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DEPARTMENT OF MECHANICAL AND NUCLEAR ENGINEERING

ASSESSING THE EFFECTIVENESS OF VIDEO TUTORIALS ON KNOWLEDGE TRANSFER AND RETENTION DURING MACHINING TRAINING

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ABSTRACT

Physical prototyping, or developing a model of a design concept that exhibits important aspects of the product, is an essential part of the mechanical design process that cannot be undertaken without the development of basic machining skills. Currently, Penn State offers hands-on machining training for all mechanical engineering students through the Learning Factory. In an attempt to streamline this training, video tutorials were developed to simulate the standard training and provide a potential alternative to the hands-on experience. Therefore, the focus in this research was testing these video tutorials to determine how effective different technical communication methods are during machining training. Retention rates of the knowledge learned through the hands-on training versus the video tutorials in combination with the hands-on training were also assessed.

Overall, video tutorial training was found to be more effective than hands-on training for both the manual mill and lathe in initial testing, with the differences in knowledge transfer being statistically significant in both cases. For retention, the group that viewed the video tutorials experienced knowledge decay at a slower rate for both machines, but the result was not statistically significant. Furthermore, the higher levels of noise in the machining environment were found to negatively impact the students' learning. The objectives in this study are to identify a number of possible improvements in communication, specifically to allow inexperienced students to more easily attain proficiency in basic machining. Future work to assess alternative training programs and measure student improvements are also discussed.

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CHAPTER 1:

PHYSICAL PROTOTYPING AND ITS ROLE AT PENN STATE

1.1 THE IMPORTANCE OF PHYSICAL PROTOTYPING

Physical prototyping, or developing a model of a design concept that exhibits some important aspects of the product that is of interest to the designer, is an essential part of the mechanical design process (Ulrich, et al, 2007). By producing physical prototypes, one can detect unanticipated phenomena in a design concept. For instance, elevator railings with good corrosion resistance could exhibit poor surface quality for safety brake engagement. Creating a physical model may also reduce the number of costly iterations, particularly when dealing with a high number of uncertainties due to new technology or the innovative nature of the product. Additionally, a prototype may eliminate a task from the critical path of the design process. In the case of a product that uses a printed circuit board, a hand-built board may be fabricated while waiting for the production version to be finished, expediting testing procedures.

While physical prototyping can help the design process, it can also aid in the successful functioning of a design team. In a 2001 study, it was determined that developing physical prototypes "improves interdisciplinary communication and supports a concurrent, time-oriented approach and collaboration in balanced teams" (Vandevelde, et al. 2001). Furthermore, it stimulates the project leader's ability to support and defend the product and gain senior management's support and attention. By helping the project leader recognize ideas and approaches, physical prototypes have been shown to motivate this leader to advocate the project beyond his or her own tasks. This also allows senior management to view the milestones of a project more easily and allows them to explicitly express support

(Vandevelde, et al. 2001). Lastly, research has confirmed that physical prototyping also results in a higher quality and more reliable product (Bourell, et al., 2002; Jacobs, 1995).

1.2 CURRENT PROTOTYPING RESOURCES AT PENN STATE

Stressing the importance of physical prototyping as a high quality design tool as well as an integral part of building collaboration skills, Penn State places a large emphasis on the engineering "shop" (Lamancusa, et al., 2008). Within the university, the College of Engineering and College of Arts & Architecture both stress design methodologies and prototyping techniques by including them in multiple courses throughout their respective curricula. In fact, the College of Engineering requires that all undergraduate mechanical engineering students participate in a capstone design course, in which students are assembled into teams and paired with corporate sponsors through the Learning Factory program to produce a solution to a current engineering problem (Lamancusa, et al, 2008). This course often involves a large amount of design work and culminates in a physical prototype, to create a functional model. By requiring this course, Penn State is stressing one of the fundamental concepts behind prototyping, namely, "Students need a context of real life experiences in order to make sense of engineering science. Otherwise, that knowledge is meaningless abstraction and is neither memorable nor transferable" (Lamancusa and Simpson, 2004).

In order to produce these functional prototypes, The Bernard M. Gordon Learning Factory, the largest student-accessible machine shop on campus, is frequently utilized. According to 2011 data, over 600 students utilized the Learning Factory for their capstone design projects (The Pennsylvania State University, 2012), and that is only a small sampling of the total number of courses that employ the facility's resources. This facility has tremendous capabilities including manual and CNC machining, waterjet cutting, rapid prototyping, welding, assembly, and metrology (Lamancusa and Simpson, 2004), all of which contribute to a more robust ability to create a physical prototype.

As part of a summative assessment, the Learning Factory was analyzed at the end of its original grant in 1998. The study revealed that 88% of students said that the program allowed them to apply engineering science fundamental to solve real-world problems, and 78% felt more confident in solving real-world problems. Industry partners agreed, with 95% of them believing Learning Factory students would be more useful to their companies (Lamancusa, et al., 2008). Furthermore, Lamancusa and Simpson (2004) also established that physical prototyping promotes better teamwork, with 93% of industry partners believing the projects promoted team skills.

1.3 DEVELOPING MACHINING SKILLS

In order to utilize the Learning Factory to its full potential and maintain a safe working environment, comprehensive machining skills must be learned. While students occupy all stages of the learning curve, from novice machinists up through mastery, basic skills courses are required in order to use the machines and operate them safely. Even a development of basic machining skills is important because as McGinley (2010) points out, "Those with a broader and deeper comfort zone in a manufacturing setting are likely to bring parts to fruition more quickly, cheaply, effectively, safely, and with less hassle than naïve peers."

For most students, developing machining skills begins by participating in machining training offered by the Learning Factory staff designed first and foremost to promote safe prototyping practices. The main component of this training is on the proper use of two machines: (1) a manual lathe and (2) a manual mill.

1.3.1 MANUAL LATHE

Manual lathing (see Figure 1) is a subtractive manufacturing process used to perform various cutting and drilling operations. Unlike most machining processes, the tooling is quasi-stationary while the workpiece rotates about an axis of symmetry. The rotational speed of the material relative to the tooling provides the power needed to cut into the piece of stock material. Manual lathing differs from Computer Numerical Controlled (CNC) lathing because the machinist completely controls the manual lathe, from spindle speed, to feed rate, to tooling choice while creating the part; whereas, CNC lathing uses a computer program to automatically determine these parameters and cuts the part without any machinist input while the lathe is running. One limitation to lathing with respect to the workpiece is that the piece must be symmetrical and in most cases cylindrical. Advanced lathing is commonly used in woodturning and metalworking and can create objects such as candlestick holders, gun barrels, woodwind instruments, and large custom bolts.

Focusing on the development of basic machining skills, cutting operations including facing the part, shearing the sides, cutting off part of the stock, and drilling a hole through the middle of the part are taught during the Learning Factory's training. With these procedures, parts can be made such as washers, shafts, and pieces with changing diameters.

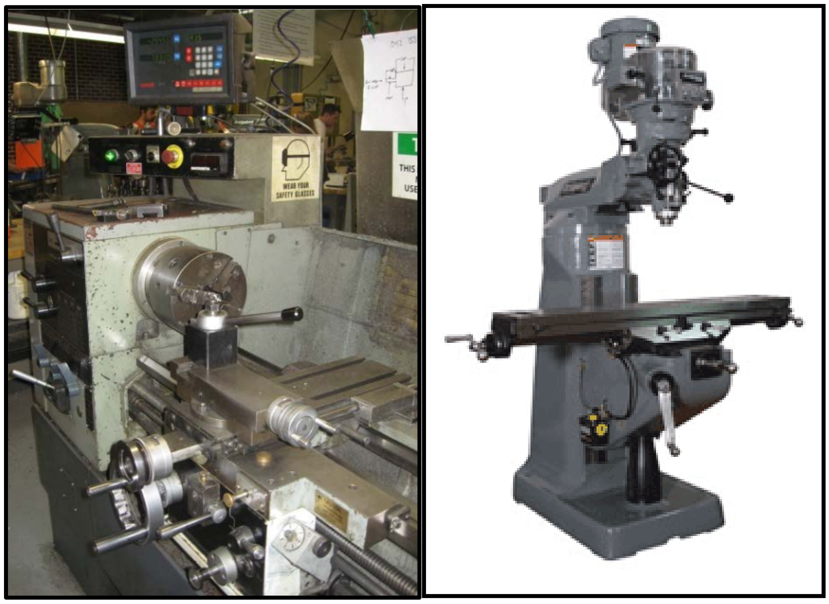

Figure 1: A Manual Lathe in the Learning Factory (left) and a Bridgeport Vertical Mill used in the Learning Factory (right)

1.3.2 MANUAL MILL

Milling is a subtractive manufacturing process used to perform various complex 3D cutting operations. One of the most flexible basic machining practices, it is extremely useful and can create many different geometries. It operates by using a fixed rotating spindle equipped with a cutting tool to machine a part that is moved into the way of the tool by 3 separate axis controls (see Figure 1). Milling can be performed on any metal, but it is generally most useful with aluminum or steel. Milling is an essential manufacturing process to nearly every industry.

During the Learning Factory's training, basic machining skills taught on the mill include touching off, end milling, face milling, drilling, tapping, and countersinking. These procedures comprise a comprehensive list of basic skills that can be performed on each machine to create a simple component of a prototype.

1.4THESIS MOTIVATION, OBJECTIVES, AND ROADMAP

Although enrollment throughout the University Park campus has been essentially constant since 2009, up only 1.1 percent (Shockey, 2009; 2011), the number of mechanical engineering students has steadily risen in that time frame, with a 6.7 percent growth(College of Engineering, 2010; 2012). This increase in mechanical engineering enrollment, coupled with the expansion of the corporate-sponsored capstone design program since 2007, has increased the usage of the Learning Factory dramatically. Training the students on how to use the machinery through hands-on techniques has become more difficult as more students have enrolled in the training and group size has increased. Additionally, more noise is now being generated within the Learning Factory from other students using the available equipment while training is being conducted. This noise makes it difficult to hear everything the instructor is saying, causing many students to lose focus during the training.

While this training is necessary to familiarize students with the machinery and Learning Factory environment, the effectiveness of the technical communication in the class is often called into question, as many students either make a variety of extremely simple mistakes or are too unsure about the operating procedures to even attempt to use the machine even after completing the training. These shortcomings call into question both the amount of knowledge that is transferred via this hands-on training and the amount of knowledge that is retained after it. This thesis explores the role of technical communication in a machining environment, including its effectiveness and efficiency.

To support the Learning Factory's machining training, the role of hands-on learning versus audiovisual learning is assessed. Specifically, video tutorials were developed that teach students in the exact manner that the hands-on training is taught. This thesis compares the information gained in the hands-on training alone versus the information gained from viewing the tutorials alones, to analyze which is more effective in helping the students learn the basic operation of the manual mill and manual lathe. Furthermore, the thesis studies whether students retain the knowledge at a higher rate if both the tutorials are watched and the hands-on training is taken versus just participating in the current hands-on training.

The next chapter reviews previous work that is relevant to this study, specifically related to audiovisual tutorial development and retention studies. Chapter 3 discusses the methodology used in developing the video tutorials and assessment quizzes, while also detailing the process used to carry out both testing procedures. Chapter 4 presents the results and analysis of this study. In the final chapter, recommendations for improvements to the training are made as well as a set of potential future studies that may be undertaken to yield valuable information regarding how the Learning Factory's training affects the development of basic machining skills.

CHAPTER 2:

REVIEW OF RELEVANT LITERATURE

In order to establish background for the current research, several papers related to audiovisual tutorial development and integration were reviewed. These papers helped establish guidelines and a basis for the research. Additionally, they helped formulate specific questions that need to be addressed within this study. Once audiovisual tutorial development and assessment were reviewed, retention rates and the effect of different instruction methods were investigated. A summary of the findings follows

2.1 AUDIOVISUAL TUTORIAL DEVELOPMENT AND ASSESMENT LITERATURE

Before delving into research concerning how tutorials could be implemented and assessed, a comprehensive study on the Learning Factory was reviewed to determine exactly what students learned in relation to using this facility and taking advantage of its resources. The psychological experience of prototyping was also assessed in order to gain an understanding of exactly what skills students need to develop through prototyping. Additionally, employing teaching strategies within the context of audiovisual tutorials was reviewed to learn what the tutorials should include to be more effective.

Lamancusa, et al. (2008) review the need for hands-on machining in engineering curriculum and the goals for addressing this need through the Learning Factory at Penn State. The authors assert that students yearn for direct hands-on experiences in engineering design while industry partners call for changes in academic curricula to include more work relevant to professional practice. From these needs, the Learning Factory was developed to provide a large facility that would be solely dedicated to hands-on instruction of undergraduates and provide practice-based curriculum in product dissection and concurrent engineering among other topics. Understanding the goals of the Learning Factory is vital to help guide the design of the audiovisual tutorials and also the construction of the machining quizzes.

Gerber and Carroll (2011) discuss the overall experience of prototyping and the learning and psychological impacts it provides. One team of thirty-five designers was evaluated specifically on prototyping over an eighteen month period on one user-centered design task. The analysis of low-fidelity prototyping in the design process revealed three main conclusions—prototyping reframes failure as an opportunity for learning, fosters a sense of forward progress, and strengthens beliefs about creative ability. This study only looked at one large team and not smaller teams in which each member has more project management responsibility which could reveal more about how the prototyping process affects leadership. Overall, this thesis addresses these findings by teaching students basic machining skills that are designed to be specifically used for low-fidelity prototyping; it will also contribute to this study's conclusion that design is a learning process by assessing whether knowledge is gained more effectively through focused tutorials or hands-on experiences and instruction.

Ford (2004) discusses common rhetorical strategies, how effective they are, and how each can be applied to common engineering classes. Using twelve engineering students, the researchers drew on seven writing assignments for the participants to assess how knowledge transfer occurred and what strategies were useful in these occurrences. Overall, several implications for classrooms were found, but the one that is most useful for this thesis is that committing to learning and using a common vocabulary in the classroom is necessary in order to help transfer concepts through different contexts. One of the main shortcomings of this paper is that only twelve students were assessed since the study was aimed at more qualitative data; another broader study could be used in order to evaluate just how effective using a common vocabulary is. The current study addresses this research by using a definitive technical vocabulary for the tutorial design while the hands-on course may use a more differentiated vocabulary. Furthermore, this thesis assesses the relationship between knowledge transfer and time by conducting a retention study which is suggested for future work by Ford.

Once the process of prototyping and tutorial design were analyzed, construction, implementation, and assessment of tutorials were investigated. Noise levels of machining shops and their effect on production were also reviewed to establish whether the learning Factory was a conducive environment for hands-on machining training.

Fang, et al. (2007) discuss their efforts to develop an innovative instructional model to improve cognitive learning and student motivation in undergraduate manufacturing engineering education. In order to do this, they set up an interactive computer program that consisted of three learning modules, each covering a major aspect of metal machining. As of publication time, results were still being gathered, and the modules were still being assessed for effectiveness, but initial data revealed that 90% of students rated their experience using the computer program as positive while 71% stated that the program was preferred for confirming initial thoughts. Although their study addresses effective manufacturing education, it does not tackle basic machining skills instead focusing on more quantitative measuring techniques such as cutting force, tool wear, and surface roughness. While their study only dealt with the students' opinions on the modules and how they affected their confidence levels and did not evaluate the academic effectiveness of the computer modules, this thesis extends their work by addressing this question and quantitatively testing the effectiveness of audiovisual tutorials in aiding in manufacturing education.

Jou (2005) summarizes the implementation and use of an interactive online system that teaches basic machining techniques such as turning, milling, and drilling. The system was implemented for undergraduate courses at the National Taiwan Normal University and used to familiarize students with these manual machining techniques, even allowing user input to see the effects of feed rate, cutting tools, and other process parameters. From students' use of the system, the researcher concluded that it not only reduced the cost and time associated with traditional teaching methods, but also eased the students' trepidation about using the physical machinery for early stages of hands-on practice. While the study was useful for seeing that a computerized teaching system can be implemented successfully for machining education, minimal analysis was conducted as to how effective the system was in communicating the machining procedures or what interactive techniques were considered especially useful. This thesis extends this previous work by analyzing the effectiveness of audiovisual instruction in teaching basic machining principles.

While Fang, et al. and Jou deal with machining techniques but do not quantitatively measure their tutorials' effectiveness, Merino and Abel (2003) directly assessed the difference of tutorials from human counterparts in teaching effectiveness; however, they do so within the realm of engineering economics. The one hundred fifty engineering students that were part of their study were split into two groups based on previous engineering economics knowledge. The two groups were tested, then shown three consecutive audiovisual tutorials on accounting principles, and then tested again to evaluate how much information was learned. The authors found that as expected the students who had previously received instruction in engineering economics scored higher on the initial testing, but after the tutorials were viewed the difference in the post-tutorial testing between the two groups was negligible. The study concluded that in a combined form with traditional lecturing the computer mediation acts as a supplement; however, as a singular method of instruction it acts as a competent tutor, bringing students to the same level of knowledge as their peers. The proposed study expands upon these findings. While their research looked at the competence of computer tutorials as a singular method versus supplementary instruction for students who already had subject knowledge, the proposed study examines the effectiveness of audiovisual tutorials versus simple hands-on lecturing in students who have little to no previous knowledge of the subject.

