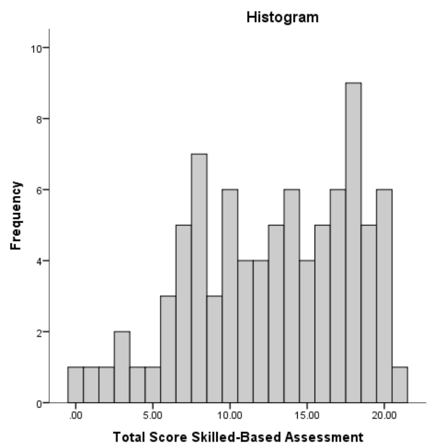


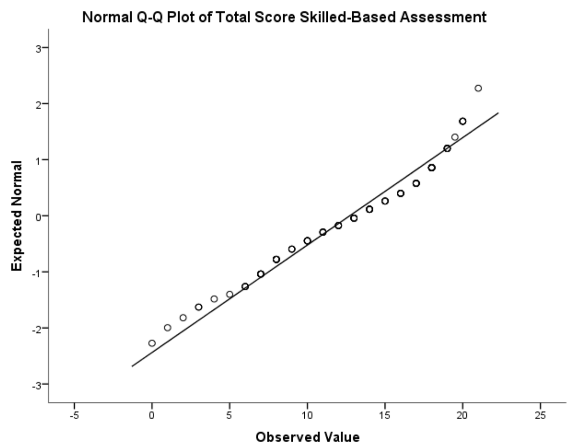
In conclusion, the normalized gains data does follow a normal distribution.

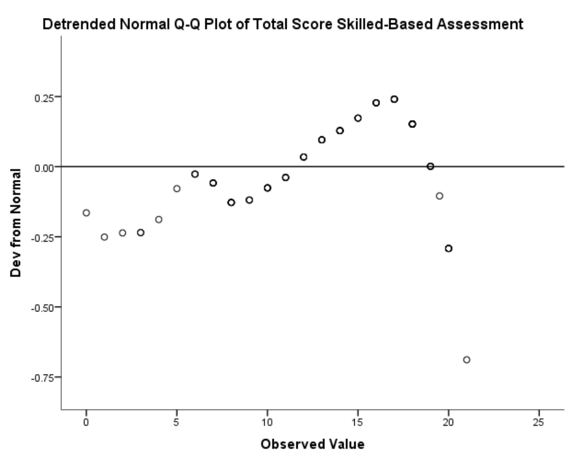
Further Investigation: Total Score Skilled based assessment

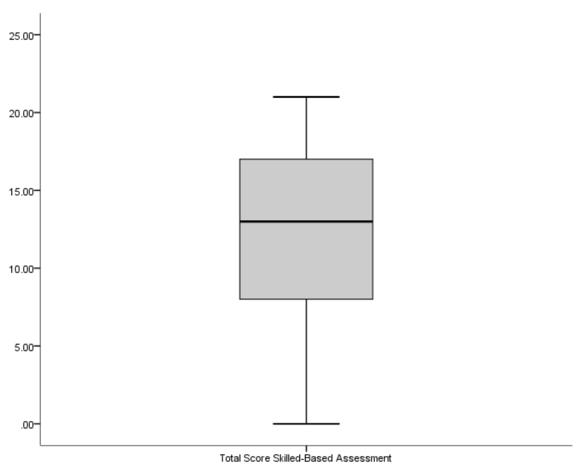
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Total Score Skilled-Based Assessment	.107	86	.016	.956	86	.005





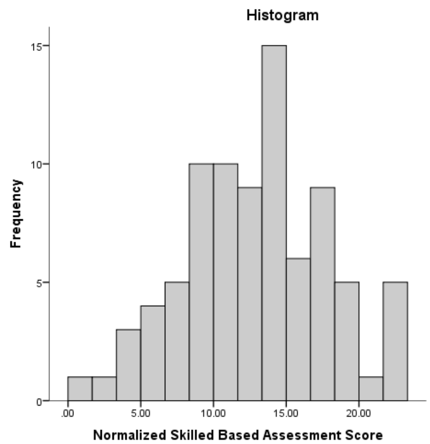


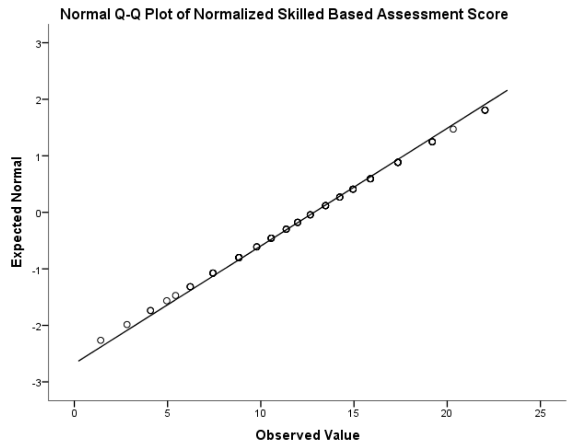


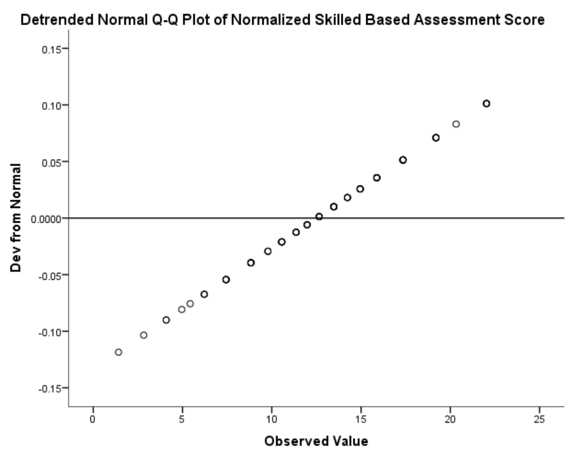
A two-step approach for transforming continuous variables to normal was followed (Templeton, 2011). Once normalized, a Shapiro-Wilk test was redone. This resulted in the following analysis:

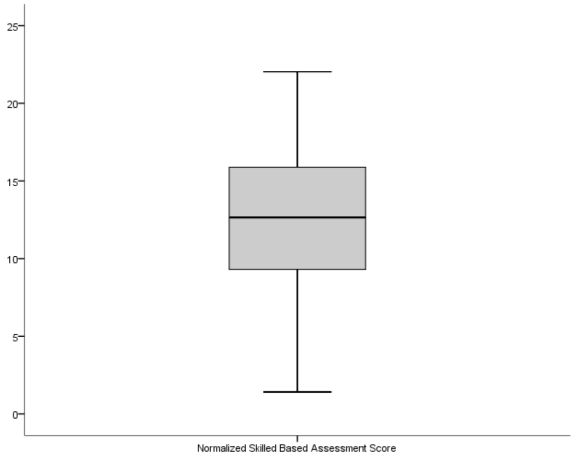
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Total Score Skilled-Based Assessment	.063	84	.200*	.985	84	.457