McNaught, et al. (1995) also utilize video tutorials to assess how effective computer-assisted learning can be in a technical environment. Students of different pre-determined abilities were shown either a video or a video with accompanying tutorials and then assessed on their ability to answer questions and perform procedures that were shown in the each. Overall, the students who viewed both the video and tutorial performed better in the lab and on the administered quizzes; however, students gained more understanding of technical skills needed than the theoretical underpinnings. The current study addresses these results by testing both technical practices and theoretical reasoning behind the procedures in the tutorials. Furthermore, the current experiment improves upon the methodology of their study simply by not associating a grade with it, so that no bias in focus will occur for either the technical or theoretical aspects of the tutorials.

Once tutorial implementation and assessment was covered, the effect of noise in machining tasks was investigated to determine if this was a viable reason that students were not learning as much. Mohammed and Hasam (2004) looked at the effect of noise on a person's ability to conduct a manual machining task. By varying both the noise levels, the consistency of the noise, and the experience of the machinist, the researchers were able to find statistically significant results relating to how much noise affects humans in a manual machining environment. The study showed that in a continuous noise environment, the noise level and amount of work experience were statistically significant. Furthermore, in an intermittent noise environment, the noise level was statistically significant for machinists with less than seven years of experience. This fact is addressed in the current study by showing that noise has an effect on how much students can learn in a machining environment, not just on machining performance.

2.2 RETENTION LITERATURE

Ibrahim and Al-Shara (2007) examine the role of interactive learning in both an online environment and how new technology can make an impact on improving teaching strategies. The paper is based on the authors' firsthand experience in using innovative learning-by-doing techniques and utilizing interactive tools. By assessing retention rates, the authors were able to conclude that access to visual imagery increases retention by seventy to eighty percent, and applying instructions in a consistent way allows aids in what students retain. Furthermore, interactivity increases students focus and decreases the time need to cover material by forty to sixty percent. Unfortunately, no standard methods are mentioned in this study; so, it is difficult to determine exactly how these specific statistics were calculated. This thesis addresses similar research by studying retention rates from students who participated in interactive learning alone through a hands-on course and those who combined the course with audiovisual learning to initially reinforce the same principles.

While Ibrahim and Al-Shara provide valuable conclusions into how audiovisual tutorials may be effective in promoting knowledge retention, Biggs (1999) thoroughly discusses retention rates through different learning practices, concluding that audio visual learning will only result in 15% retention rates over a period of time while 75% of knowledge will be retained through practice by doing over the same time period. This retention difference is due to the fact that practice by doing uses active learning while audio visual learning uses a more passive approach. This study however does not look at the effects of combined learning, so the current research delves into this matter, measuring the retention rates of combined audio visual and practice by doing learning versus just practice by doing.

CHAPTER 3:

RESEARCH METHODS

In this chapter current machining training procedures at the Learning Factory and the development of instruments to improve this training are detailed. Furthermore, the two research methods, their participants, stimuli, and how each was analyzed are explained.

3.1 CURRENT PRACTICE AND INSTRUMENT DEVELOPMENT

3.1.1 CURRENT TRAINING PROCEDURE

For Learning Factory machining certification, hands-on training sessions are conducted for the first five weeks of the semester. On any given night, twelve to eighteen students participate in the training session. This training is broken down into three main components: (1) overall safety in the Learning Factory, (2) minor tooling, and (3) large manual machinery operation. The last part is what is seen as the most important part for most engineering students because these machines—the mill and lathe—are unfamiliar to most students, but highly useful in the prototyping process. Depending on the size of the group, the students are split into two groups and one is taught the mill first while the other group receives instruction in the lathe. Once both groups are done, they switch machines. Typically, it takes 25-30 minutes to completely train a group to use the lathe and 30-40 minutes to teach a group how to operate the mill. Once all students have been trained on both the mill and lathe, they are officially certified and are free to leave; they can then return to the Learning Factory when it is open and use the machines for prototyping.

3.1.2 INSTRUMENT DEVELOPMENT

In order to streamline the training process and increase overall knowledge gained, video tutorials were developed. Quizzes based on the training were then created to assess the effectiveness of the video tutorials versus the hands-on training.

VIDEO TUTORIAL DEVELOPMENT

The mill and lathe video tutorials were developed in the same way. First the introductory machining training was filmed using an experienced teaching assistant at the Learning Factory as the instructor. Each tutorial had the same instructor in order to provide consistency for the students. The training was filmed early in the morning in a one-on-one session to avoid additional background noise. The instructor taught the class to the camera exactly as he would a student group to preserve consistency across the instruction methods so that direct comparisons could be made.

Figure 2: Screenshot of the Lathe Video Tutorial as Text Begins to Scroll Across the Screen

During editing, scrolling text was added to highlight concepts that were more complex, meaning those that explained why the machine worked a certain w ay or why a procedure need to be performed in an exact way. These complex concepts were identified in coordination with the Learning Factory Teaching Assistants. Additionally, text was added to reinforce extremely important concepts, usually relating to safety or the fundamentals of operation. Other than the scrolling text, the content of the training was preserved exactly.

MACHINING QUIZ DEVELOPMENT

Once the tutorials were complete, two machining quizzes were developed, one for each machine. These quizzes, given in Appendix A, were limited to ten questions and were multiple-choice to provide for a simple, quick assessment of the learning that occurred. These quizzes were constructed based on the information present in the video tutorials, which were based on the content presented in the hands-on training. In order to assess the different modes of instruction that the tutorials presented, namely, audiovisual only, text only, and audiovisual reinforced with text, the quiz divided the questions the same way. In the milling quiz, three questions were based on audiovisual only information, three had information presented only by text, and four had audiovisual information that was reinforced with text. In the lathe tutorial, these categories were split evenly, with three questions being dedicated to each category.

3.2 BASELINE TESTING

3.2.1 PARTICIPANTS

For the initial baseline testing, participants were sampled directly from the Learning Factory's machining training. This selection procedure ensured that the students had little to no prior experience with either the lathe or the mill, so that the quizzes given should reflect the raw information gained from either the video tutorials or the hands-on class, depending on which group the student was placed. In total, 249 students participated in this portion of the study. While the participants of this machining class were primarily juniors from Mechanical Engineering Product Design Methodology (ME 340), several others, including senior Bioengineering majors in their capstone design classes and underclassman engineers involved in extracurricular activities such as the Formula SAE car, also took part in the study.

For the study, participants were divided into one of two groups, either the experimental group or the control group. These groups were separated by training night, meaning all participants on one night would be part of the same group. For example, every participant on January 26th was in the experimental group, while every participant on January 27th was in the control group. The groups were assigned randomly, so that each day of the week varied, which helped account for variance in the hands-on course instructor. This study received nearly 100 percent participation among the students enrolled in this machining class.

3.2.2 STIMULI

The stimuli for this study were determined by the group in which a participant was a part. The experimental group was subjected to two video tutorials, one on the manual lathe which was 16 minutes long and one on the manual mill which was 20 minutes long. The lathe tutorial was always shown first followed by the mill tutorial. In addition text notes scrolled along the bottom of the screen to provide rationale for what was being taught and to reinforce information to the students.

The control group's stimulus was simply the teaching by the hands-on course instructor. These students participated in the class that is normally conducted within the Learning Factory, covering the same basic material as the video tutorials, but doing so in the actual machine shop with hands-on training. For this group each student also operated the machine while completing the training.

3.2.3 PROCEDURE

While the two groups of participants received their stimuli by completely different methods, the procedure for testing the raw knowledge gained from each experience was relatively similar. First, informed consent for the entire study was obtained for every participant at the same time as when initial data for the machine training is completed. Next, each group learned how to operate the first machine (the lathe or mill), either by tutorial or hands-on teaching, then took a short multiple choice quiz covering the material that was taught. Next, the students were taught the other machine's procedures and then took a separate quiz on that material. With the experimental group, the participants were then dismissed to continue with the hands-on training. After completing the second quiz, the control group had completed the class and was allowed to leave. These processes can be seen in Figures 3 and 4, and the quizzes are included in Appendix A.

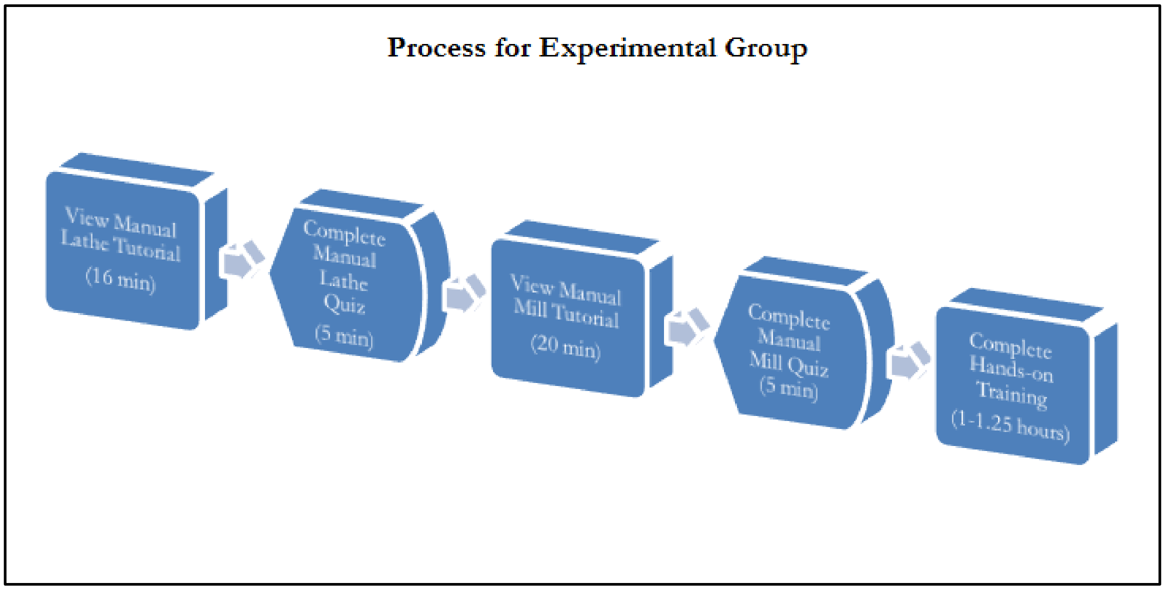

Figure 3: Flowchart of the Training Process for Members of the Experimental Group (Total Time-1.75-2 hours)

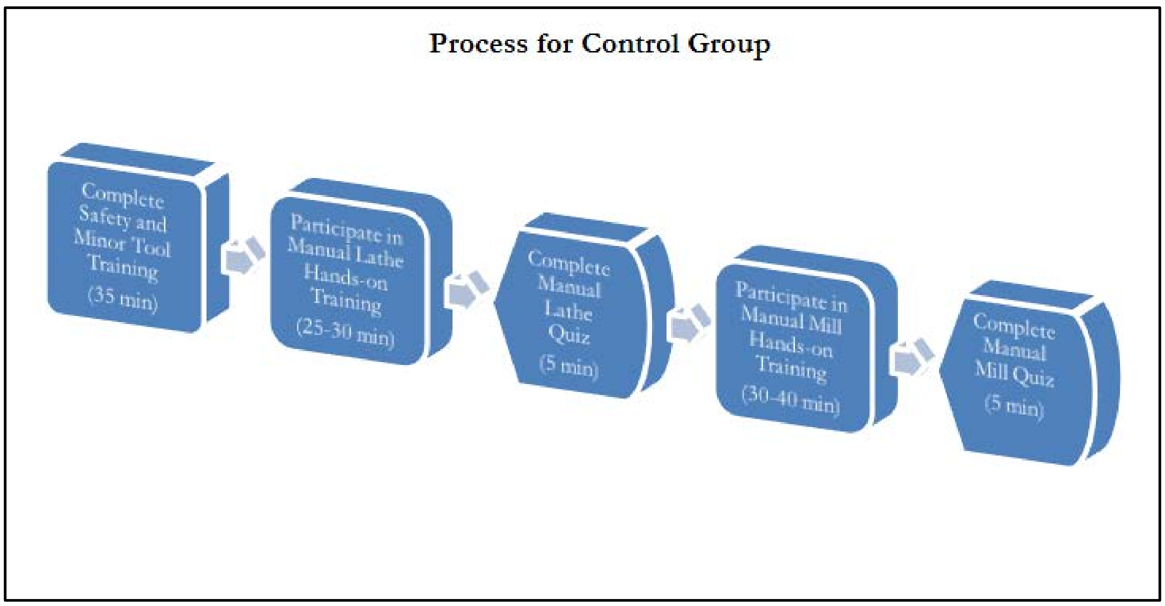

Figure 4: Flowchart of the Training Process for Members of the Control Group (Total Time-1.75-2 hours)

3.2.4 ANALYSIS

The baseline testing data was analyzed in a variety of ways. First, each quiz was graded on accuracy; the grade attained was the basis of all analysis. The overall averages between the two groups were compared for every machine. Secondly the percentage correct for each individual question was analyzed to allow a more complete comparison of what methods were better for learning different types of information (i.e., safety, technical data). The number of students earning each score for each tutorial and group was also assessed, showing trends in participants' grades. Lastly, the overall trend of the grades versus the date of testing was evaluated to judge if the date had any effect on the students' results.

3.3 RETENTION TESTING

3.3.1 PARTICIPANTS

Since the retention testing sought to retest students on the information learned in the machining class, the participants were taken specifically from Mechanical Engineering Product Design Methodology (ME 340). Although other students participated in the baseline testing, the predominant majority were enrolled in this class (ME 340), which is why the retention testing was able to gather 156 participants. The retention testing was only undertaken once all ME 340 students had completed the machining training; so, all students in this portion of the study had already taken the same two quizzes as part of the initial study. Students in ME 340 who had completed the training in a previous semester were excluded from this testing so that new participants would not be introduced to the study. Furthermore, the testing was conducted before the participants had revisited the Learning Factory and gained more experience with the machinery.

3.3.2 STIMULI

There were no new stimuli introduced for this part of the testing. Students simply relied on the information already transferred either through the hands-on training or the video tutorial and hands-on training (i.e., the baseline experimental group completed both forms of training) to complete the quizzes.

3.3.3 PROCEDURE

For this part of the study, the lead investigator conducted the testing in each section of ME 340. Consent was already obtained during the study at the Learning Factory; so, no new forms were distributed. Quizzes were distributed to every student who had participated in the machining training that semester, and they were given approximately ten minutes to complete both quizzes (five minutes each). These were comprised of the same questions as the baseline testing; so, the exact same knowledge originally learned was assessed. In addition to the knowledge, students were asked to identify whether they had viewed the video tutorials as part of their machine training and on approximately what date they had completed this training. After completing the quizzes, they were collected, and the students resumed class.

3.3.4 ANALYSIS

The analysis done for retention testing was very similar to the baseline testing since the goal of the second testing was to examine if any trends in retention occurred. Once again, overall percentages for each machine and each baseline group were analyzed. Individual questions were also evaluated, as well as the distribution of scores. All of these were measured against the number of weeks that had passed since the student had completed the machining training. No pairing of this data with the baseline data was done; so, only overall averages were assessed, not retention based on individuals.

CHAPTER 4:

RESULTS AND DISCUSSION

In this chapter the complete results of all testing is discussed, with several different analysis methods being detailed. Explanations for trends in the data are also postulated.

4.1 BASELINE TESTING

4.1.1 MANUAL MILL

When analyzing the baseline testing results, the first approach was to simply compare the overall quiz results between the experimental testing group, which watched the video tutorials, and the control group, which did not (see Figure 5).

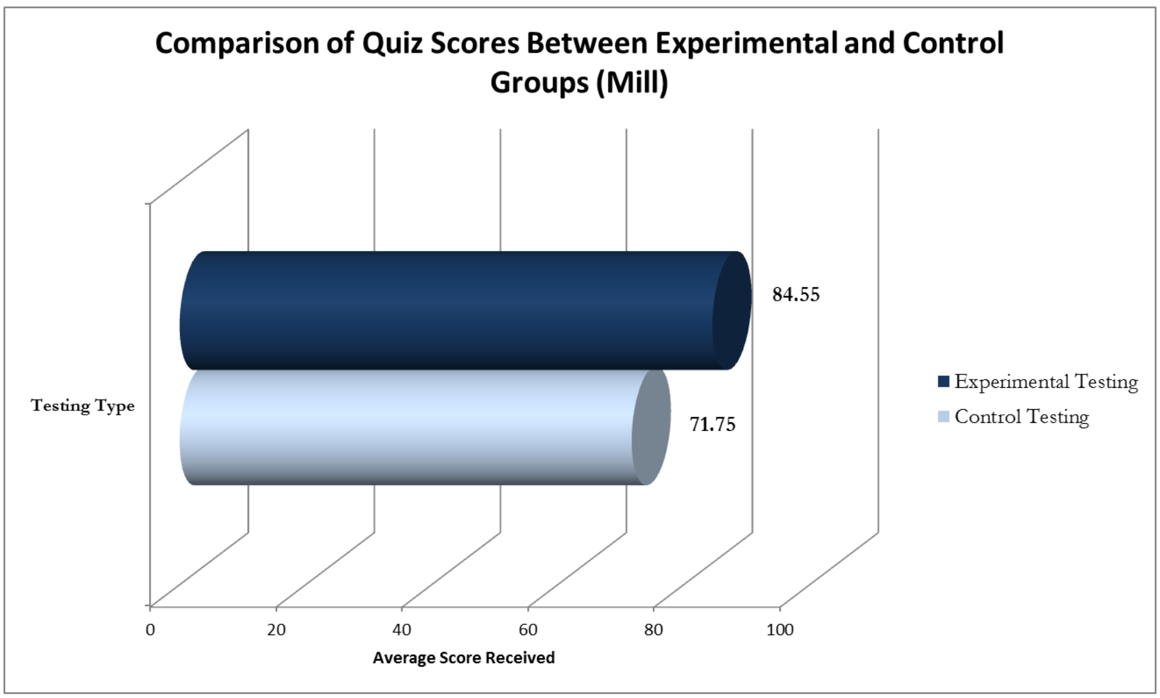

Figure 5: Comparison of the Baseline Testing Results for the Manual Mill

As seen in Figure 5, the experimental testing group who viewed the mill tutorial averaged 84.55% while the control group only averaged 71.75%. This nearly thirteen point difference appeared significant, but statistical testing was performed to verify that it was. A standard two sample t-test was performed with the overall data set (given in Appendix B). This showed that the standard deviation for each set was similar with the experimental group's being slightly smaller at 14.3 compared to the control group's 15.7. Furthermore, the t-test concluded that the overall results were statistically singificant; a p-vlaue of 0.000 was determined. This shows that the tested factor, in this case viewing the video tutorial, did in fact positively affect the result of the quizzes. A boxplot summary of the results is shown in Figure 6.

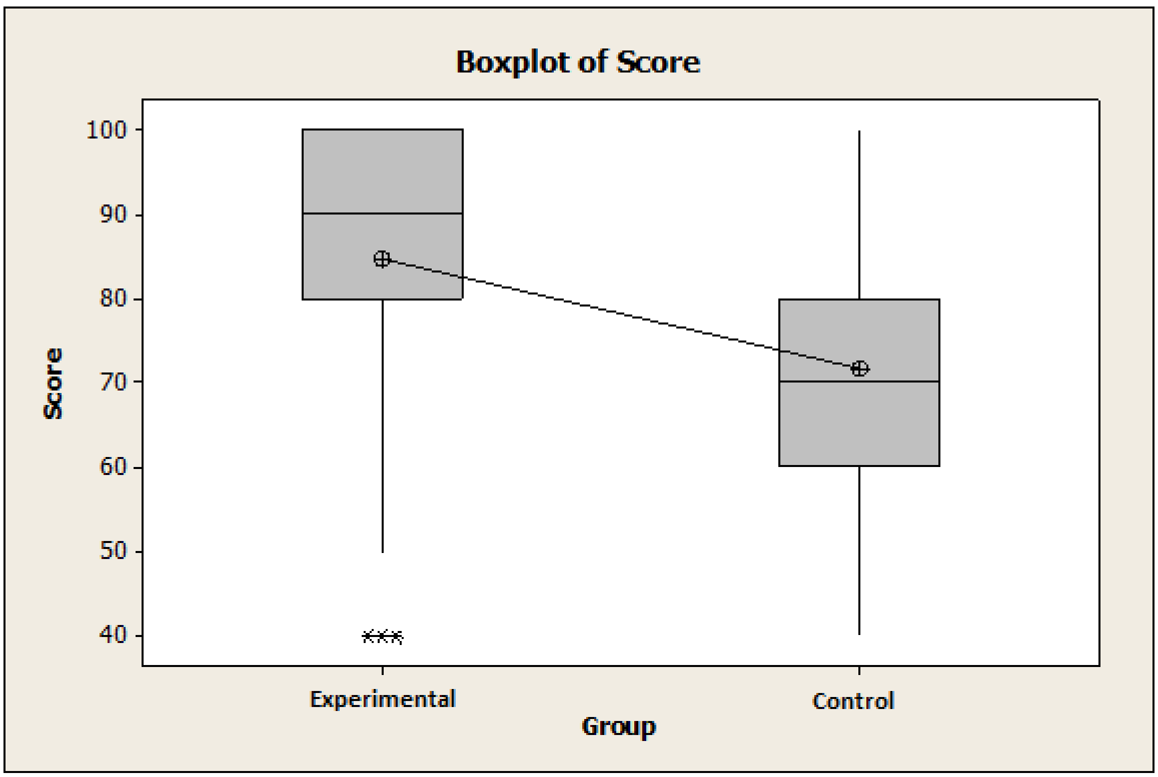

Figure 6: Boxplot Analysis of Manual Mill Testing Results

Figure 6 illustrates several key differences in the overall data set between the two groups. First, the crosshairs show the two groups' averages, but one is below the median line (the line through the middle of the box) while the other is above it. This illustrates a key factor in the results being significant; the experimental group had many more high scores, with a few outliers (shown as asterisks in the figure) pulling down the average, but not affecting the median as much. Meanwhile the control group actually had several high scores pulling up the average while the majority of the data pulled the median downward. Also, it is worthwhile to note that the control group's data contains no outliers, showing that students from that group received a large range of scores; whereas, the experimental group's data is more concentrated. In order to substantiate this data, the overall distribution of scores was established (see Table 1 and Figure 7).

Table 1: The Distribution of Scores for Testing Groups on the Manual Mill

Testing Grade (%)	Mill Tutorial-Experimental	Mill Tutorial-Control
Overall Number of Results	123	126
100	33 (26.8%)	9(7.1%)
90	36 (29.3%)	17(13.5%)
80	29(23.6%)	29(23.0%)
70	14(11.4%)	28(22.2%)
60	5(4.1%)	25(19.8%)
50	3(2.4%)	11(8.7%)
40	2 (1.6%)	7 (5.6%)
30	1(0.8%)	0

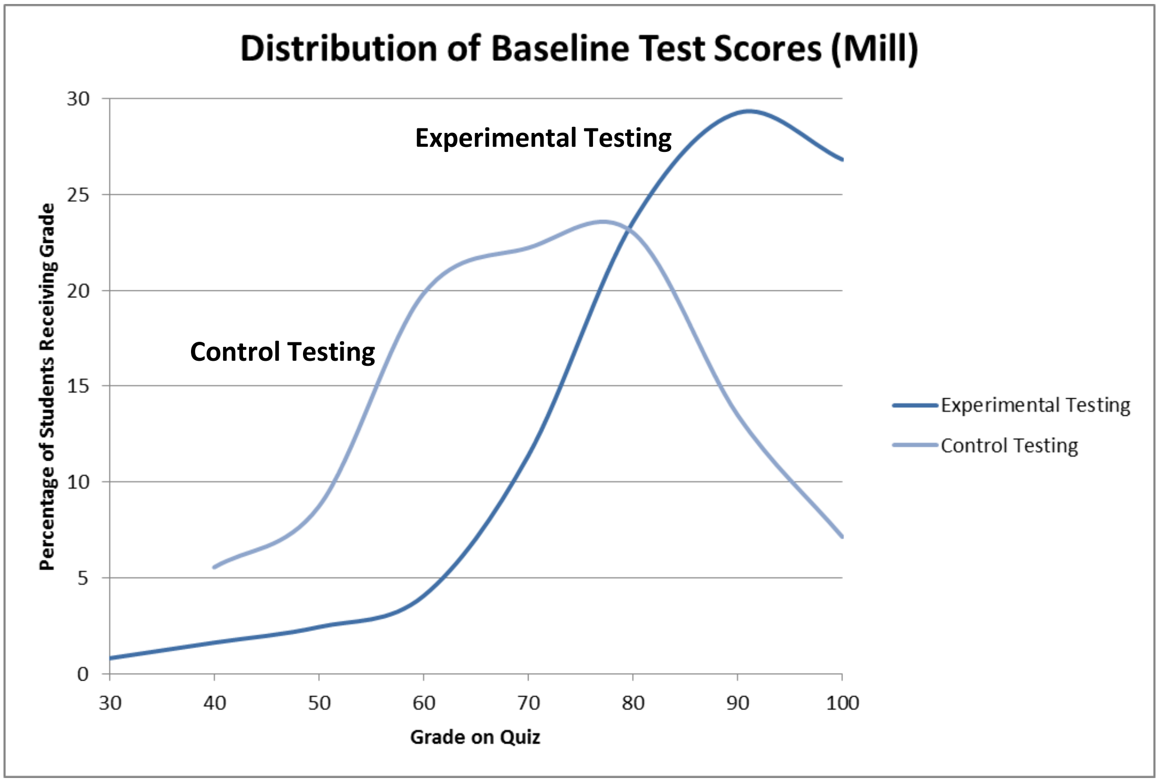

Figure 7: Graph Illustrating the Differences in the Distribution Patterns of the Grades between the Two Testing Groups for the Manual Mill

Clearly, the control data in Figure 7 follows a standard bell curve centered around the average of 71.75, while the experimental data peaks much higher, with 56 percent of the scores being 90 or above, but is held back by a few much lower results (5 percent of experimental students scored 50 percent of below). These results showcase that tutorials were much more effective at teaching the material since more than half of the students in that group missed one question or less; whereas, nearly the exact same percentage of the control group students scored a 70 percent or below.

Once the overall difference and distribution of scores were analyzed, a closer examination of the individual questions and the trends between experimental and control group was performed. These results are summarized in Table 2 and Figure 8.

Table 2: Comparison of the Testing Results between Groups on a Question-by-Question Basis (Manual Mill)

Question #	Question Type	Percentage Correct-Experimental	Percentage Correct-Control
1	Audiovisual and Text	91.06	80.16
2	Text Only	84.55	76.98
3	Audiovisual Only	89.43	58.73
4	Text Only	82.93	55.56
5	Audiovisual and Text	87.80	78.57
6	Text Only	79.67	65.08
7	Audiovisual and Text	81.30	70.64
8	Audiovisual Only	81.30	77.78
9	Audiovisual and Text	74.80	69.05
10	Audiovisual Only	92.68	84.92

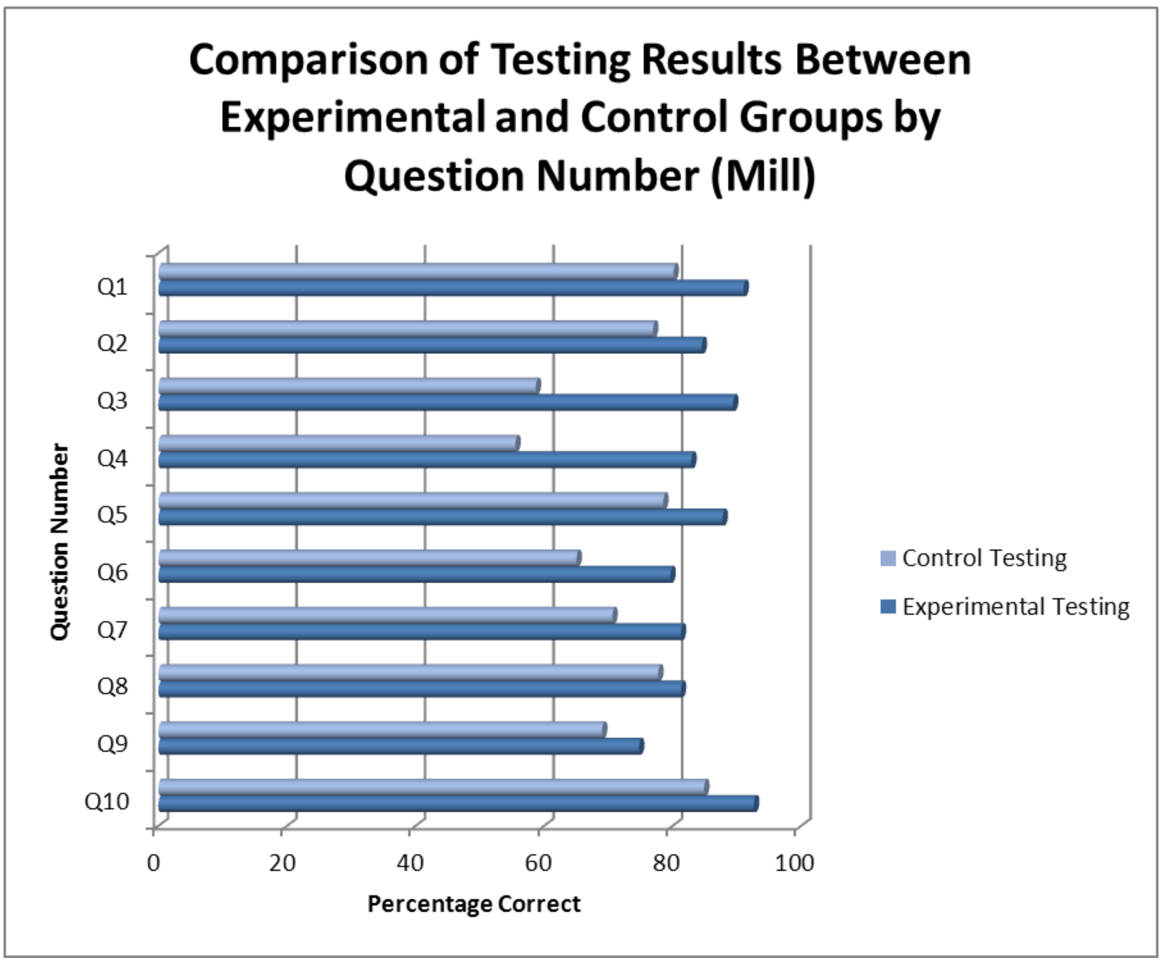

Figure 8: Comparison of Testing Results Between Experimental and Control Groups by Question Number for the Manual Mill

By analyzing the data found in Table 2 and Figure 8, it is evident the experimental group who viewed the video tutorial scored better on every single question on the quiz. However, these percentages fluctuate depending on the question type and teaching technique. In order to analyze how students learn, the tutorial was split into three different categories of teaching with questions representing each method.

Audiovisual only questions are questions in which information that was necessary to answer the question correctly was conveyed only through the instructor teaching the class in the tutorial, not any scrolling text. Text only questions asked information that was only obtainable through scrolling text in the tutorial and not mentioned by the instructor. Audiovisual reinforced with text questions asked about concepts that were deemed more important and therefore were addressed through both the instructor speaking and demonstrating the concept while text scrolled across the video.

AUDIOVISUAL ONLY

Questions 3, 8, and 10 were designated Audiovisual Only questions for the mill tutorial. On these questions, the overall average was 87.8 percent for the experimental group versus 73.8 percent for the control group. Since the averages for both groups were higher than the overall averages, the difficulty of the questions arises. The design of the tutorial also reflects this, since the questions that were chosen to be audiovisual were not viewed as questions that were difficult enough to necessitate additional reinforcement.

Of the three questions, Question 3 had the highest difference between the averages of the groups: 30.7 percentage points. This also was the highest spread between the two groups for any question overall. While the average for the experimental group is higher than the overall average for the control group, it is the extremely low average of the control group that creates such a large spread. One possibility for such a low average is a difference in terminology. Touching off is the official term used by the Learning Factory for the procedure that provides a reference for all future cuts; however, not all instructors necessarily use this term prominently or at all in their training. Therefore, the consistency of the hands-on training for this particular issue seems to be lacking.

Question 8 represents another terminology question, but the difference in averages in only about four points. This shows the hands-on training is consistent in the use of peck drilling as a term. Since there is no substitute for this term, every instructor must use it to demonstrate proper drilling technique; so, it is shown in the exact format as the tutorial.

Lastly for the audiovisual only group, Question 10 produced the highest average, not only of this group but overall. This is the only true/false question of the quiz; so, only having two choices may have helped lead to a higher average. However, the video tutorial takes about 5 minutes to tap the hole, during which time the mill is never shown in operation. This should be more than enough time for the students to audiovisually recognize that the mill should not be running when the hole is tapped. The average for the control group was also well above the overall average, at nearly 85 percent. This shows the concept is easily transferred across the two instruction modes.

TEXT ONLY

Questions 2, 4, and 6 were represented only via scrolling text in the tutorial. This means that they involved more complex explanations or concepts. The complexity is reflected in the results from these questions—the experimental group averaged 82.4 percent, and the control group averaged 65.9 percent. While both of these averages are below the overall averages, the large difference shows the text explanations are more effective and draw more focus of the participants than the instructor taking the time to explain these concepts.