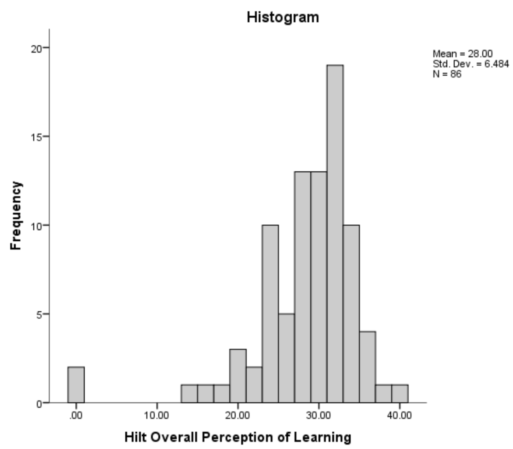


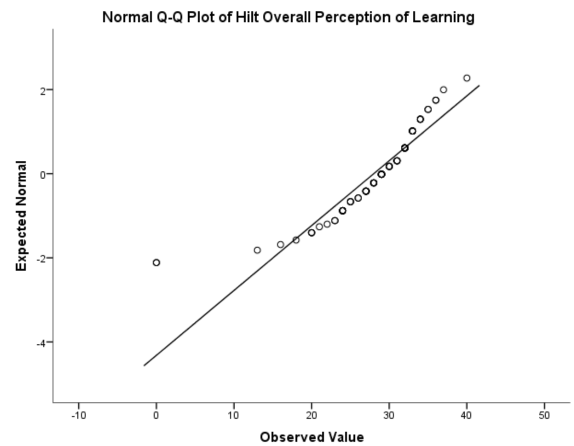
In conclusion, the normalized skilled based assessment scores follow a normal distribution and parametric tests can be conducted on this data.

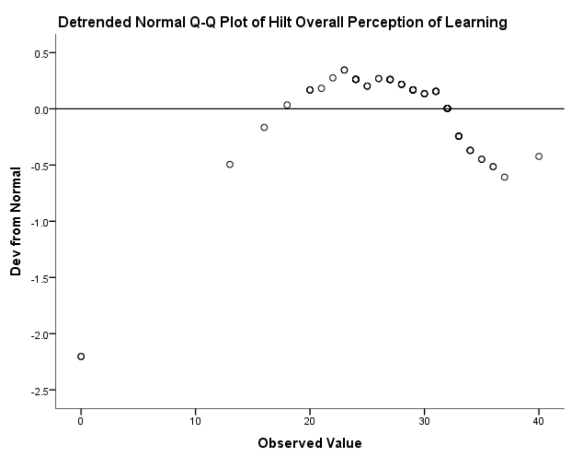
Further Investigation: Hilt Overall Perception of Learning

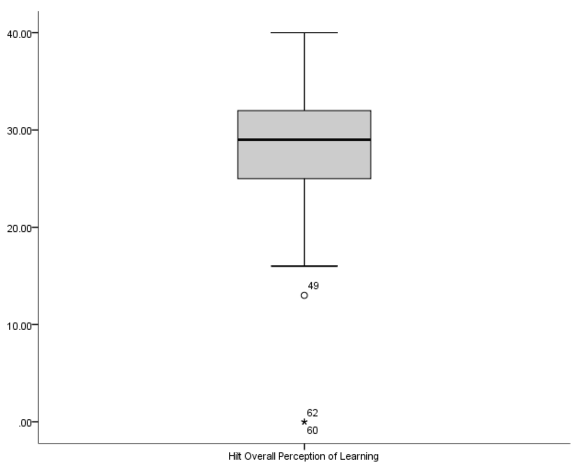
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Overall Perception of Learning	.148	86	.000	.838	86	.000





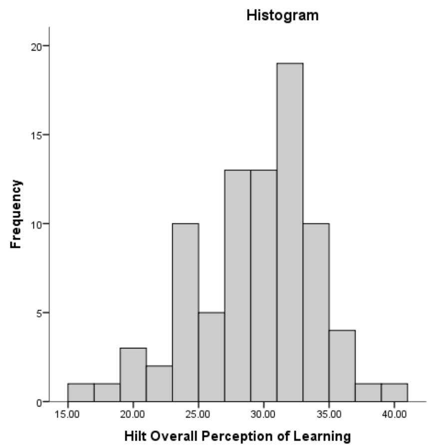


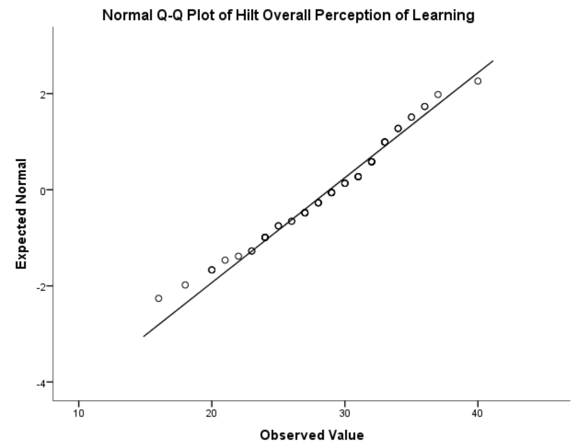


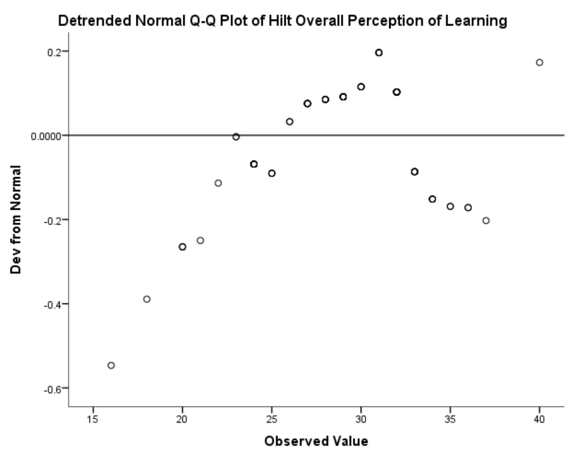
Outliers 60, 62, and 49 were removed from the data and a Shapiro-Wilk test redone. Below are those results.