Of the three questions in this group, Question 4 had the largest spread between the two groups' averages. This 27 percentage point difference reflects that explanations of complex situations, such as uneven cuts and tooling vibrations, can be more explicitly elucidated through text. Furthermore, this question produced the lowest average of any question in the control group, showing once again that long explanations are difficult to convey in a hands-on setting with loud machining equipment and cramped spaces. While the averages are closer for Question 6, that result illustrates the same concept. The correct answer requires a slightly longer explanation which students in a hands-on environment may not focus on; whereas, the text of the tutorial draws the students' attention to the concept rather than gaining the knowledge through passive listening.

AUDIOVISUAL REINFORCED WITH TEXT

Questions 1, 5, 7, and 9 reflected a hybrid of the other two teaching techniques, namely an audiovisual format with scrolling text to reinforce the importance of the concept. Considering these concepts were more important and usually more complicated than audiovisual only questions, the averages by both groups were respectable. The experimental group averaged 83.7 percent on these questions while the control group averaged 74.6 percent. This shows that the experimental group scored slightly below the average; whereas, the control group scored slightly above average. However, the experimental group still scored 9 percent better than the control group on average.

These questions followed a similar trend with the differences being between 9 and 11 percentage points save for Question 9. None of the control group averages were particularly low, which makes the average difference more significant. Furthermore, the high averages on both show that the concepts were thoroughly covered in both modes of instruction and the importance of them was stressed properly. The double reinforcement of the audiovisual and text seems to have worked since these questions yielded a significant difference from the control group and while being more complex concepts than audiovisual only still returned an average that was only four percentage points below that grouping.

While individual questions revealed some important trends in the data and emphasized some differences between the two instruction modes as well as shortcomings, the trend in quiz scores versus date tested also illustrated a key difference between the two teaching styles (see Figure 9). Ideally, the experimental group results would not show an incline or decline in the average score versus the date tested since the tutorial is shown in a volume controlled room with about same number of students in each group, all silently focused on the screen. On the other hand, the noise and activity in the machine shop increases as the semester progresses; so, the control groups cannot hear as well during the later testing dates. This also contributes to a decreased focus from the group since many cannot hear what the instructor is saying.

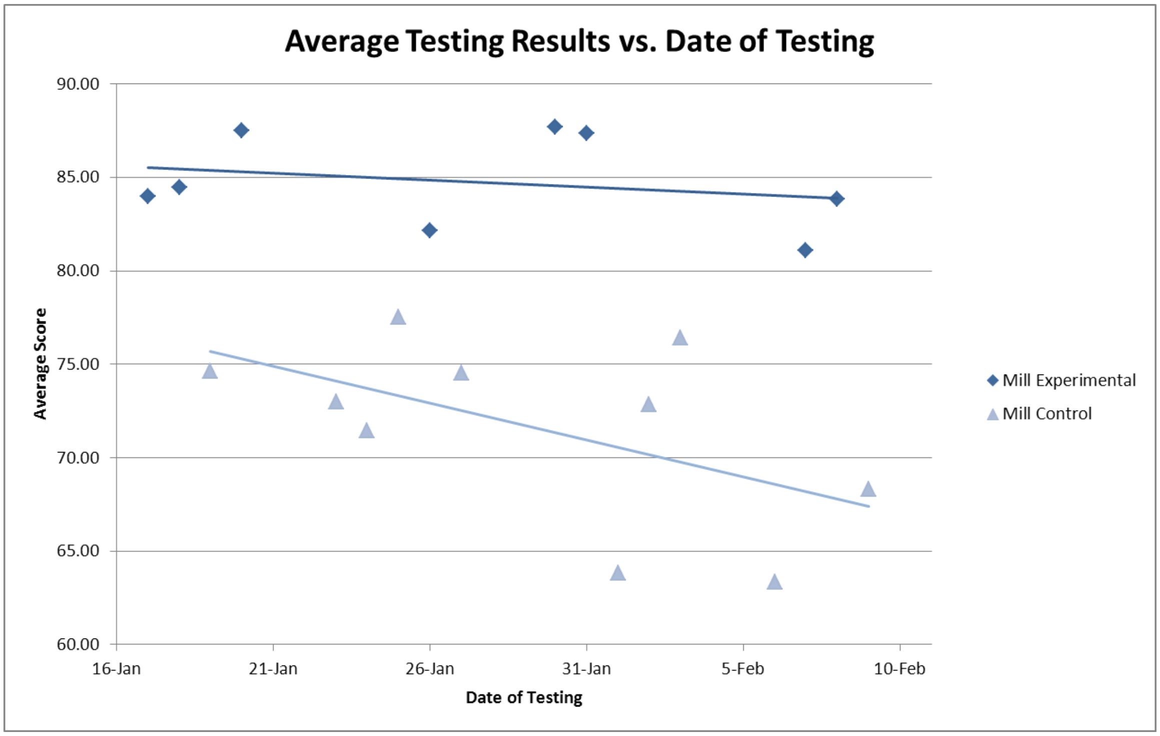

Figure 9: Comparison of the Testing Results for Each Group versus the Testing Date (Manual Mill)

From this figure it is readily apparent that the control group's average result declines much more rapidly than the experimental group's result. A numerical comparison of the two trendlines further demonstrates this, showing that the control group's decline is nearly five and a half times as rapid as the experimental group's. As stated above, this can be attributed to the increasing noise factor in the machine shop leading to a lack in focus from the students.

4.1.2 MANUAL LATHE

For the manual lathe, the average results were much closer than those of the manual mill (see Figure 10). As with the mill, the first step was to assess the overall average scores and determined their statistical significance.

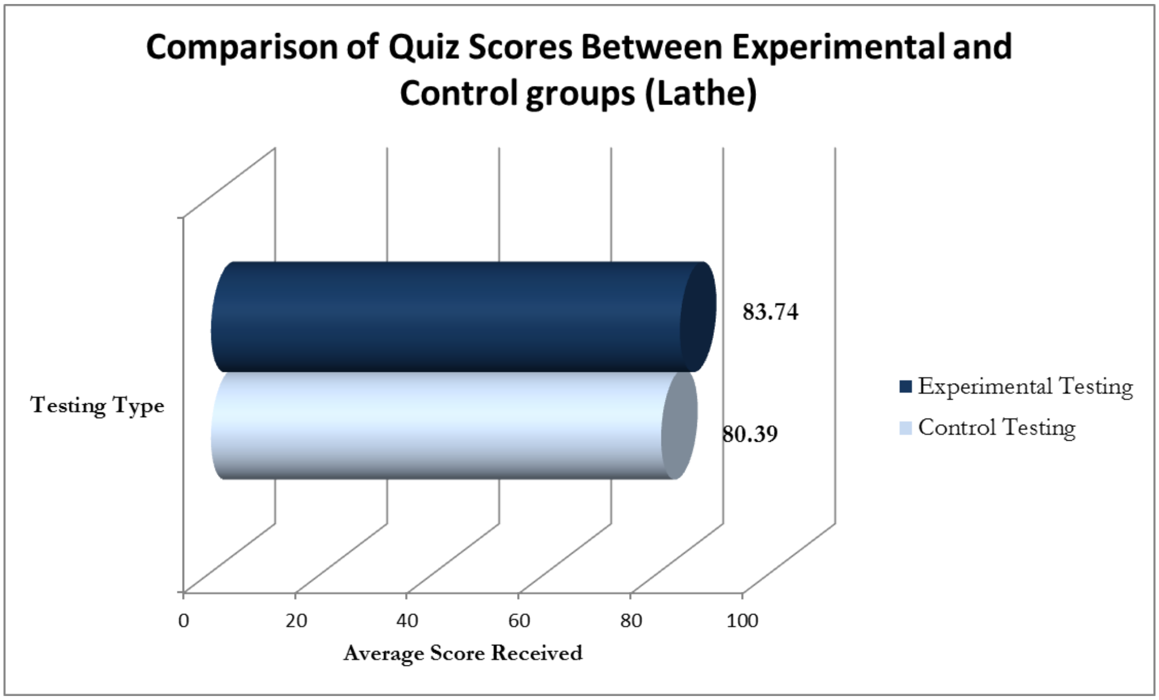

Figure 10: Visual Comparison of the Baseline Testing Results for the Manual Lathe

While the manual mill testing showed a difference nearly 13 percentage points, the lathe's testing results were much closer with only three percentage points separating the experimental group from the control group on average. This was analyzed using the same statistical testing measure as the mill testing, a two sample t-test. The results showed that the standard deviation was actually higher for the experimental group at 15.8 than the control group (13.7). Although this did not conform with the mill's results, the test calculated that p-value was 0.040, showing a significant difference between the two types of instruction. A boxplot of this result is given in Figure 11.

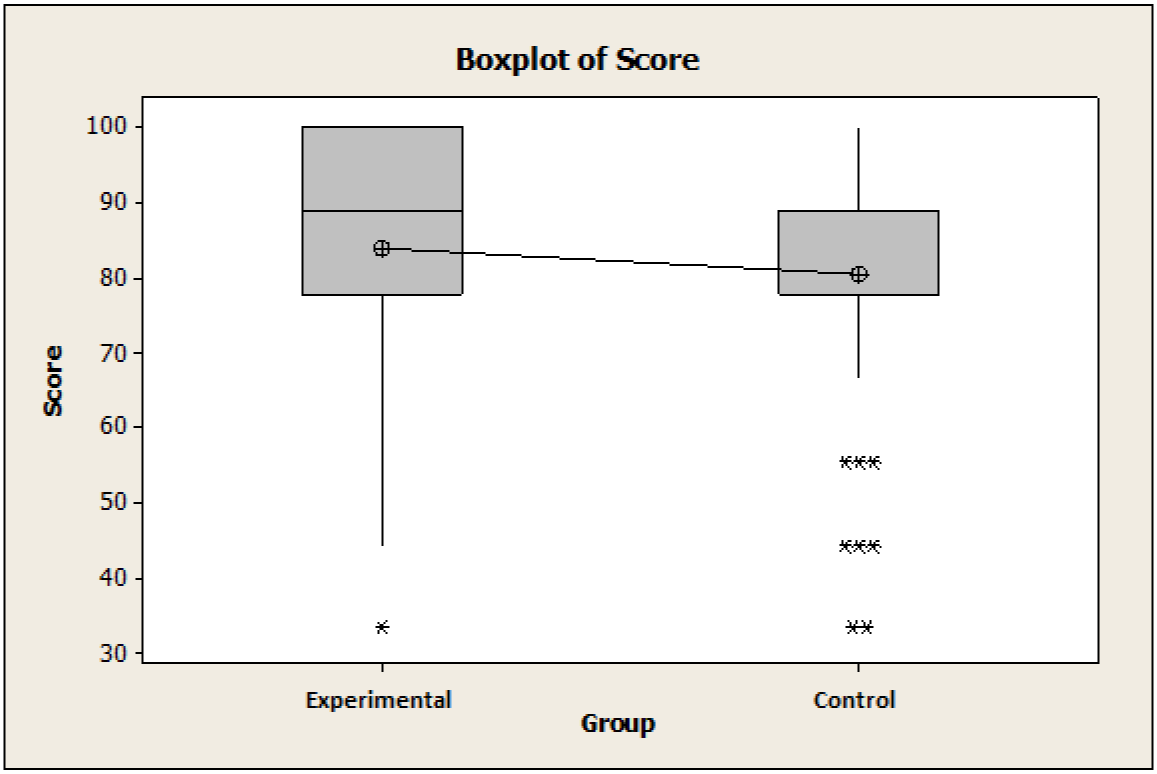

Figure 11: Boxplot Analysis of Manual Lathe Testing Results

Once again after evaluating the significance of the overall averages, the overall to distribution of scores was calculated to better illustrate the trends in the grades and see the effect of outliers. The distributions are plotted in Figure 12.

Table 3: Distribution of Scores for Testing Groups on the Manual Lathe

Testing Grade (%)	Lathe Tutorial-Experimental	Lathe Tutorial-Control
Overall Number of Results	123	119
100	34 (27.6%)	13(10.9%)
88.89	41 (33.3%)	44(36.9%)
77.78	26(21.1%)	35(29.4%)
66.67	10(8.1%)	19(15.9%)
55.56	4(3.3%)	3(2.5%)
44.44	7(5.7%)	3(2.5%)
33.33	1(0.8%)	2(1.7%)

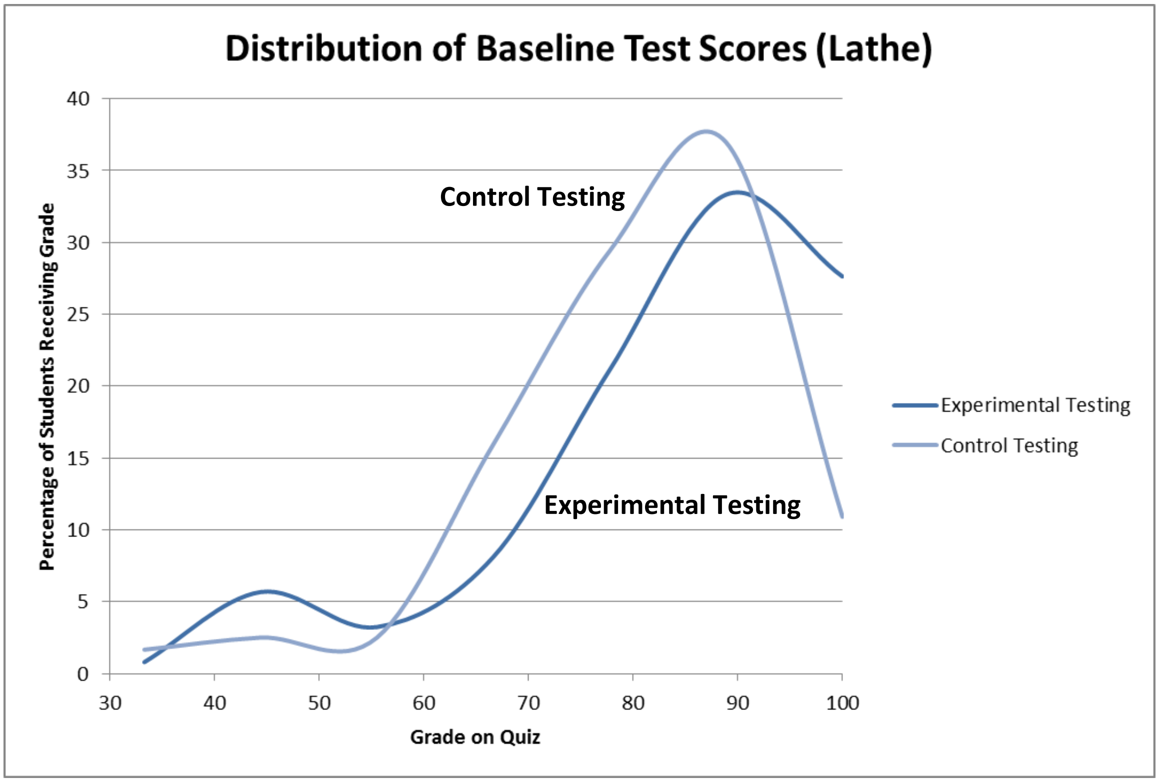

Figure 12: Graph Illustrating the Differences in the Distribution Patterns of the Grades between the Two Testing Groups for the Manual Lathe

With this data, one can see both distributions follow a similar pattern with two main differences. First, the number of perfect scores is drastically different: 27.6 percent of experimental test scores were 100's, while only 10.9 percent of control tests attained that score. This calls into question how the averages can be so similar while the percentage of students achieving the highest score is so different for the two groups. While there is a large discrepancy at that point, the percentages of students attaining 88.88 percent and 77.77 percent are very similar. While this helps average the data, one of the main components driving the averages closer together was the high percentage of lower scores for the experimental group. Ten percent of students viewing the tutorial scored 55.55 percent or lower; on the other hand, not even seven percent scored that low from students who were in the control group. This may be due to the physical course illustrating some of the explanations better than the tutorial, and thus participants who did not pay strict attention to the tutorial missed the explanation while the students in hands-on course were able to see a better physical illustration of the principle. When the results were analyzed on a question by question basis (see Table 4 and Figure 13), this trend was apparent.