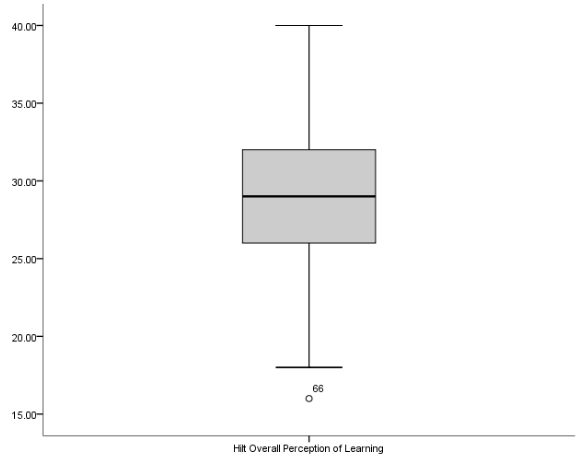
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Overall Perception of Learning	.115	83	.008	.975	83	.112







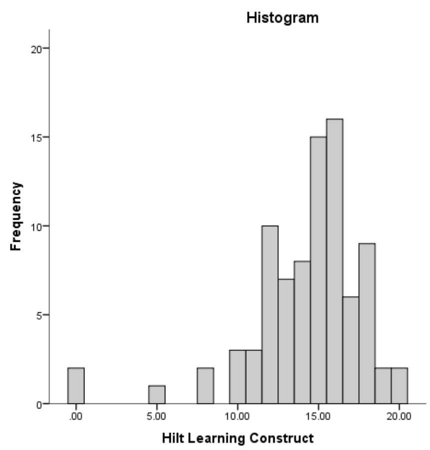


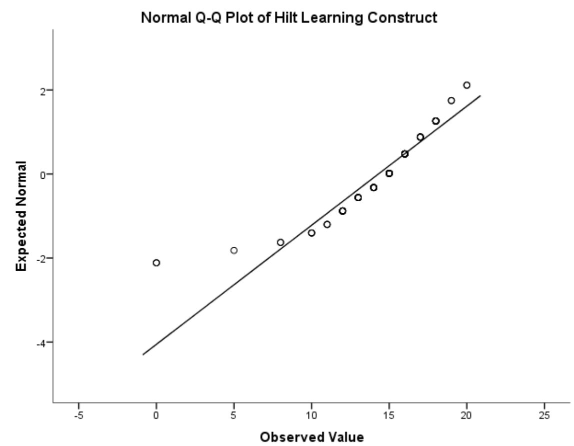
In conclusion, the overall perception of learning data does follow a normal distribution.

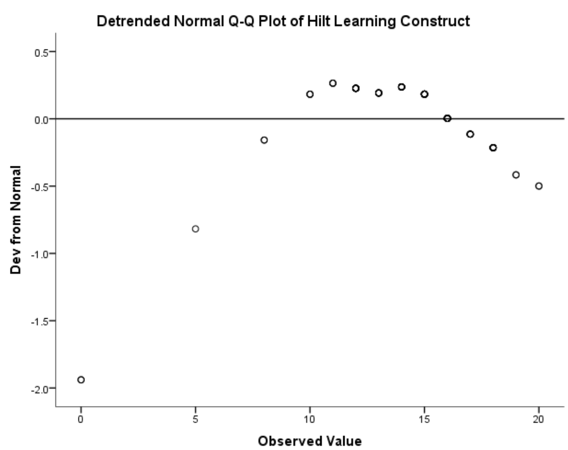
Further Investigation: Hilt Learning Construct

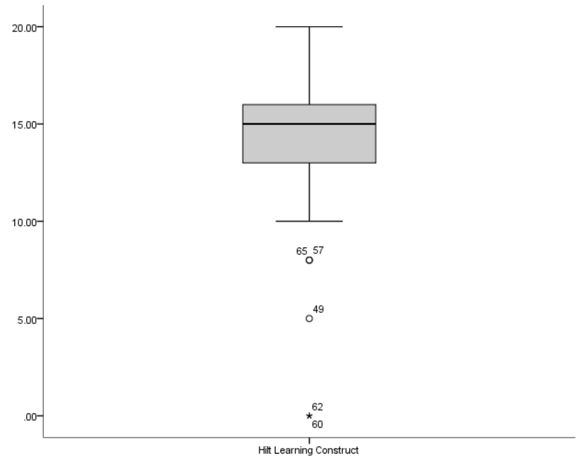
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Learning Construct	.160	86	.000	.862	86	.000





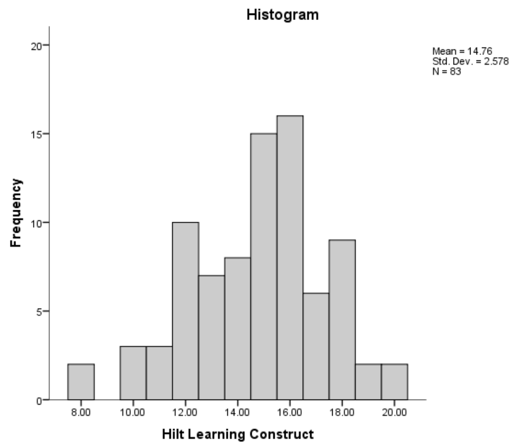


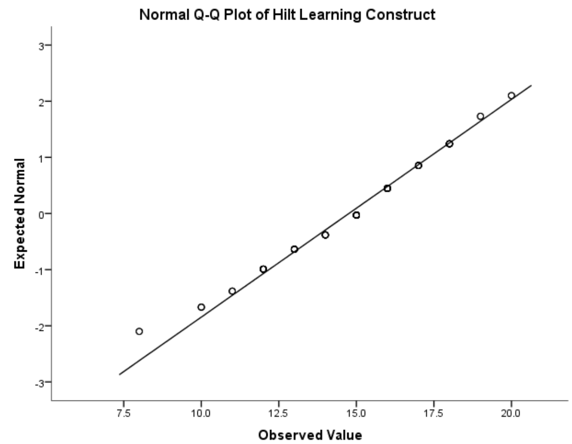


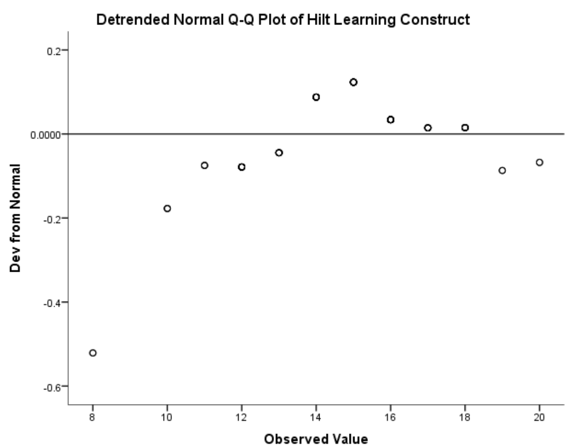
Outliers 60, 62, and 49 were removed from the data and a Shapiro-Wilk test redone. Below are those results.