Table 4: Comparison of the Testing Results between Groups on a Question-by-Question Basis (Manual Lathe)

Question #	Question Type	Percentage Correct- Experimental	Percentage Correct- Control
1	Audiovisual and Text	96.75	85.71
2	Text Only	70.73	54.62
3	Audiovisual Only	82.92	89.91
4	Audiovisual and Text	90.24	87.39
5	Audiovisual Only	87.80	87.39
6	Text Only	69.91	81.51
7	Audiovisual and Text	93.50	93.28
8	Text Only	65.85	55.46
9	Audiovisual Only	95.93	88.24

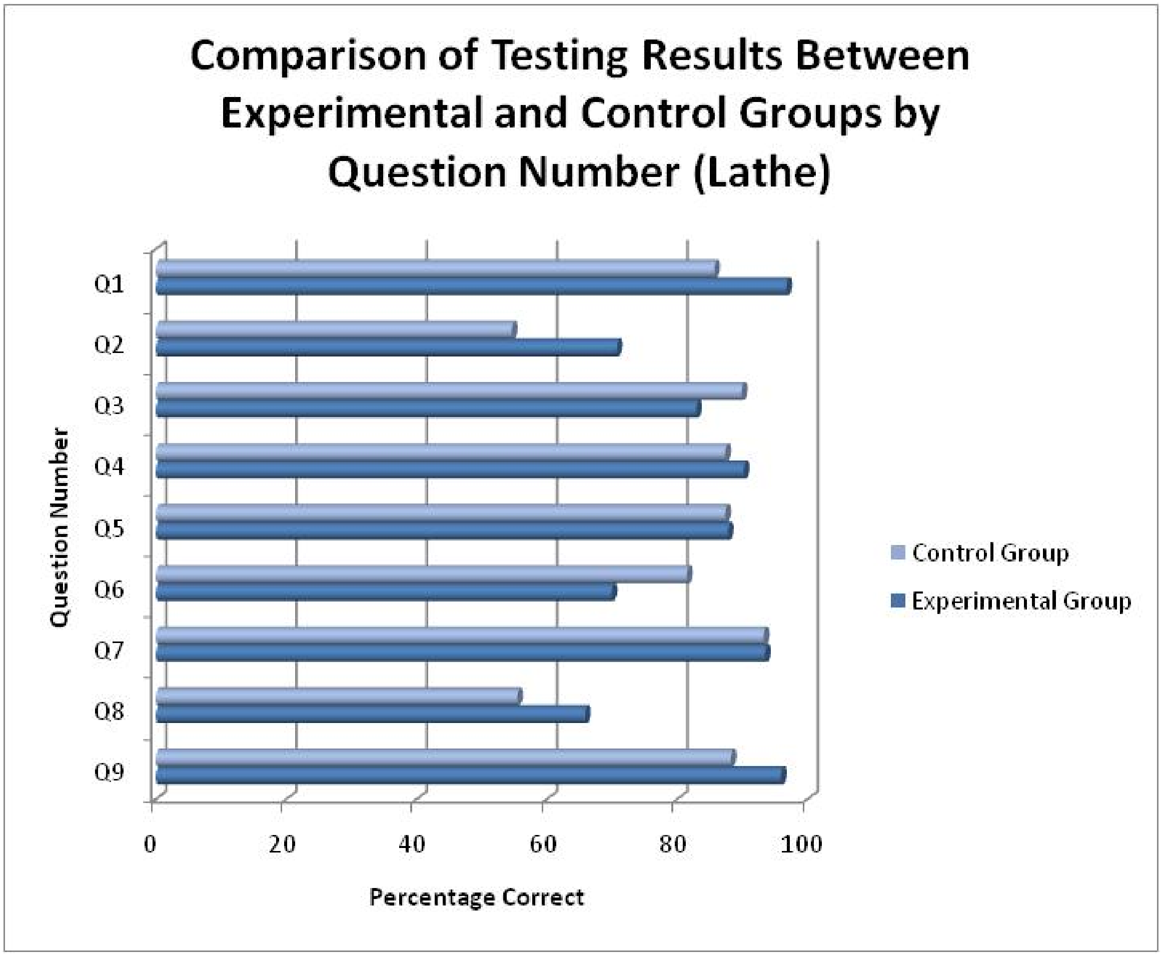

Figure 13: Comparison of Testing Results Between Experimental and Control Groups by Question Number for the Manual Lathe

As seen in Table 4 and Figure 13, the spreads between the individual questions reflect the closeness of the averages as well. While the mill testing had differences as high as thirty percent between the experimental and control groups on some questions, the highest spread between averages on any one question for the lathe was only sixteen percent (Question 2). In this case the average on some of the questions was higher for the control group, which did not happen on any question for the manual mill. In order to analyze what types of communication were most effective, the questions were divided into sub-categories.

Once again, the sub-categories were audiovisual only, text only, and audiovisual reinforced with text as indicated in Table 4. Audiovisual only questions were used to highlight basic concepts, usually physical operation techniques only. Text only information conveyed complex concepts, meaning the explanation of why something was happening rather than just doing it. Lastly, audiovisual reinforced with text were concepts that were deemed extremely important, usually related to safety or the very basics of operation, so they were shown in both formats within the tutorials.

AUDIOVISUAL ONLY

From the lathe tutorial, Questions 3, 5, and 9 are considered to be audiovisual only, meaning the instructor shows or mentions the principle during the tutorial, but no scrolling text is used to expound on it. For these questions, the average spread was only 5.3 percentage points, which is severely lessened by the miniscule spread between the groups in Question 5.

Question 3 has the second highest spread of the three, with a large advantage being displayed by the control group. If one looks specifically at this question (see Appendix A), it is clear that the question addresses a completely physical phenomenon that may be better observed in a hands-on environment. When grading each quiz, the most common incorrect answer was that "if more material is extruding from the jaws than is clamped down, the part is liable to fall out." Since the students viewing the tutorial could not necessarily see the physical strength of the lathe's jaws, it may have been an attractive choice for someone who was unsure. However, the control group saw the lathe and the stock material placed in it firsthand; so, this choice may have seemed less likely for them due to the firsthand experience of seeing vibrations in the material more easily when the machine was in operation.

For Question 5, the spread was negligible, amounting to only 0.41 percentage points, and both the averages on this question were higher than the quiz averages, indicating that this question was easy for the majority of students. In the video tutorial, the cut off operation is clearly demonstrated and shown in low gear, with the instructor very blatantly turning the large gear selector while explaining why the operation must be done in low gear. Additionally, changing the gear selector emitted a noise which may have helped students remember that this operation was different from the others. In the hands-on training, the exact same explanation and clear changing of the gear selector was shown; so, the nearly equal averages make sense.

Lastly, Question 9 showed a higher spread of 7.68 percentage points in favor of the experimental group. In the video tutorial, the cut off tool and blade are explained very well, and the instructor clearly states it is the thickness of the blade that must be taken into account. In the hands-on training students may not have been able to see the geometry of the blade as well if they were in the back or may have confused the dimensions due to imprecise communication.

TEXT ONLY

Questions2, 6, and 8 were determined to only be addressed via scrolling text during the video tutorials, which makes them more likely to be complex explanations rather than quick recollection questions. Large differences were seen in all three, with the average difference being 12.7 percentage points. This swing went both ways though, with two questions being dominated by the experimental group and on in favor for the control group.

It should also be noted that these three questions comprised the three lowest correctly scored questions of the nine on the quiz for both groups.

First, Question 2 is the first principle in the tutorial that is addressed only by text. While the maximum length of material that should be extruded from the lathe is a simple physical principle, the students may not be able to estimate that the size of the material sticking out from the lathe throughout the entire tutorial is only 2-3 inches. Therefore, this question relies almost solely on text recollection rather than a thorough understanding of the geometry. For hands-on training participants, the exact number may not explicitly be mentioned depending on the instructor. This inconsistency in the hands-on training could directly contribute to the lower average by the control group, but the concept is important; therefore, it is really the hands-on training that fails in its technical communication methods here.

Question 6 is a complex explanation problem that is only mentioned by text in the tutorial but is fully explained by all instructors during the hands-on training. This brief text explanation may have been lost on some students as the angle of the cutting shown during the tutorial did not allow the student to see that the cutting tool was not traversed all the way to the center of the part. The firsthand explanation and subsequent hands-on cutting that the participants actually did in the control group would have reinforced this concept much more thoroughly. Therefore, the large advantage held by the control group on this question is not surprising.

Lastly, Question 8 is another more complex principle. Both the gear selector and spindle speed adjustment are shown during the tutorial but not explicitly explained, especially the spindle speed. Aside from being only text based, two other factors may have complicated the experimental group responses. First, the gear selector is specifically shown being adjusted while the lathe is off; however, the spindle speed is adjusted more slyly. This may have confused students and contributed to a preponderance of answers suggesting that both are adjusted while the machine is off. Secondly, both of these operations do adjust the speed of the spindle, the gear selector just creates a large adjustment, while the spindle speed is more like fine tuning. Thus, students may also have been confused about which was done while the lathe was off and which was done while the lathe was operating. This confusion would have affected both the experimental and control groups equally, which is reflected in both groups scoring more than fifteen points below their averages on this question.

AUDIOVISUAL REINFORCED WITH TEXT

Questions 1, 4, and 7, all questions utilizing audiovisual techniques while being reinforced by text, constituted three of the four most correctly answered questions for the experimental group. The experimental group also scored higher on all three of these questions, making the audiovisual reinforced group the only group in which all three were in the tutorial's favor. The average split was only 4.7 percentage points though, the lowest of the three question groupings; however, this is largely affected by Question 7 which only had a 0.22 percentage point difference between groups.

Question 1 is a fairly simple and well-reinforced concept throughout the video tutorial. It then comes as no surprise that students averaged the highest score on this question. The principle is not only shown for several minutes as the material is first being faced, but reinforced via scrolling text. Additionally, the recap near the end of the tutorial once again reminds students that facing was the first operation. For the control group, the average was still fairly high, and above the overall average. However, the control group averaged eleven percentage points lower than the experimental group. The large difference is somewhat perplexing since this concept is equally reinforced in both groups. While the experimental group is subject to audiovisual and text reinforcement, the control group has visual and hands-on reinforcement. The difference may be explained by students in the back of the group not being able to clearly see the facing being demonstrated then not being sure what they were doing when they themselves were actually cutting the material. Other than this factor, the averages should have been similar due to this concept being explained in multiple ways in both groups.

Next, Question 4 showed a 2.85 percentage point spread between the groups, with both being higher than the average. Once again, multiple reinforcements helped the experimental group, while the reinforcement of using the machine to perform shearing and facing operations reinforced the principle for the control group. The overall difference is not big enough to be significant. Question 7 can also be included under this category since its spread was only 0.22 points. Both of the averages were extremely high, and this principle was repeated twice in the tutorial and shown explicitly during the hands-on training. Such averages indicate that both methods are adequate for this spatial principle.

While this question type analysis illustrated some key differences in how study participants were able to gain knowledge, the trend in the quiz scores versus the date tested also showed a key difference between the two teaching methods. As with the mill, the lathe also generates a lot of noise, and more noise in the machine shop also contributes to control group students not being able to hear or see what is going on during the hands-on training (see Figure 14).

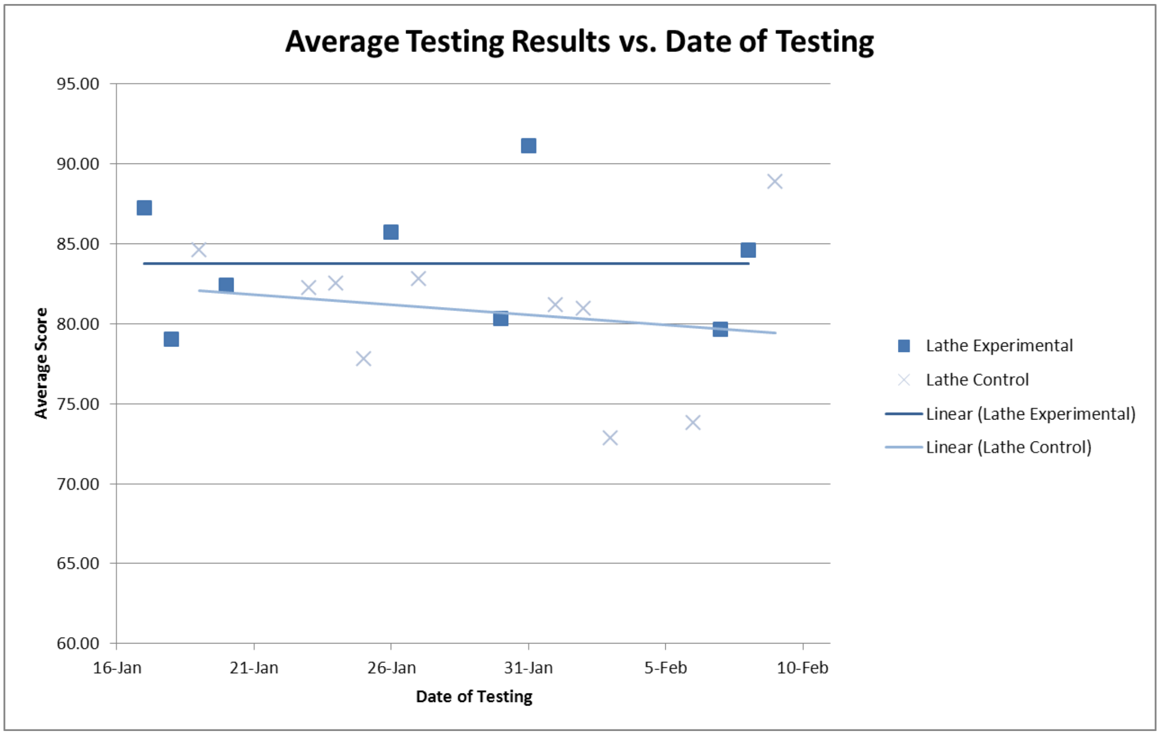

Figure 14: Comparison of the Testing Results for Each Group versus the Testing Date (Manual Lathe)

While individual questions revealed some important trends in the data and emphasized some differences between the two teaching techniques as well as shortcomings, the trend in quiz scores versus date tested also illustrated a key difference between the two teaching styles. Ideally, the experimental group results would not show an incline or decline in the average score versus the date tested since the tutorial is shown in a volume-controlled room with the about same number of students in each group, all silently focused on the screen. On the other hand, the noise and activity in the machine shop increases as the semester progresses, which negatively affects the control group and their ability to hear the instructor. Since it is difficult to learn in this environment, a decreased focus manifests in the group.

Overall, the baseline testing showed the tutorials were much more effective in allowing students to learn the necessary concepts during basic machining training. Each tutorial produced a statistically significant difference over the control testing for the same concepts. Additionally, the three unique instruction methods—audiovisual only, text only, and audiovisual reinforced with text—were largely successful in the tutorials, with audiovisual only explaining simple concepts, text only being used to illustrate more complex concepts, and audiovisual reinforced with text demonstrating very important, critical concepts. The average versus date of testing also revealed a downward trend in the averages in the control group the farther into the semester the testing occurred, while the experimental group remained steady in the knowledge gained. This is most likely due to increased noise and usage of the machine shop later in the semester while the tutorial room stays constant; so, students' focus should not diminish in that setting.

4.2 RETENTION TESTING

In order to assess the retention of this training, the rate at which students' knowledge decayed was measured on an overall basis and a question-by-question basis for each group. The overall data was measured for statistical significance while the questions were examined individually for any prominent trends. For each machine, the rate of knowledge decay was evaluated in the same way. The averages for each group and week were calculated, and then a linear regression was conducted to establish a linear trendline. (The slope of the line then reflected how many percentage points lower students scored per week as time passed.

4.2.1 MANUAL MILL

From the data in Table 5 and Figure 15, one can see that the control group's score did decline more rapidly, about 150 percent as fast as the experimental group's score. This was determined by a simple comparison of the slopes reported in Table 5. In order to determine if this difference was significant, an ANOVA generalized linear model test was constructed to calculate the p-value of the trend and determine whether the rate of decay depended on both time and original group. For this test, the p-value was calculated as 0.379, showing that there was not a statistical significance that the rate of decline depended on the group. While the overall difference in rate of decline may not have been significant, the difference in the individual questions was analyzed to determine whether any specific questions were significant.