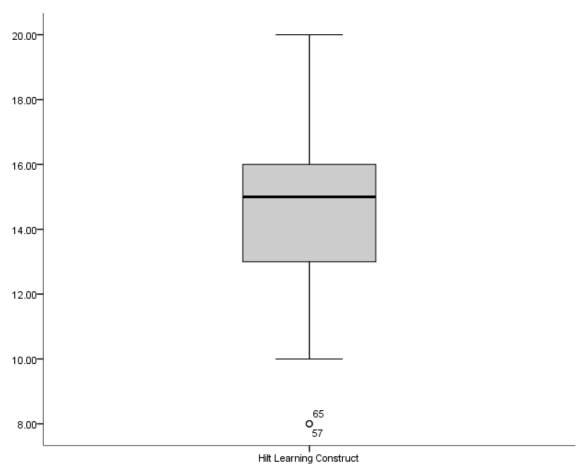
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Learning Construct	.140	83	.000	.971	83	.053







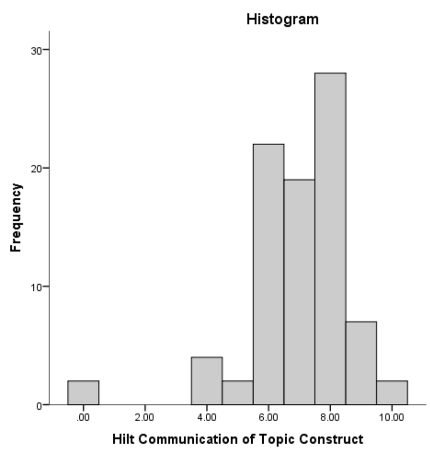


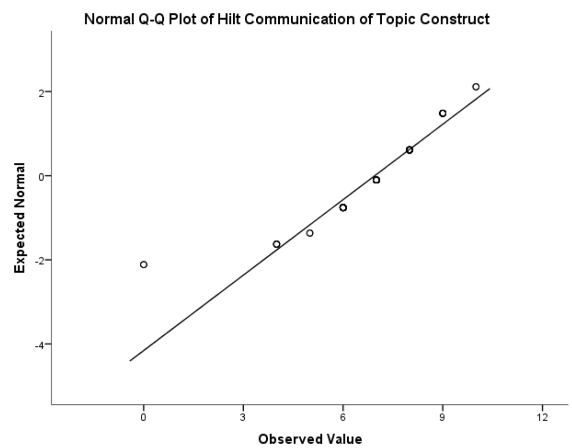
In conclusion, the Hilt learning construct data does follow a normal distribution.

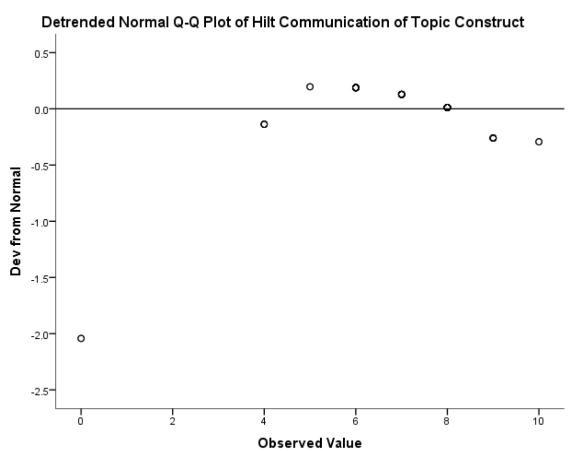
Further Investigation: Hilt Communication of Topic Construct

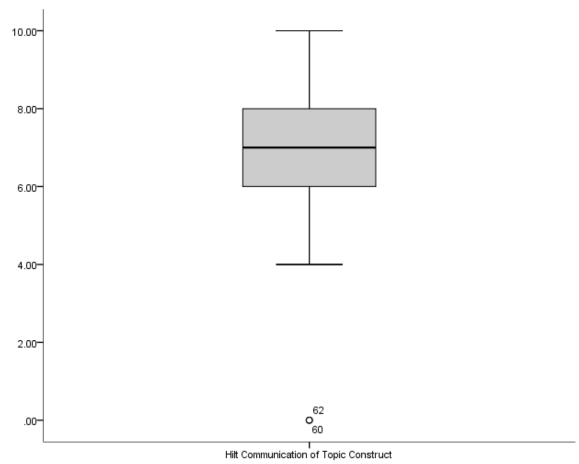
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Communication of Topic Construct	.191	86	.000	.839	86	.000





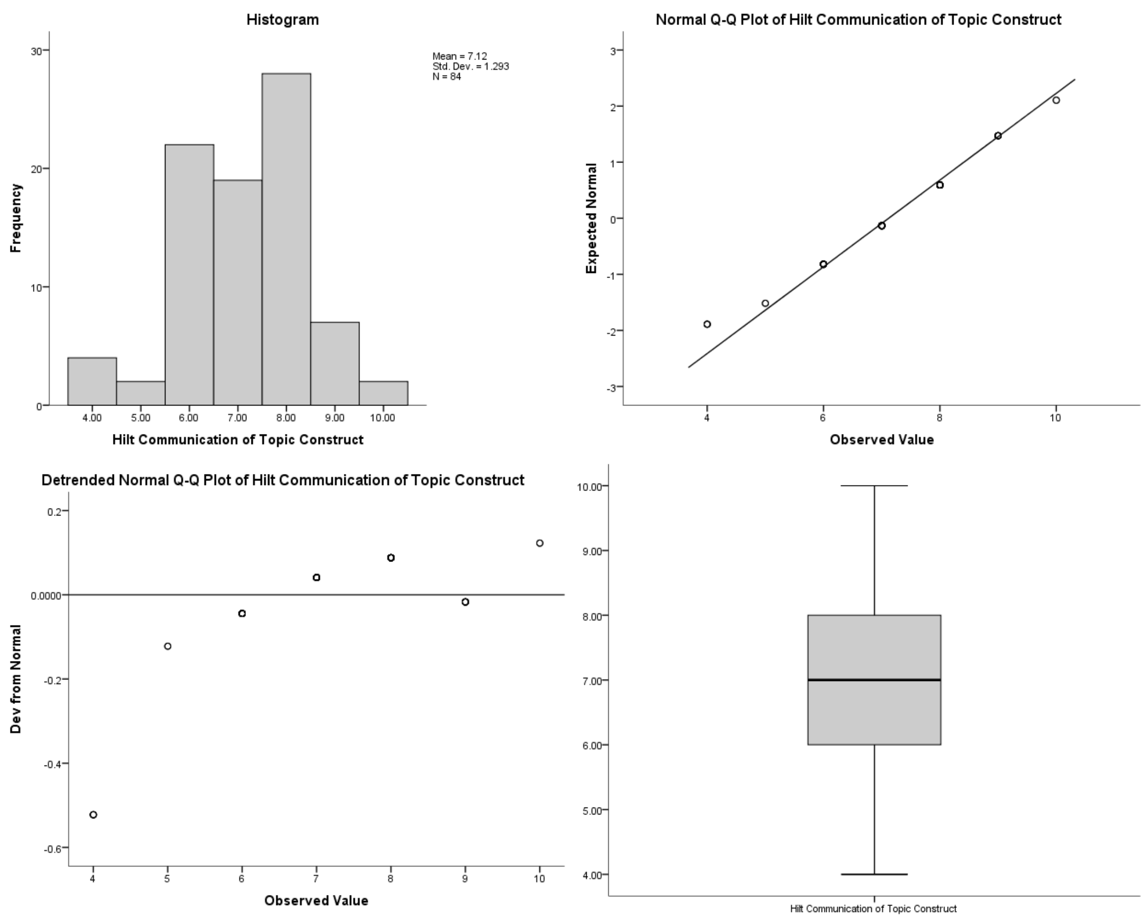




Outliers 60 and 62 were removed from the data and a Shapiro-Wilk test redone. Below are those results.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Communication of Topic Construct	.193	84	.000	.924	84	.000

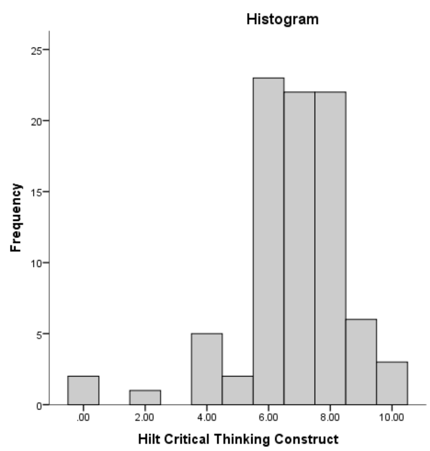


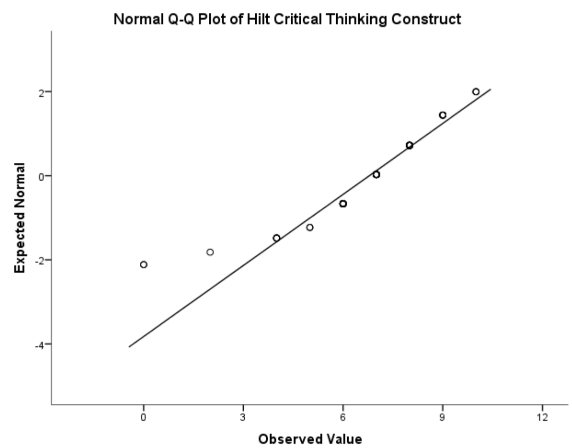
In conclusion, the Hilt communication of topic construct data does not follow a normal distribution.

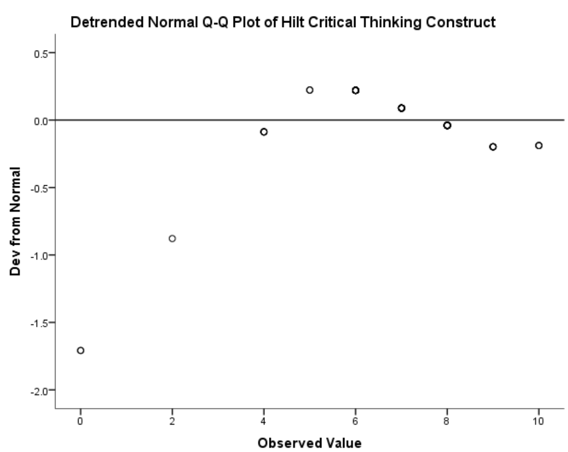
Further Investigation: Hilt Critical Thinking Construct

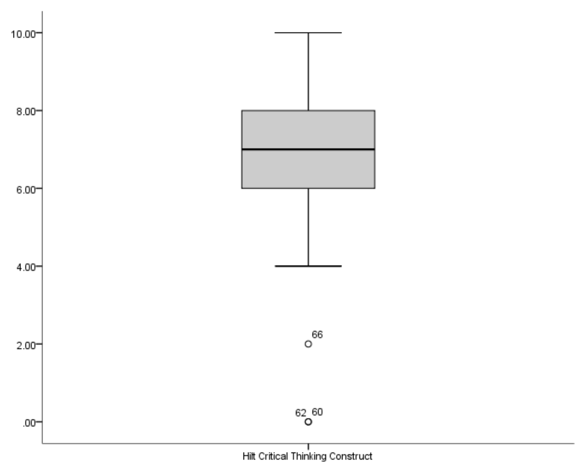
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Critical Thinking Construct	.212	86	.000	.866	86	.000





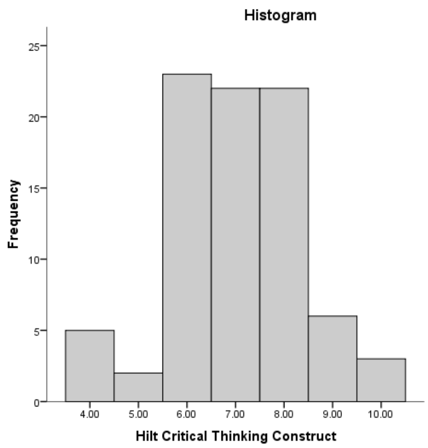


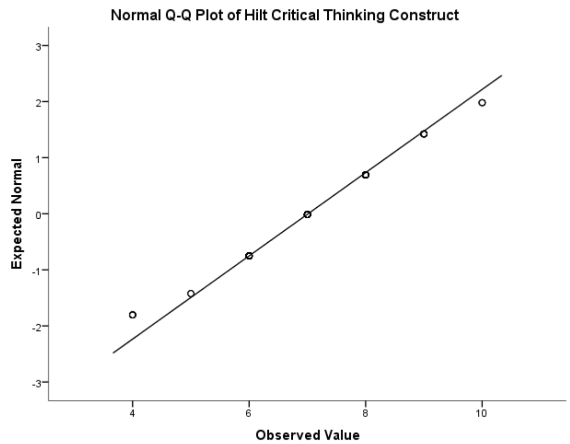


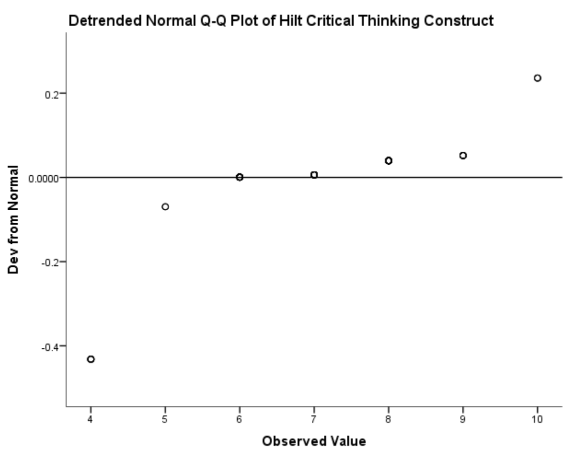
Outliers 60, 62 and 66 were removed from the data and a Shapiro-Wilk test redone. Below are those results.

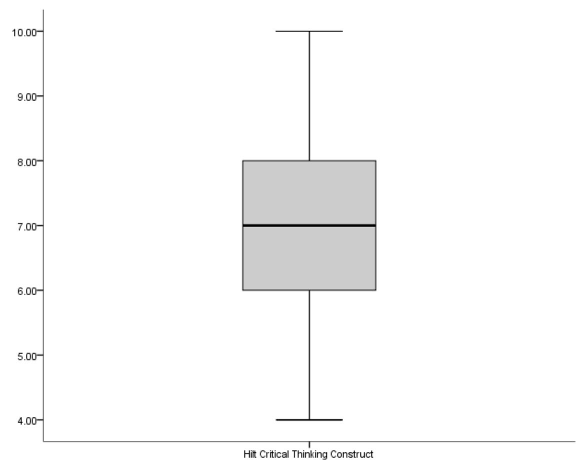
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Hilt Critical Thinking Construct	.142	83	.000	.933	83	.000