Table 5: Rate of Decay of Students' Knowledge (Manual Mill)

Testing Method	Rate of Knowledge Decay (% per week)
Mill Tutorial- Experimental	-1.279
Mill Tutorial- Control	-1.852

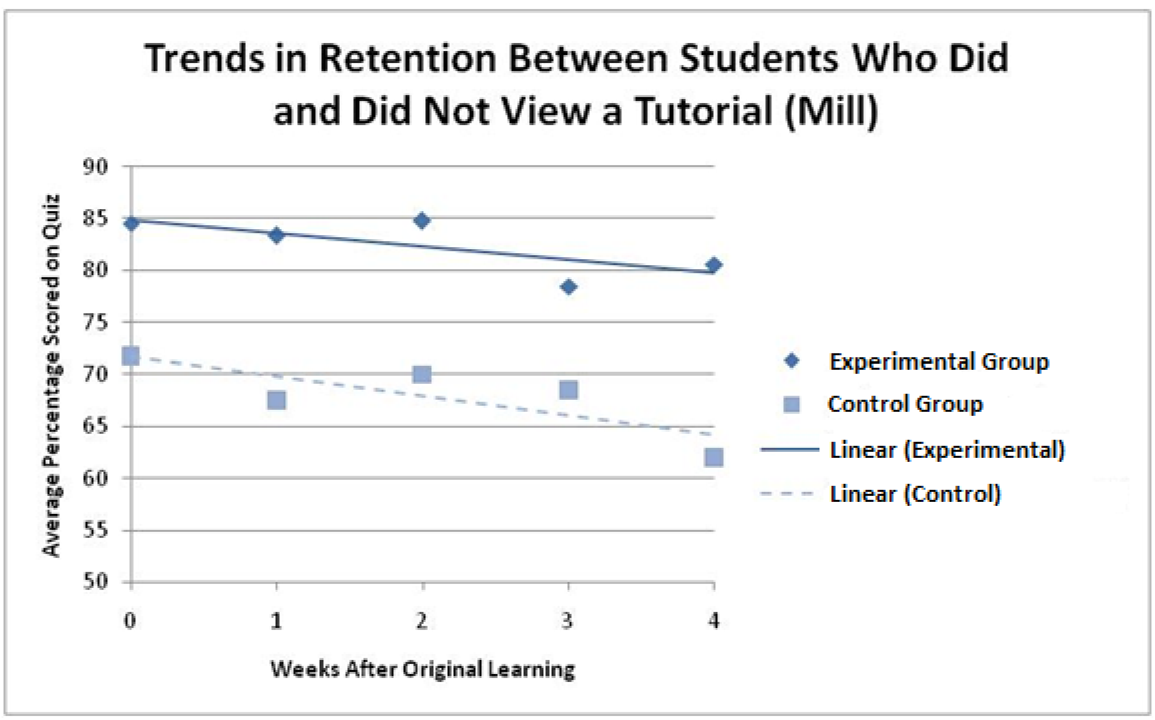

Figure 15: Graph of Linear Trend of Knowledge Decay for Both Testing Groups (Manual Mill)

Individual questions were also analyzed for retention rates (see Table 6 and Figures 16 and 17). This was done in the same way as the overall retention data, namely, the means for each question were calculated on a weekly basis and linear trendlines were established to quantify the rate of decay in percentage points lower on average per week.

Table 6: Rate of Decay in Individual Questions (Manual Mill)

Question #	Question Type	Rate of Decay-Experimental Group (% per week)	Rate of Decay-Control Group (% per week)
Q1	Audiovisual and Text	-1.2	-1.622
Q2	Text Only	-1.783	-4.305
Q3	Audiovisual Only	-0.86	4.026
Q4	Text Only	-7.83	-0.96
Q5	Audiovisual and Text	-3.1	5.24
Q6	Text Only	2.54	-3.728
Q7	Audiovisual and Text	-0.3	-4.961
Q8	Audiovisual Only	0.043	-5.071
Q9	Audiovisual and Text	-1.483	-6.491
Q10	Audiovisual Only	1.186	-0.635

***negative values reflect decay**

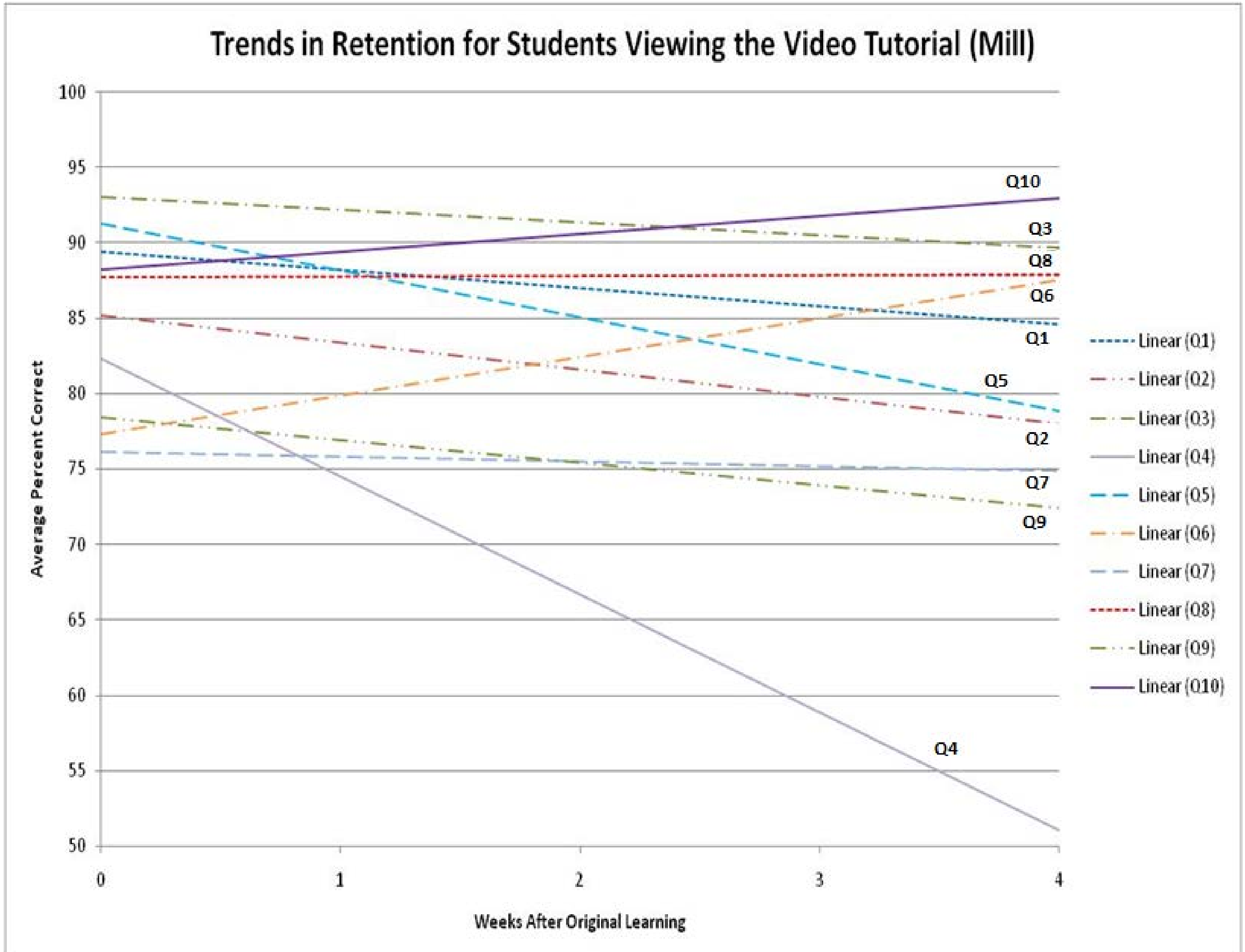

Figure 16: Trends in Retention Individual Questions among the Experimental Testing Group (Manual Mill)

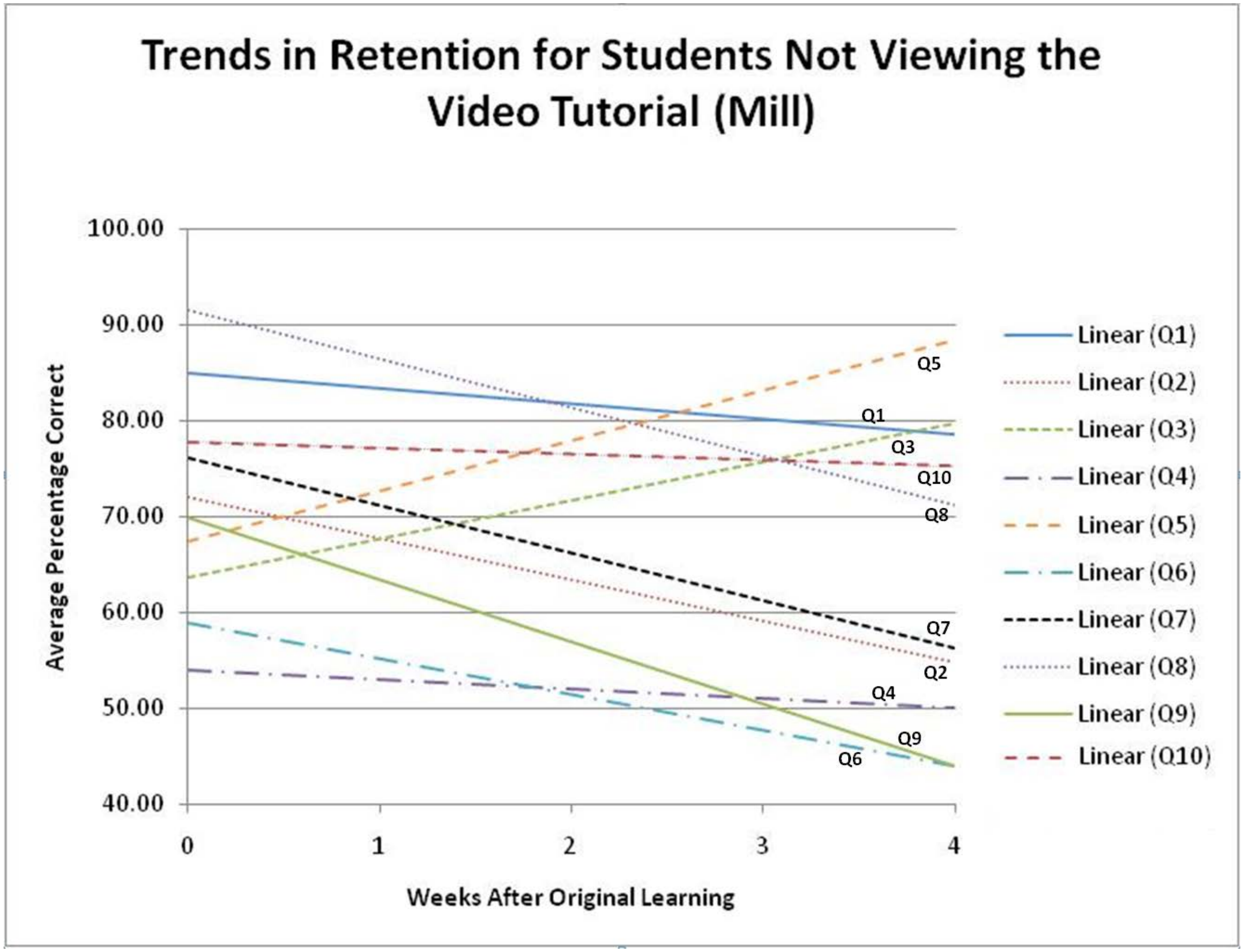

Figure 17: Trends in Retention Individual Questions among the Control Testing Group (Manual Mill)

For the most part, the trends of the individual questions make sense. The experimental data declined more slowly than the control data except in a few cases (see Figures 16 and 17). One interesting trend that occurred for both groups on several questions is that the average on a given question actually rose rather than declined. For the experimental group this could happen since the original testing occurred after just viewing the tutorials. The group then participated in the hands-on training; so, additional information that was missed from the tutorial may have been gained during the hands-on training. The control group's average rising is harder to explain. The most probable possibility is just that not every baseline participant took part in the retention testing; so, certain data points may be missing from any given week. For example, only ten people compromise the control data at Week 4. One other factor that could additionally complicate the data is that some students may have gained additional experience in the Learning Factory between the baseline and retention tests through using a mill to machine an L-bracket as part of a class assignment. Gaining more first-hand experience with more freedom to discover the machinery's capabilities would likely cause the student's overall knowledge to rise.

Overall, seven of the ten questions still showed averages that declined faster for the control group than the experimental group. The only questions that did not follow this trend were Questions 3, 4, and 5, of which two—Questions 3 and 5—illustrated the phenomenon in which the control averages actually improved. So, the main outlier in the data was Question 4, which showed the fastest decline of any question for the experimental group. Question 4 asked what the most probable cause of uneven cuts and vibration was, which is a more complex topic, and it already had one of the lower averages on the baseline testing; so, it is not a surprise that this showed a rapid decline. The question is more difficult than most and is conveyed through text only in the tutorial. Therefore, students from the control group may have actually observed this physical phenomenon during training and therefore been able to retain the data better than students who viewed the tutorial but did not focus on the hands-on training.

4.2.2 MANUAL LATHE

The results in Table 7 and Figure 18 show that the control group's rate of knowledge decay is nearly three times faster than the experimental group's. This data was analyzed statistically to determine the correlation between the testing method and the data. The resulting p-value was 0.066, which is close to the threshold of statistical significance. If more participants were able to be tested for the retention data, a statistically significant difference may have been achieved. While these results did not yield a definitive correlation between the use of the tutorials and a diminished decay rate, the individual questions were analyzed to assess any important trends (see Table 8 and Figures 19 and 20).

Table 7: Rate of Decay of Students' Knowledge (Manual Lathe)

Testing Method	Rate of Knowledge Decay (% per week)
Lathe Tutorial-Experimental	-0.558
Lathe Tutorial-Control	-1.637

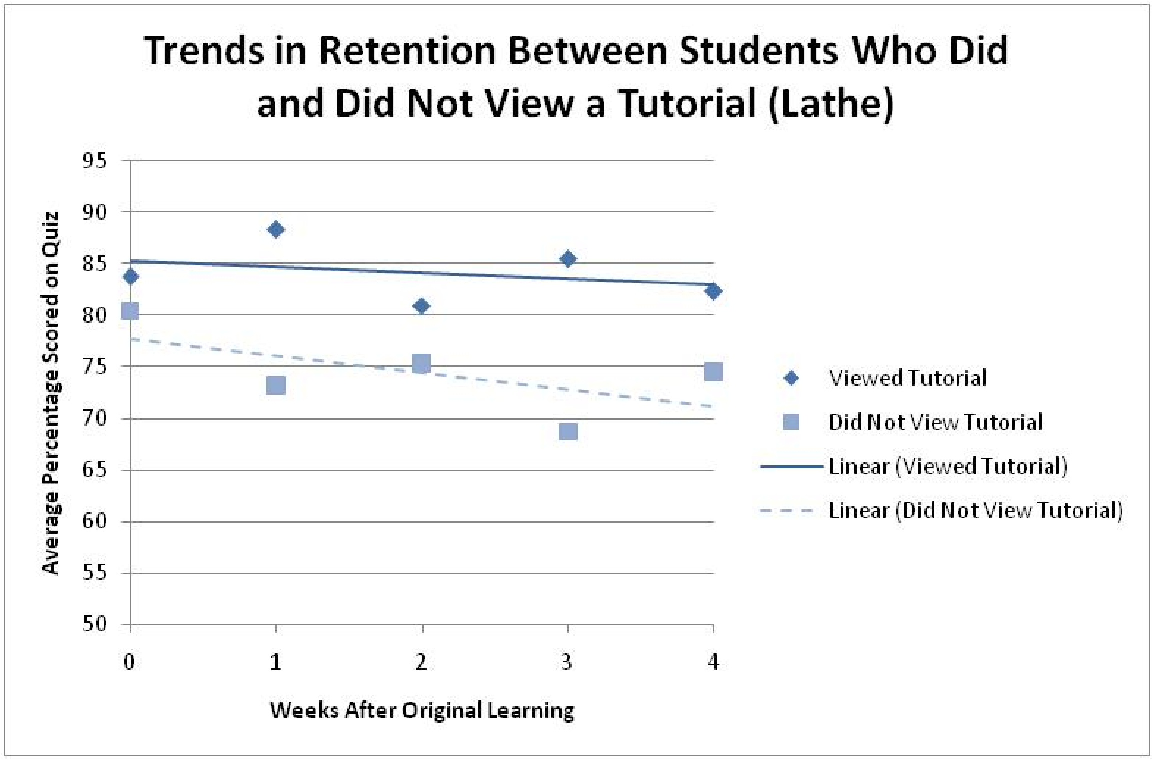

Figure 18: Graph of Linear Trend of Knowledge Decay for Both Testing Groups (Manual Lathe)

Table 8: Rate of Decay in Individual Questions (Manual Lathe)

Question #	Question Type	Rate of Decay-Experimental Group (% per week)	Rate of Decay-Control Group (% per week)
Q1	Audiovisual and Text	-0.184	-0.202
Q2	Text Only	-2.191	-0.893
Q3	Audiovisual Only	-0.179	-0.057
Q4	Audiovisual and Text	-4.29	-1.478
Q5	Audiovisual Only	-3.805	1.082
Q6	Text Only	1.7	-7.105
Q7	Audiovisual and Text	2.4	-3.428
Q8	Text Only	0.927	-1.501
Q9	Audiovisual Only	0.6	-1.193