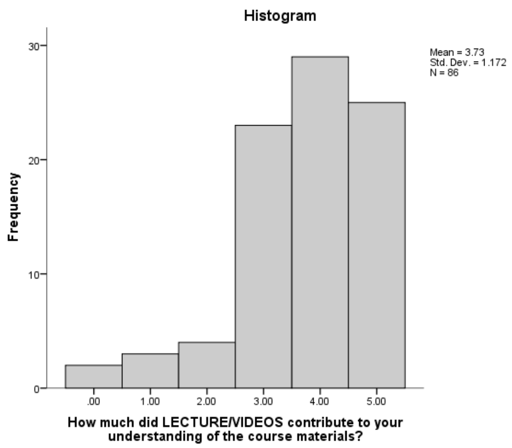


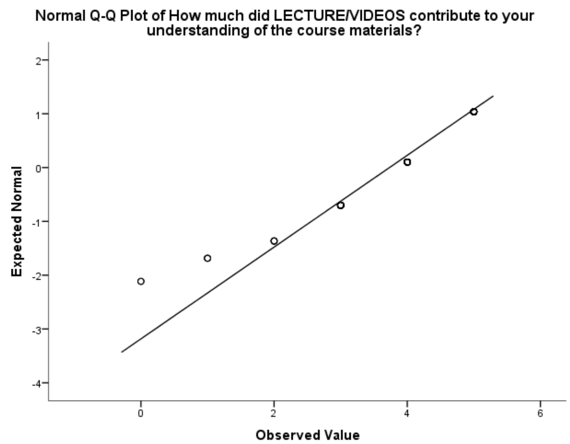
In conclusion, the Hilt critical thinking construct data does not follow a normal distribution.

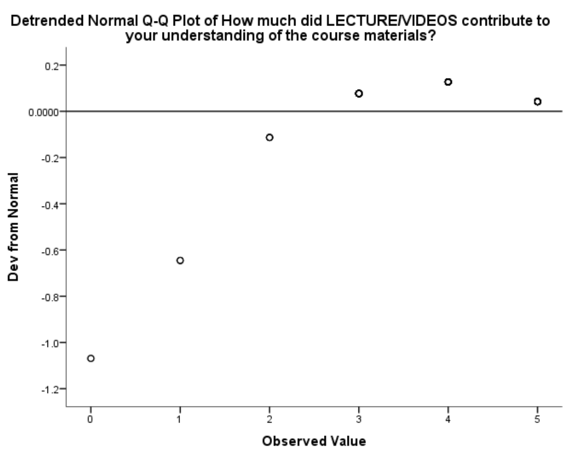
Further Investigation: Lectures/Videos

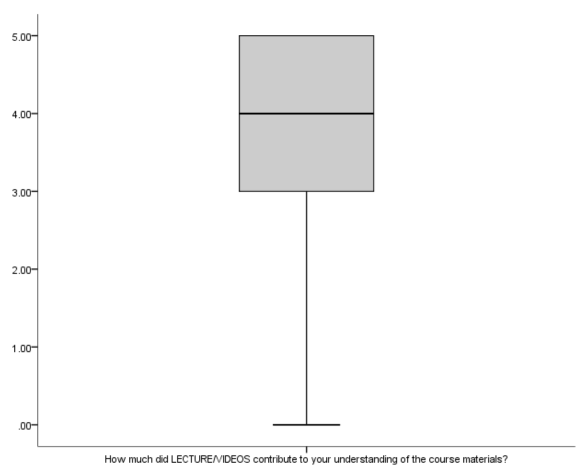
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
How much did LECTURE/VIDEOS contribute to your understanding of the course materials?	.218	86	.000	.850	86	.000







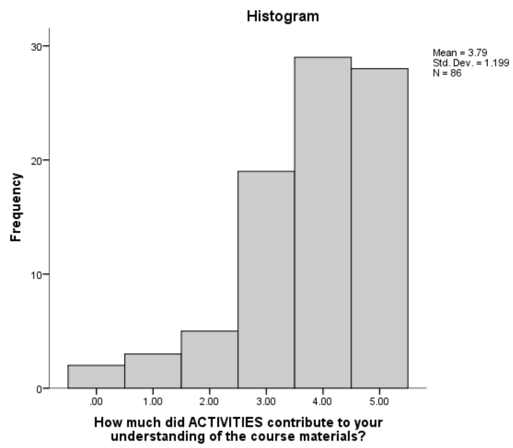


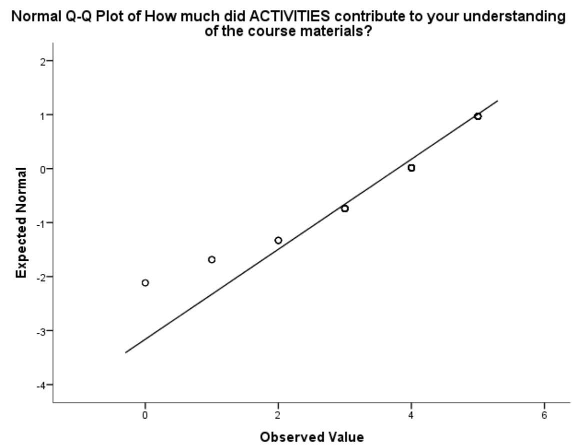
The histogram shows that the data is skewed to the right. Extreme values were removed from the data, but did not change the results of the Shapiro-Wilk test nor the interpretation of the plots. In conclusion, the lectures/videos data does not follow a normal distribution.

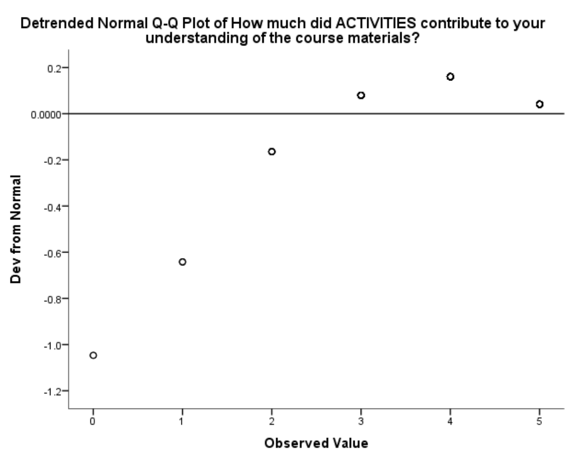
Further Investigation: Activities

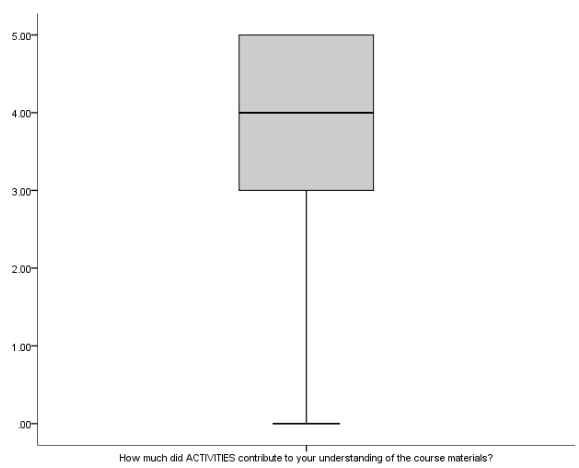
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
How much did ACTIVITIES contribute to your understanding of the course materials?	.232	86	.000	.841	86	.000









The histogram shows that the data is skewed to the right. Extreme values were removed from the data, but did not change the results of the Shapiro-Wilk test nor the interpretation of the plots. In conclusion, the activities data does not follow a normal distribution.

APPENDIX Z

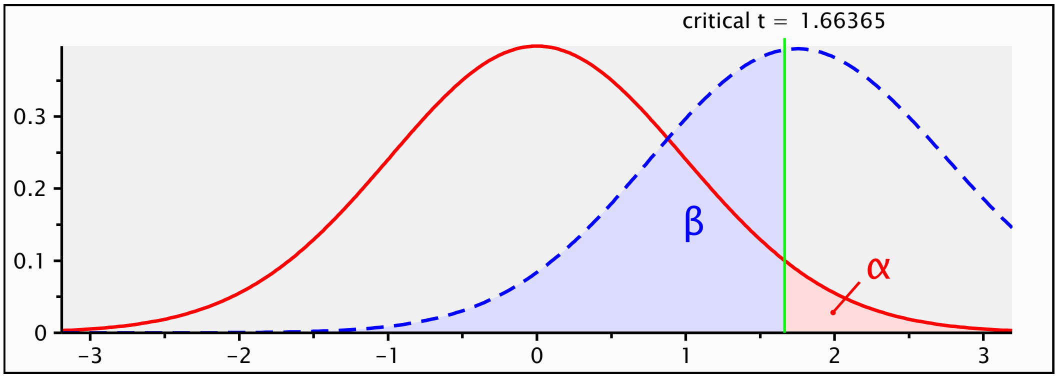
Large Scale Study's Summary of Subjective Results of Subjective Data from Digital Learning Group

Subjective Measures	Mean (SE)	Max	%
Usability Total	68.20 (16.37)	100	68.20
System Usability	26.60 (7.65)	40	66.50
Information	25.57 (4.96)	30	85.23
Interface Quality	9.80 (3.07)	15	65.33
Technology Acceptance			
Perceived Usefulness	9.18 (3.08)	15	61.20
Perceived Cognitive Absorption	21.44 (6.25)	35	61.30
Perceived Ease-of-Use	10.29 (3.40)	15	68.60
Information Quality	31.65 (6.62)	45	70.33
Service Quality	24.76 (4.64)	35	70.74
System Quality	20.62 (3.49)	30	68.73
Confirmation	9.82 (2.72)	12	81.83
Satisfaction	9.68 (3.24)	12	80.67
Continuance Intention	9.09 (3.19)	12	75.75
NASA TLX Total Workload	39.84 (14.54)	100	39.84
Mental Demand	46.58 (25.06)	100	46.58
Physical Demand	15.00 (18.03)	100	15.00
Temporal Demand	20.79 (24.31)	100	20.79
Performance	32.05 (22.03)	100	32.05
Effort	42.12 (27.46)	100	42.12
Frustration	52.55 (34.34)	100	52.55

APPENDIX AA

Post Hoc Achieved Power Test

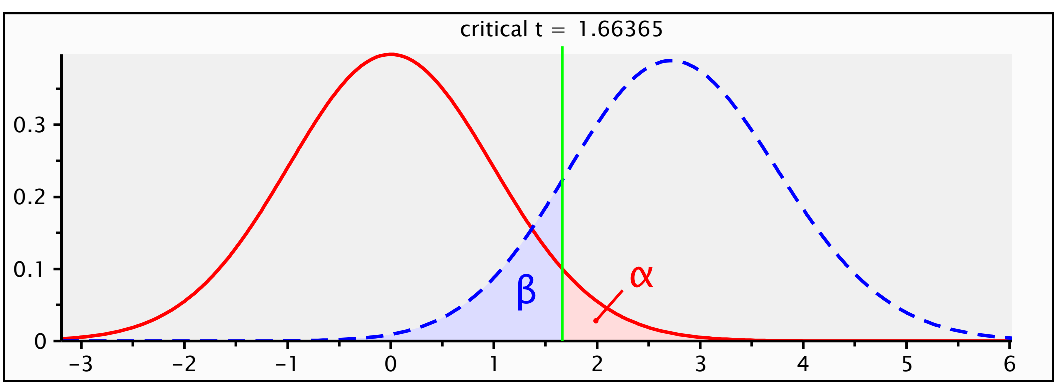
Hilt Overall Perception of Learning Scores



t tests – Means: Difference between two independent means (two groups)

Analysis:	Post hoc: Compute achieved power		
Input:	Tail(s)	=	One
	Effect size d	=	0.3854520
	α err prob	=	0.05
	Sample size group 1	=	44
	Sample size group 2	=	40
Output:	Noncentrality parameter δ	=	1.7643592
	Critical t	=	1.6636492
	Df	=	82
	Power (1−β err prob)	=	0.5417816

Hilt Communication of Topic Construct



t tests – Means: Difference between two independent means (two groups)

Analysis:	Post hoc: Compute achieved power		
Input:	Tail(s)	=	One
	Effect size d	=	0.5996472
	α err prob	=	0.05
	Sample size group 1	=	44
	Sample size group 2	=	40
Output:	Noncentrality parameter δ	=	2.7448114
	Critical t	=	1.6636492
	Df	=	82
	Power (1−β err prob)	=	0.8593041

APPENDIX AB

COMPLEX METROLOGY TASK

Participant #: ________________________ (*This will be filled out by the test administrator*)

Main journal #1 on this cam crank was machined down to remove defects. To ensure that the piston is securely attached to the cam crank, inserts must be used to reduce the diameter of the piston. Based on a piston to cam crank clearance maximum of 0.25 mm, determine which piston should be used on this cam crank, piston 1 or piston 2.

APPENDIX AC

PRE PROBLEM-SOLVING SELF-EFFICACY

Participant #: ______________________ (*This will be filled out by the test administrator*)

Please rate how certain you are that you can solve metrology problems at each of the levels described below.

Rate you degree of confidence by reporting a number from 0 to 100 using the scale given below:

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately can do					Highly certain can do

	Confidence (0-100)
Can solve 10% of the problems	______
Can solve 20% of the problems	______
Can solve 30% of the problems	______
Can solve 40% of the problems	______
Can solve 50% of the problems	______
Can solve 60% of the problems	______
Can solve 70% of the problems	______
Can solve 80% of the problems	______
Can solve 90% of the problems	______
Can solve 100% of the problems	______

POST PROBLEM-SOLVING SELF-EFFICACY

Participant #: ______________________ (*This will be filled out by the test administrator*)

Please rate how certain you are that you can solve metrology problems at each of the levels described below.