***negative value reflects decay**

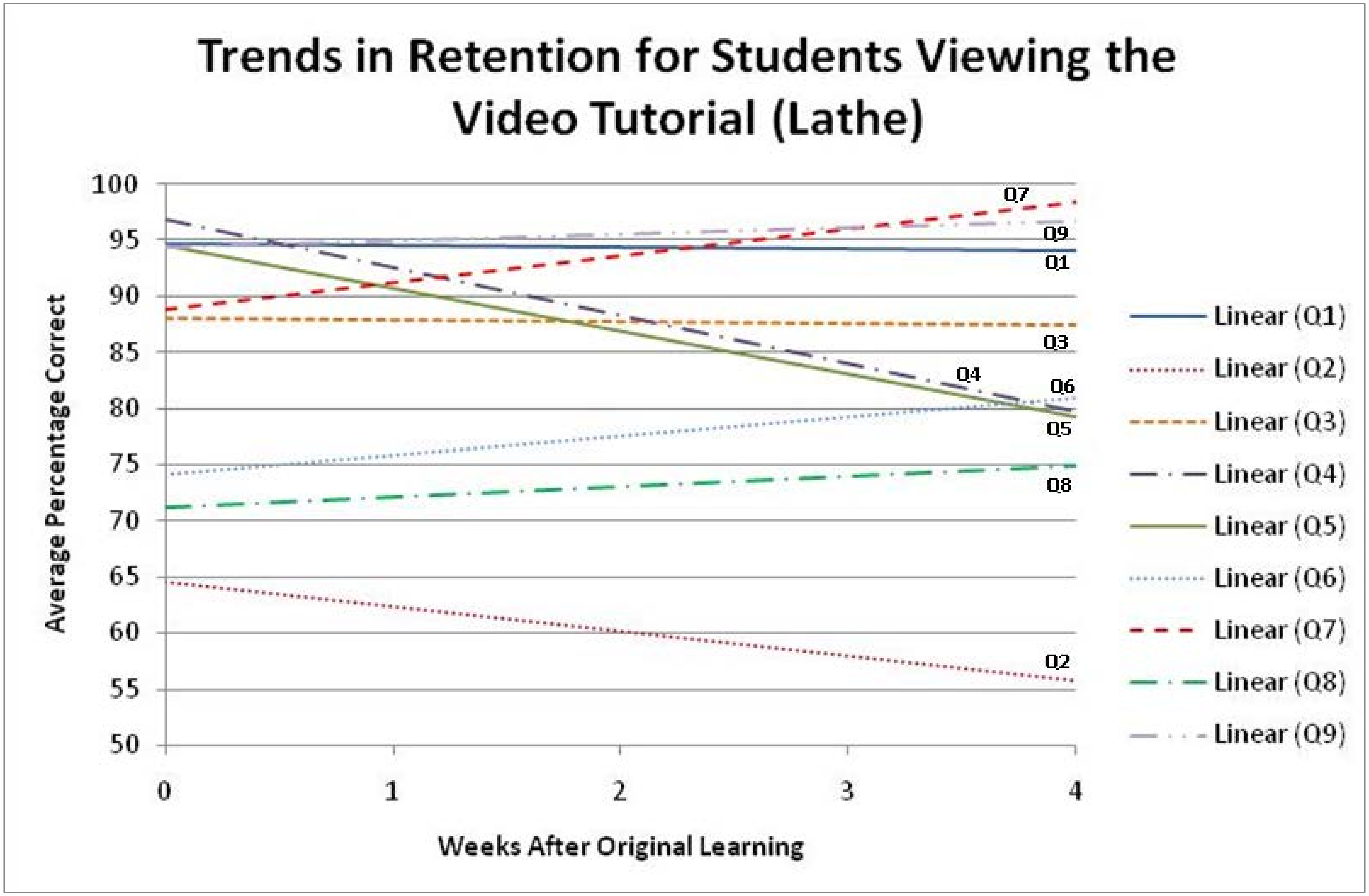

Figure 19: Trends in Retention Individual Questions among the Experimental Testing Group (Manual Lathe)

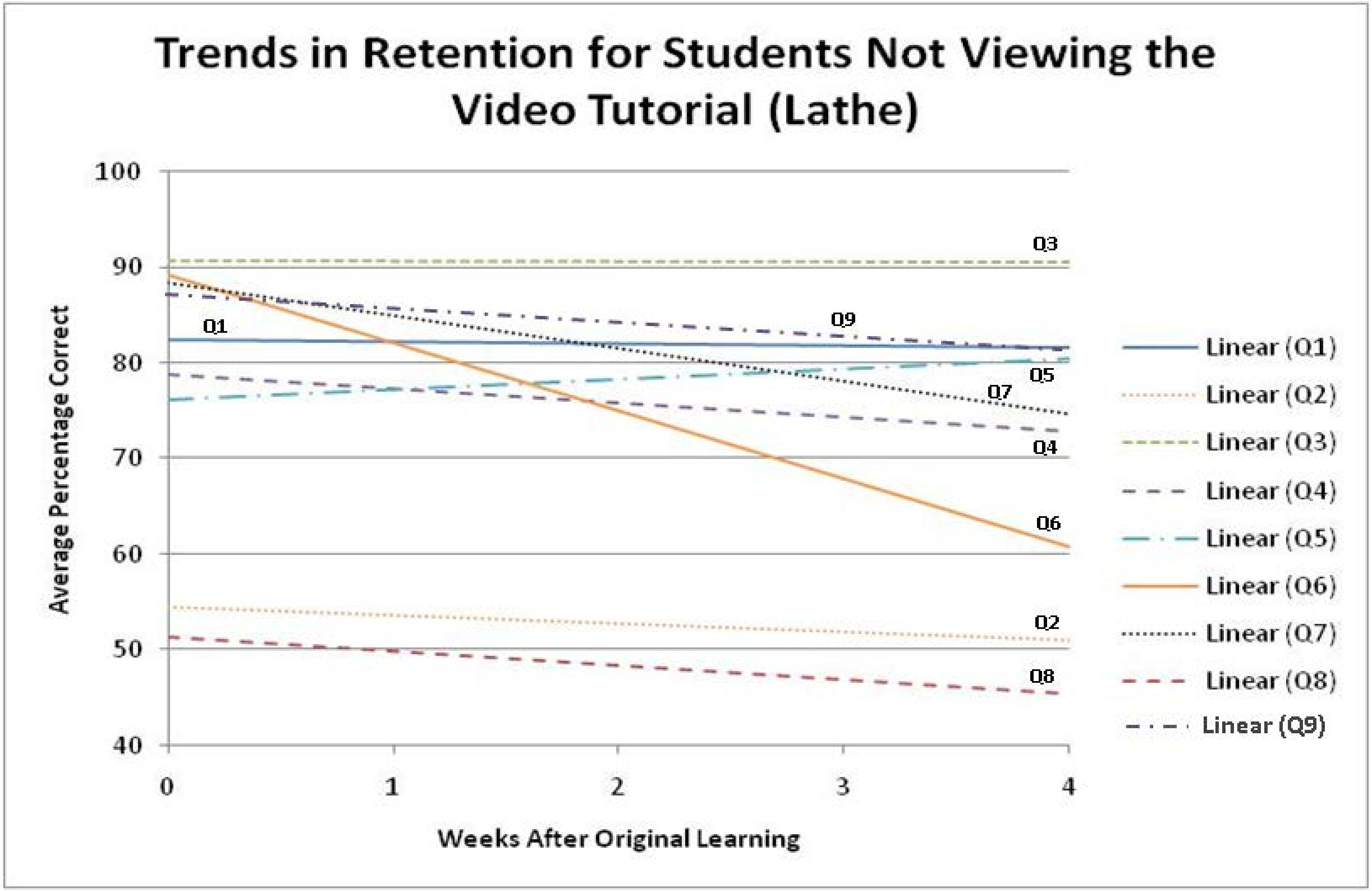

Figure 20: Trends in Retention for Individual Questions among the Control Testing Group (Manual Lathe)

When looking at the decay rates between individual questions (see Figures 19 and 20), not many definitive trends emerge. Questions2, 3, 4, and 5 actually showed a slower decline in retention than the experimental group, with Question 4 showing an increase in overall scores. This is most likely due to one of two reasons. Added experience could easily solidify the knowledge of which gear the lathe needs to be in for certain operations, or inadequate sample sizes particularly in Weeks 1 and 4 could artificially skew the scores higher.

CHAPTER 5:

CONCLUSIONS& RECOMMENDATION FOR FUTURE WORK

5.1 CONCLUSIONS AND CONTRIBUTIONS

In conclusion, the baseline testing revealed statistically significant differences in the average knowledge gained by the study's participants for both the manual mill and manual lathe. The mill testing yielded a 13% difference between students who viewed the video tutorials and those who did not, while viewing the video tutorial for the lathe resulted in a 3.5% increase in test scores over students who did not. In addition, the median result for both machines was higher than the mean for the experimental groups, indicating a few low outliers skewed the data slightly. The score distributions for the two tutorials also reflected this, 55% of students from the experimental group scoring a 90% or higher versus only 20% of students doing so from the control group. The lathe also yielded similar results, with 60% of the experimental group scoring 88.89% or better, while only 47% of the control group produced this result.

With the large discrepancy in the baseline results, there are several factors that can be attributed to the differences. First, students were more focused in the video tutorial environment. The screen was directly in front of them and was the focal point of the room, and the environment was quiet with no distracting noises. On the other hand, students in the control group were subjected to a loud, industrial facility with a lot of machining noise and people walking around. This had a prominent effect on the scores of the control group as seen in Figures 7 and 12, where the scores of the control group decay over time as the machine shop begins to contribute more noise and commotion to the learning environment as the semester progresses. Secondly, the format of the video tutorials also played a large role in score differences. The tutorials were set up to explain simple concepts, which only show how to operate the machine, with audiovisual instruction only; complex concepts, which explain why certain procedures must be performed, with text instruction only; and simple, yet extremely important concepts with text and audiovisual instruction This combination produced a very effective outcome with the experimental group scoring higher on seventeen of the nineteen total questions. While text-based instruction is often found to be ineffective, using it to explain more complex concepts allowed the students to see the event while simultaneously understand why it was being done a certain way, leading to an overall reinforcement of that concept. From the baseline results, it became clear that the learning environment and video tutorial set up were much more effective than the machine shop and hands-on training in teaching basic principles of machining.

In the retention testing, the experimental group's knowledge for both machines decay more slowly than the control group's; however, the difference in decay was not statistically significant. Agreeing somewhat with Biggs (1999), the control groups who experienced learning by doing as well as demonstration retained 89.9% of their original knowledge on the mill information and 90.9% of their knowledge on the lathe tutorial over four weeks. The experimental group students experienced both of these learning techniques as well as audiovisual learning, which resulted in 94.6% of knowledge being retained from the mill and 97.3% retained from the lathe. Therefore, it is evident that the audiovisual tutorials contributed to about a five to six percent increase in retention rates over just demonstration and hands-on learning.

5.2 LIMITATIONS AND FUTURE WORK

Overall, the study was a success, but there are a few limiting factors. First, the retention testing assumed no additional experience with the machines between the two test dates. While this appeared to be true for the majority of the students being tested for retention, one section of ME 340, approximately 20 students, had attained more experience with the mill by creating a simple L-bracket. This could have easily skewed retention numbers for both the experimental and control groups, since it is unknown how many of those students viewed the tutorials. Secondly, the number of students for the retention testing was not the same as the number in the baseline testing; therefore, retention testing did not have sufficient samples to obtain significant results. For example, of the students tested for retention, only twelve fell in the category of one week removed from training that did not view the tutorials, and only ten participants in the retention study were in the group that was four weeks removed from training without the video tutorials. If the retention testing had been conducted on all of the original participants, a statistically significant result may have been achieved.

For the Learning Factory machining training, it is evident that the tutorials should be implemented at some level, but the hands-on experience gained from the manual course is invaluable (Lamancusa, et al., 2008). Therefore, hybrid training would be extremely valuable. The overall concepts could be taught through the more focused environment, consistently generated by the tutorials and then reinforced by allowing the students to practice their techniques on the machines afterward and providing supplementary instruction as needed. This would allow the students to gain more overall knowledge through the tutorials and provide them with applicable hands-on experience that would make them more comfortable using the machines.

Although the testing clearly measured the impact of the tutorials on knowledge gain and retention, the real measure of how effective the audiovisual learning can be is how students machining skills actually improve. Therefore, there are several testing measures that can be taken to quantify this. One way to do this is to create a more exhaustive, comprehensive quiz that covers more of the machining skills as well as safety features and procedures. However, since this is the first hands-on training for many students, safety and machine setup are essential concepts to convey prior to future use. Though a more comprehensive quiz may help researchers learn what machining concepts are more difficult to understand than others, the main way to understand whether the tutorials are effective is through physical machining tasks. Future tests can measure completion time for a simple project, such as the ME 340 L-bracket assignment, or attempt to quantify how many machining errors are made throughout the semester.

In addition to measuring the physical effect on students' machining skills, testing should be conducted on how students from different majors gain and retain the knowledge. This study focused only mechanical engineering students, although some bioengineering and civil engineering students did participate in the baseline testing. Future studies could look at how well the terminology is transferred to students of different majors because they may not be familiar with some of the terms used in the tutorials; mechanical engineering students are more likely to already have a grasp on machining jargon. Retention in these students would also be interesting to test since machining knowledge is more supplementary to most of these students given the nature of their coursework.

Finally, given their effectiveness the tutorials should be distributed online in coordination with DIGINet, ideally for everyone with a PSU WebAccess account. Using the WebAccess account is an efficient way to measure statistics on the number of unique users, number of times a specific user visits the page, and the major of a particular user (McGinley, 2010). This would allow for complete demographic information of students who use manual machining tools to be gathered. Content-wise, students could view the tutorials as a quick refresher if they need to use the machine later but do not remember how to do specific tasks. Students could also use these online tutorials to assess whether either machine meets their machining needs. Making the tutorials available online through DIGINet would also increase the overall knowledge of the machining capabilities present at Penn State and promote the Learning Factory and other machining labs as prominent resources at Penn State.

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APPENDIX A: MACHINING QUIZZES

Effectiveness of Video Tutorials in a Machining Environment Testing Questions

Manual Mill Tutorial

1. Where should the wrench never be while the mill is in operation?
   a. On the back of the mill
   b. On top of the mill
   c. On the table of the mill
   d. On the learning factory table
2. What type of fluted cutter should be used for soft materials?
   a. Two-Fluted End Mill
   b. Three-Fluted End Mill
   c. Four-Fluted End Mill
   d. Flycutter
3. What is the first machining process that should be done in order to provide a reference for all future cuts
   a. Touching Off
   b. End Milling
   c. Tabling
   d. Contacting
4. What is most likely to cause vibration & uneven cuts while milling?
   a. Wrong tooling choice
   b. Cutting too much in one pass
   c. Not using machining oil
   d. Loose tooling and workpiece
5. What is an appropriate cut depth for a soft metal such as aluminum?
   a. 0.01"-0.015"
   b. 0.025"-0.03"
   c. 0.035"-0.04"
   d. 0.045"-0.05"
6. If a problem arises while the mill is the middle of a cut, what should you do?
   a. Immediately shut off the mill
   b. Leave the mill running and contact a TA
   c. Finish the cut and shut off the mill
   d. Back the tooling out of the cut and shut off the mill
7. What type of drill bit should always be used to pre-drill a hole?
   a. Spur Bit
   b. Prick Punch
   c. Center Punch
   d. Standard Drill Bit
8. What type of drilling style should be used to avoid breaking drill bits and unneeded pressure on the tooling?
   a. Boring
   b. Thru Drilling
   c. Peck Drilling
   d. Hammer Drilling
9. What gear should the mill be in while tapping?
   a. High Gear
   b. Low Gear
   c. Neutral
10. The mill should never be in operation when a tap is being started.
    a. True
    b. False

Figure 21: Baseline Manual Mill Quiz with Correct Answers Circled (also used in Retention Testing)

Effective of Video Tutorials in a Machining Environment Testing Questions

Lathe Tutorial

1. What is the first machining operation that should always be performed?
   a. Shearing
   b. Facing
   c. Reaming
   d. Cutting Off
2. What is the maximum amount of material that should extrude from the lathe's jaws at any one time?
   a. 2-3 inches
   b. 3-4 inches
   c. 4-5 inches
   d. 5-6 inches
3. Why shouldn't too much material stick out of the lathe's jaws at any one time?
   a. The table will interfere with the spindle causing collisions
   b. The drilling apparatus will interfere with the tooling
   c. If more material is extruding from the jaws than is clamped down, the part is liable to fall out
   d. It will cause vibrations when rotated leading to imprecise cuts & tooling wear
4. What gear should the lathe be in for shearing and facing procedures?
   a. High Gear
   b. Low Gear
   c. Neutral
5. What gear should the lathe be in for cut off operations?
   a. High Gear
   b. Low Gear
   c. Neutral
6. Why shouldn't tooling be traversed all the way to the middle of the part?
   a. It causes too much tooling fatigue wear
   b. It generates too much heat causing the workpiece to begin melting
   c. The middle of the part is stationary & contact with it will cause tooling damage
   d. The table's physical limitations will not allow it to traverse that far
7. When shearing, the table will automatically stop before it runs into the spindle, regardless of the length of your cut.
   a. True
   b. False
8. When should the gear selector and spindle speed be changed?
   a. Both when the machine is not running
   b. Both when the machine is running
   c. Spindle speed when the machine is not running, gear selector when the machine is running
   d. Spindle speed when the machine is running, gear selector when the machine is not running
9. When cutting off, what aspect of the tool must be taken into consideration in order to generate a part of the correct length?
   a. Length of the blade
   b. Blade Material
   c. Thickness of the Blade
   d. Height of the Blade