Rate you degree of confidence by reporting a number from 0 to 100 using the scale given below:

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all				Moderately can do						Highly certain can do

	Confidence (0-100)
Can solve 10% of the problems	______
Can solve 20% of the problems	______
Can solve 30% of the problems	______
Can solve 40% of the problems	______
Can solve 50% of the problems	______
Can solve 60% of the problems	______
Can solve 70% of the problems	______
Can solve 80% of the problems	______
Can solve 90% of the problems	______
Can solve 100% of the problems	______

APPENDIX AD

Framework Code Book

Framework Phases

Transfer is a dynamic creation of associations between target tool read out from the external inputs and source tools activated from long term memory. Readout, activation and associations are mediated through higher-order control by epistemic meta-tools which are in turn activated through priming by cover meta-messages in the external input.

Phase I	The interviewer provides external input describing the problem scenario. Additionally, the interviewer also primes the learner through 'covert messages' to activate epistemic meta-tools.
Phase II	The activated epistemic meta-tool controls the process by which the learner weighs the relevance and reads-out certain pieces of input information to be used as a target tool in the reasoning process
Phase III	The epistemic meta-tool activates source tools from long-term memory. If "knowledge as propagated stuff" epistemic meta-tool is activated, then the learner is more likely to use knowledge acquired through formal instruction. If "knowledge as fabricated stuff" epistemic meta-tool is activated, then the learner is more likely to use self-constructed knowledge. The learner establishes associations or relationships between the source and target tools. The activation process is implicit, while the association process is typically explicated by the student.

External Inputs

Answers the question: What prompts transfer?

- An external input is information provided by the interviewer via a protocol question, follow-up or clarification questions, as well as other hints or cues.
- Interaction with the interviewer is an example of social interaction which may cue students to access various knowledge elements or tools in their reasoning.

Tools

Answers the question: What transfers?

- Pre-existing tools
    - Tools from student's prior experience or knowledge gained through everyday life or instruction.

- They can be resources or facets and mental models that the student possesses.
- Tools enable us to characterize what a student transfers from his/her prior knowledge and experience.
- What an expert may consider a surface feature may be structurally substantive for a learner.
- Knowledge as propagated stuff: 'facts' acquired from 'authoritative' sources such as a textbook or an instructor, rather than from personal life experiences or peers.

- Created tools
    - Tools that are dynamically constructed at an earlier instance in the interview such as knowledge acquired while reasoning through previous questions.
    - Created tools are more likely to be utilized by a student operating in "knowledge as fabricated stuff"

Workbench

Answers the questions: "What relations of similarity are created? How are they supported by the environment?"

- Includes various mental processes that may utilize external inputs and tools
- Workbench processes include:
    - Making connections between various tools or executing a known rule or procedure
    - Reorganization and restructuring of knowledge: assimilation and accommodation, conceptual combination, hybridization
    - Analogical, inductive, or deductive reasoning
    - Decision making
- Affords the opportunity for the researcher to investigate the learners' ability "to learn new information and relate their learning to previous experiences" (Bransford and Schwartz's, 1999)

Answer

- Marks a stopping point in the reasoning process and not necessarily the final outcome or conclusion
- An answer can be decisive, indecisive, and none.
    - Decisive: Student arrives at a single conclusion
    - Indecisive: when a student is unable to choose between two answers or when a student requests more information
    - None: "don't know"

Framework Metaphor – The computer

The external input is analogous to the human sensory inputs or computer input devices: mouse, keyboard, etc.

Tools correspond to information stored in long term memory that is retrieve before usage, similar to data on the hard drive that is loaded into a buffer before usage.

The workbench corresponds to the processes in the short term working memory or in a computer's CPU.

The answer corresponds to the output action or speech by the individual or in the case of the computer, the information displayed on the monitor or printed.

Transfer involves retrieval of information from the long term memory followed by its processing in the working memory.

Other Key Terms

Source Tools: are pre-existing knowledge or experiences from a prior context such as a real-life experience, classroom instruction, popular media, or even previous interview questions.

Target Tools: are attributes of the 'target' situation. Target tools may include surface features, deep structures, affordances, or states of affairs

Epistemic Meta-tools: are epistemic resources ("knowledge as propagated stuff" or "knowledge as fabricated stuff") that a student activates to exercise executive control over workbench processes.

Read-out: is the process by which a learner recognizes the relevance of certain attributes or transfer tools in the external inputs.

Activation: is the process by which a learner recalls into working memory, source tools or epistemic meta-tools that are dormant in long term memory.

Association: is the process by which a learner interconnects tools in the working memory. These can be inferential, casual, analogical, deductive, or inductive. It is often difficult to distinguish between activation of a tool and its association with other tools. When students explicated the associations that they construct, then activation is implied.

Priming: is a higher order process by which covert meta-messages influence a way in which a learner frames the situation and activates certain epistemic meta-tools.

Control: is a higher order process by which a learner enhances or suppresses associations, activations, and read-out based on the epistemic meta-tools.

Examples

From literature

	Code
Interviewer: Why doesn't the rear wheel stop moving when you stop pedaling?	External Input
Student: Inertia, because it's already in motion so it tends to just keep going in motion unless a force is applied to stop it.	Source Tool: Newton's first law
Interviewer: What is force?	External Input
Student: Force is for instance if I put my hand and I push down that is me putting force on the wheel. So I guess force is a … we just covered that definition today. Force is a downward pull on an object	Target tool: the spinning wheel Source tool: Force Association: bike pedal and her kinesthetic feeling

APPENDIX AE

Test of Normality for Dependent Variables for Phase II

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
AveragePreSelfEfficacy	.209	17	.047	.903	17	.077
Average_PostSelfEfficacy	.336	17	.000	.740	17	.000
Normalized_Gains	.147	17	.200*	.942	17	.337

APPENDIX AF

Excerpts

Source tool, conventional learning group, Matthew

RESPONDENT: So it, yeah, but the 44.8 is just going to be too tight. It's going to bind, yeah. But with just a little polishing, that would be the one to go with, right? I mean, if I was building something up, I would polish that one to fit and have it just be spot on, I would think. Because you, just because you can have .25, which sounds actually like a lot, doesn't mean you really necessarily want to have the maximum. I don't know.

I mean, I'm getting exposed to this actually outside of the class, but it's very spotty, and it's a little bit here, a little bit there. I'm actually trying to rebuild some motorcycle engines with people who know what they're doing. And there's actually some different schools of thought about, for example, wrist pins in pistons, and you want a tight fit or a floating fit. And I'm learning that, yeah, there's the math, and then there's, this guy builds performance race bikes, and he's got one opinion about how tight the fit should be. And this guy builds performance vintage stuff, and he's got a different opinion about it.

INTERVIEWER: Exactly.

RESPONDENT: So, yeah, so I have to think through a lot of that.

INTERVIEWER: Even though there's tolerances, there's . . .

RESPONDENT: There's tolerances, and then there's tolerances.

INTERVIEWER: Yes.

RESPONDENT: Yeah, so, but with the tools, you can tell what the tolerances are, and it does take a little practice. And I would have thought we'd use the inside gauge that has the balls on it, the expanding gauge for that. But that ought to do, but that's a different order of magnitude of accuracy between that and this.

INTERVIEWER: Right. Correct.

RESPONDENT: Which also you have to think about. Because when you're going this accurate, and then you're going to that, it's like, oh, well, I just kind of, you know, there's no point, so.

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