Figure 22: Baseline Manual Lathe Quiz with Correct Answers Circled (also used in Retention Testing)

APPENDIX B: COMPLETE TESTING RESULTS

	# of participants	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Average	High	Low
17-Jan	20	18	17	16	18	17	15	16	16	16	19	84.00	100	40
18-Jan	18	16	17	16	17	16	15	15	13	11	16	84.44	100	50
20-Jan	12	12	11	11	10	12	10	10	10	8	11	87.50	100	60
26-Jan	14	12	11	13	11	13	9	12	12	10	12	82.14	100	50
30-Jan	13	13	10	13	11	10	12	12	11	10	12	87.69	100	60
31-Jan	15	14	12	14	11	12	13	14	13	13	15	87.33	100	60
7-Feb	18	17	13	17	14	17	14	9	15	13	17	81.11	100	30
8-Feb	13	10	13	10	10	11	10	12	10	11	12	83.85	100	70
		91.06	84.55	89.43	82.93	87.80	79.67	81.30	81.30	74.80	92.68			
Total Participiants:	123	Average:	84.55											

Figure 23: Raw Results of the Baseline Testing for the Manual Mill Experimental Group

Date	# of participants	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Average	High	Low
17-Jan	20	19	17	16	19	18	13	17	18	20	87.22	100	55.56
18-Jan	18	18	10	14	16	15	11	17	10	17	79.01	100	55.56
20-Jan	12	12	8	11	11	11	7	11	7	11	82.41	100	66.67
26-Jan	14	13	12	13	12	11	10	14	10	13	85.71	100	55.56
30-Jan	13	13	9	9	10	10	10	13	7	13	80.34	100	44.44
31-Jan	15	15	12	13	15	15	13	14	12	14	91.11	100	44.44
7-Feb	18	17	8	14	16	16	14	17	9	18	79.63	100	44.44
8-Feb	13	12	11	12	12	12	8	12	8	12	84.62	100	44.44
		96.75	70.73	82.93	90.24	87.80	69.92	93.50	65.85	95.93			
Total Participiants:	123	Average	83.74										

Figure 24: Raw Results of the Baseline Testing for the Manual Lathe Experimental Group

Date	# of participants	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Average	High	Low
19-Jan	13	10	11	10	7	13	8	7	8	12	11	74.62	100	40
23-Jan	10	4	9	2	7	10	7	9	8	8	9	73.00	90	50
24-Jan	14	9	9	8	9	14	6	11	10	11	13	71.43	100	40
25-Jan	16	14	14	13	12	10	15	13	14	7	12	77.50	100	40
27-Jan	11	11	9	5	3	10	8	7	8	11	10	74.55	90	60
1-Feb	13	10	10	13	7	4	7	6	10	6	10	63.85	90	40
2-Feb	14	13	13	10	6	10	9	9	12	10	10	72.86	100	40
3-Feb	14	13	8	6	7	12	11	11	12	12	15	76.43	100	40
6-Feb	15	12	9	4	9	14	7	10	13	6	11	63.33	80	50
9-Feb	6	5	5	3	3	2	4	6	3	4	6	68.33	90	50
		80.16	76.98	58.73	55.56	78.57	65.08	70.63	77.78	69.05	84.92			
Total	126	Average	71.75											
Participiants:														

Figure 25: Raw Results of the Baseline Testing for the Manual Mill Control Group

Date	# of participants	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Average	High	Low
19-Jan	13	12	7	13	12	12	12	11	7	13	84.62	100	44.44
23-Jan	10	9	4	10	9	10	4	10	9	9	82.22	88.89	77.78
24-Jan	14	9	6	13	14	14	13	12	11	12	82.54	100.00	44.44
25-Jan	15	12	5	13	13	14	11	13	10	14	77.78	100.00	44.44
27-Jan	11	11	7	11	11	11	8	9	5	9	82.83	88.89	66.66
1-Feb	13	13	6	12	11	11	10	13	6	13	81.20	100.00	66.66
2-Feb	14	11	10	13	12	10	13	14	8	11	80.95	100.00	55.55
3-Feb	9	7	7	7	8	5	8	9	3	5	72.84	88.89	33.33
6-Feb	14	12	9	9	9	11	13	14	3	13	73.81	88.89	55.55
9-Feb	6	6	4	6	5	6	5	6	4	6	88.89	100.00	77.78
		85.71	54.62	89.92	87.39	87.39	81.51	93.28	55.46	88.24			
Total	119	Average	80.39										
Participiants:													

Figure 26: Raw Results of the Baseline Testing for the Manual Lathe Control Group

Mill	Exp		Lathe	Exp		Mill	Control		Lathe	Control	
Grade	#	% of students	Grade	#	% of students	Grade	#	% of students	Grade	#	% of students
100	33	26.83	100	34	27.64	100	9	7.14	100	13	10.92
90	36	29.27	88.89	41	33.33	90	17	13.49	88.89	44	36.97
80	29	23.58	77.77	26	21.14	80	29	23.02	77.77	35	29.41
70	14	11.38	66.66	10	8.13	70	28	22.22	66.66	19	15.97
60	5	4.07	55.55	4	3.25	60	25	19.84	55.55	3	2.52
50	3	2.44	44.44	7	5.69	50	11	8.73	44.44	3	2.52
40	2	1.63	33.33	1	0.81	40	7	5.56	33.33	2	1.68
30	1	0.81									
Total	123		Total	123		Total	126		Total	119	
Overall			Overall			Overall			Overall		
Average	84.55		Average	83.74		Average	71.75		Average	80.39	

Figure 27: Baseline Score Distributions for All Testing Groups

Mill-Exp Scores			**Mill-Control Scores**				**Lathe-Exp Scores**			**Lathe-Control Scores**		
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	77.77
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	77.77
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	77.77
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	77.77
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	100	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	100	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	66.66
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	55.55
100	90	80	90	80	70	60	100	88.89	77.77	77.77	88.89	55.55
100	90	80	90	80	70	50	100	88.89	77.77	77.77	88.89	55.55
100	90	80	50	80	70	50	100	88.89	66.66	77.77	88.89	44.44
100	90	80	50	80	70	50	100	88.89	66.66	77.77	88.89	44.44
100	90	80	50	80	50	50	100	88.89	66.66	77.77	88.89	44.44
100	90	70	50	50	50	40	100	88.89	66.66	77.77	88.89	33.33
100	90	70	40	40	40	40	100	88.89	66.66	77.77	88.89	33.33
100	90	70	40	40			100	88.89	66.66	77.77	88.89	
100	90	70					100	88.89	66.66	77.77	88.89	
70	90	70			**Std Dev:**	15.65014	100	88.89	66.66	77.77	88.89	
70	90	70					55.55	88.89	66.66	77.77	88.89	
70	90	70					55.55	88.89	66.66	77.77	88.89	
70	60	70					55.55	88.89	44.44	77.77	88.89	
70	60	70					55.55	88.89	44.44	77.77	88.89	
50	60	40					44.44	88.89	44.44	77.77	88.89	
50	60	40					44.44	88.89	44.44	77.77	88.89	
50	60	40					44.44	88.89	33.33	77.77	88.89	
										77.77	88.89	
	Std Dev:	14.33171						**Std Dev:**	15.7989	77.77	88.89	
										77.77	88.89	
											Std Dev:	13.70319

Figure 28: All Baseline Scores for Participants in All Testing Groups with Calculated Standard Deviations

Baseline	Average	1 week		Average	2 weeks		Average	3 weeks		Average	4 weeks		Average
#		**#**	18		**#**	21		**#**	13		**#**	17	
Q1	91.06	**Q1**	15	83.33	**Q1**	20	95.2381	**Q1**	10	76.92308	**Q1**	15	88.24
Q2	84.55	**Q2**	17	94.44	**Q2**	15	71.42857	**Q2**	9	69.23077	**Q2**	15	88.24
Q3	89.43	**Q3**	17	94.44	**Q3**	19	90.47619	**Q3**	13	100	**Q3**	14	82.35
Q4	82.93	**Q4**	13	72.22	**Q4**	15	71.42857	**Q4**	7	53.84615	**Q4**	9	52.94
Q5	87.8	**Q5**	16	88.89	**Q5**	18	85.71429	**Q5**	12	92.30769	**Q5**	12	70.59
Q6	79.67	**Q6**	13	72.22	**Q6**	18	85.71429	**Q6**	12	92.30769	**Q6**	14	82.35
Q7	81.3	**Q7**	12	66.67	**Q7**	18	85.71429	**Q7**	8	61.53846	**Q7**	14	82.35
Q8	81.3	**Q8**	17	94.44	**Q8**	21	100	**Q8**	9	69.23077	**Q8**	16	94.12
Q9	74.8	**Q9**	15	83.33	**Q9**	15	71.42857	**Q9**	10	76.92308	**Q9**	12	70.59
Q10	92.68	**Q10**	15	83.33	**Q10**	19	90.47619	**Q10**	12	92.30769	**Q10**	16	94.12
Total Average	84.55	**Total Average**		83.33	**Total Average**		84.7619	**Total Average**		78.46154	**Total Average**		80.59
Score Distributions:													
100	26.8	100	6	33.33	100	7	33.33	100		0.00	100	1	5.88
90	29.3	90	4	22.22	90	6	28.57	90	5	38.46	90	2	11.76
80	23.6	80	1	5.56	80	3	14.29	80	4	30.77	80	3	17.65
70	11.4	70	5	27.78	70	2	9.52	70	1	7.69	70	5	29.41
60	4.1	60	1	5.56	60	1	4.76	60	3	23.08	60	2	11.76
50	2.4	50	1	5.56	50	1	4.76	50		0.00	50	1	5.88
40	1.6	40		0.00	40	1	4.76	40		0.00	40	1	5.88
30	0.8	30		0.00	30		0.00	30		0.00	30		0.00

Figure 29: Raw Retention Testing Results for the Manual Mill Experimental Group with Calculated Score Distributions

Baseline	Average	1 week		Average	2 weeks		Average	3 weeks		Average	4 weeks		Average
#		#	12		#	32		#	33		#	10	
Q1	80.16	Q1	11	91.67	Q1	26	81.25	Q1	25	75.76	Q1	8	80.00
Q2	76.98	Q2	8	66.67	Q2	18	56.25	Q2	19	57.58	Q2	6	60.00
Q3	58.73	Q3	9	75.00	Q3	23	71.88	Q3	24	72.73	Q3	8	80.00
Q4	55.56	Q4	6	50.00	Q4	17	53.13	Q4	17	51.52	Q4	5	50.00
Q5	78.57	Q5	7	58.33	Q5	24	75.00	Q5	29	87.88	Q5	9	90.00
Q6	65.08	Q6	5	41.67	Q6	18	56.25	Q6	18	54.55	Q6	4	40.00
Q7	70.64	Q7	9	75.00	Q7	22	68.75	Q7	22	66.67	Q7	5	50.00
Q8	77.78	Q8	12	100.00	Q8	27	84.38	Q8	28	84.85	Q8	6	60.00
Q9	69.05	Q9	7	58.33	Q9	21	65.63	Q9	17	51.52	Q9	4	40.00
Q10	84.92	Q10	7	58.33	Q10	28	87.50	Q10	27	81.82	Q10	7	70.00
Total Average	71.75	Total Average		67.50	Total Average		70.00	Total Average		68.48	Total Average		62.00
Score Distributions:													
100	7.1	100		0.00	100	1	3.13	100		0.00	100		0.00
90	13.5	90	1	8.33	90	5	15.63	90	4	12.12	90		0.00
80	23	80	3	25.00	80	7	21.88	80	7	21.21	80	1	10.00
70	22.2	70	3	25.00	70	8	25.00	70	10	30.30	70	4	40.00
60	19.8	60	3	25.00	60	8	25.00	60	7	21.21	60	3	30.00
50	8.7	50	1	8.33	50	4	12.50	50	3	9.09	50		0.00
40	5.6	40	1	8.33	40		0.00	40	2	6.06	40	2	20.00
30		30		0.00	30	1	3.13	30		0.00	30		0.00

Figure 30: Raw Retention Testing Results for the Manual Mill Control Group with Calculated Score Distributions

Baseline	Average	1 week		Average	2 weeks		Average	3 weeks		Average	4 weeks		Average
#		**#**	18		**#**	21		**#**	13		**#**	17	
Q1	96.75	**Q1**	16	88.89	**Q1**	21	100.00	**Q1**	12	92.31	**Q1**	16	94.12
Q2	70.73	**Q2**	10	55.56	**Q2**	11	52.38	**Q2**	9	69.23	**Q2**	9	52.94
Q3	82.92	**Q3**	16	88.89	**Q3**	19	90.48	**Q3**	13	100.00	**Q3**	13	76.47
Q4	90.24	**Q4**	18	100.00	**Q4**	19	90.48	**Q4**	11	84.62	**Q4**	13	76.47
Q5	87.8	**Q5**	18	100.00	**Q5**	18	85.71	**Q5**	11	84.62	**Q5**	13	76.47
Q6	69.9	**Q6**	16	88.89	**Q6**	15	71.43	**Q6**	9	69.23	**Q6**	15	88.24
Q7	93.5	**Q7**	16	88.89	**Q7**	18	85.71	**Q7**	13	100.00	**Q7**	17	100.00
Q8	65.85	**Q8**	16	88.89	**Q8**	12	57.14	**Q8**	10	76.92	**Q8**	13	76.47
Q9	95.93	**Q9**	17	94.44	**Q9**	20	95.24	**Q9**	12	92.31	**Q9**	17	100.00
Total Average	83.74	**Total Average**		88.27	**Total Average**		80.95	**Total Average**		85.47	**Total Average**		82.35
Score Distributions:													
100	27.6	100	7	38.89	100	4	19.05	100	4	30.77	100	3	35.29
88.88	33.3	88.88	7	38.89	88.88	8	38.10	88.88	5	38.46	88.88	6	23.53
77.77	21.1	77.77	2	11.11	77.77	5	23.81	77.77	2	15.38	77.77	4	0.00
66.66	8.1	66.66	1	5.56	66.66	3	14.29	66.66	1	7.69	66.66		11.76
55.55	3.3	55.55		0.00	55.55		0.00	55.55		0.00	55.55	2	5.88
44.44	5.7	44.44	1	5.56	44.44		0.00	44.44	1	7.69	44.44	1	5.88
33.33	0.8	33.33		0.00	33.33	1	4.76	33.33		0.00	33.33	1	0.00

Figure 31: Raw Retention Testing Results for the Manual Lathe Experimental Group with Calculated Score Distributions

Baseline	Average	**1 week**		**Average**	**2 weeks**		**Average**	**3 weeks**		**Average**	**4 weeks**		**Average**
#		**#**	12		**#**	32		**#**	33		**#**	10	
Q1	85.71	**Q1**	10	83.33	**Q1**	25	78.13	**Q1**	24	72.73	**Q1**	9	90.00
Q2	54.62	**Q2**	6	50.00	**Q2**	22	68.75	**Q2**	10	30.30	**Q2**	6	60.00
Q3	89.91	**Q3**	11	91.67	**Q3**	29	90.63	**Q3**	30	90.91	**Q3**	9	90.00
Q4	87.39	**Q4**	8	66.67	**Q4**	25	78.13	**Q4**	22	66.67	**Q4**	8	80.00
Q5	87.39	**Q5**	9	75.00	**Q5**	22	68.75	**Q5**	20	60.61	**Q5**	10	100.00
Q6	81.51	**Q6**	11	91.67	**Q6**	25	78.13	**Q6**	21	63.64	**Q6**	6	60.00
Q7	93.58	**Q7**	9	75.00	**Q7**	26	81.25	**Q7**	29	87.88	**Q7**	7	70.00
Q8	55.46	**Q8**	5	41.67	**Q8**	15	46.88	**Q8**	19	57.58	**Q8**	4	40.00
Q9	88.24	**Q9**	10	83.33	**Q9**	28	87.50	**Q9**	29	87.88	**Q9**	8	80.00
Total Average	80.39	**Total Average**		73.15	**Total Average**		75.35	**Total Average**		68.69	**Total Average**		74.44
Score Distributions:													
100	10.9	100		0.00	100	3	9.38	100	1	3.03	100	1	10
88.88	36.9	88.88	5	41.67	88.88	9	28.13	88.88	8	24.24	88.88		0
77.77	29.4	77.77	3	25.00	77.77	7	21.88	77.77	5	15.15	77.77	6	60
66.66	15.9	66.66	1	8.33	66.66	7	21.88	66.66	9	27.27	66.66	1	10
55.55	2.5	55.55	1	8.33	55.55	3	9.38	55.55	7	21.21	55.55	1	10
44.44	2.5	44.44	1	8.33	44.44	3	9.38	44.44	1	3.03	44.44	1	10
33.33	1.7	33.33	1	8.33	33.33		0.00	33.33	1	3.03	33.33		0
								22.22	1	3.03			

Figure 32: Raw Retention Testing Results for the Manual Lathe Control Group with Calculated Score Distributions

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