THE EFFECTS OF STUDENT CONTROL OF MODALITY AND SELF-EFFICACY ON LEARNING IN ENGINEERING EDUCATION

A Dissertation in

Learning, Design and Technology

by

Denise Louise Turso

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The dissertation of Denise Turso was reviewed and approved* by the following:

Kyle Peck  
Professor Emeritus of Education  
Chair of Committee  
Dissertation Adviser  

Roy Clariana  
Professor of Education  
Head of the Department of Learning and Performance Systems  

Simon Hooper  
Professor of Education  

Julia Plummer  
Associate Professor of Education  

Susan Land  
Associate Professor of Education  
Director of Graduate Studies of Learning and Performance Systems  

*Signatures are on file in the Graduate School
ABSTRACT

The modality principle states that narration rather than on-screen text supports best learners in their understanding of information. Many of the modality studies involve content that is irrelevant to the participants. A few studies in the engineering domain have shown that development of self-efficacy affects students’ belief in their ability to perform and is a motivator to learn more. The purposes of this study were: 1) to determine whether students, while learning abstract and complex technical content in an authentic setting, prefer narration only or text and narration, and 2) to investigate possible relationships between student’s self-efficacy and performance. The hypothesis was that giving students the option of selecting to expose text explanations in a complex lesson would enhance self-efficacy and performance. This study stands out from the existing literature because the content was relevant to the participants and the study was conducted in an authentic setting. This quasi-experimental study, an asynchronous tutorial on control systems for a nuclear engineering three-credit course involving seventy-four undergraduate students, quantitatively assessed the choices students made with narration and text, examined their navigation patterns, and investigated whether their perceived self-efficacy in their ability changed by the end of the lesson. The results of this study showed that with this complex content and very capable learner population, there was no evidence that violating the modality principle, adversely affected student performance. In addition, the results showed that, when given the option, the majority of students chose to view the optional text throughout the online tutorial.
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Thankful to have a life-long dream come true.
Chapter 1

Introduction

Over the last decade, research studies on the modality principle with varying conditions have shown enhanced performance for multimedia lessons consisting of graphics with narration rather than graphics with text (Mayer, 2014a). However, there is still a call for more research to refine cognitive multimedia learning theory, specifically with regard to modality. “The growing number of failures to find a modality effect in recent years represents an important opportunity to fine-tune the cognitive theory of multimedia learning by identifying boundary conditions for when the effect is and is not found” (Mayer & Pilegard, 2014, p.336). These boundary conditions could include environment, authentic lesson/grade, learner control, and complex technical content.

In contrast to the majority of studies on the modality effect, Leahy and Sweller (2011 & 2016) found that no modality effect was present in some of their studies and Inan et al. (2015) found no modality effect and no significant differences between groups. This study sought to investigate this discrepancy further, to determine whether students, while learning abstract and complex technical content in an authentic setting that is learner paced, prefer narration only or text and narration and to discover any impact on performance or student’s self-efficacy.

For over twenty-five years, there has been great interest among researchers in the cognitive theory of multimedia learning. Based upon research in cognitive information processing and cognitive load theories, the cognitive theory of multimedia learning provides guidance to designers and instructors on how to design effective learning experiences. Along
with this guidance, other psychological factors such as individual differences, beliefs, and goals affect the learning process (Moreno & Park, 2010). Additional objective factors in the learning process are prior knowledge and complexity of the content. Not surprisingly, there was an abundance of literature on the best approach to present complex information. Unfortunately, most of the research studies involved content that was irrelevant to the participants in the study.

In this study, two online presentation styles were contrasted: (1) visual information, consisting of static diagrams and equations, occurring simultaneously with narration, and (2) visual information, consisting of static diagrams and equations, occurring simultaneously with narration as well as an option to reveal parallel text on the screen. The second presentation style (option to view text) was based on the proposition that because engineering content is complex and learners have very different levels of expertise, this ability to read parallel text would support the learner’s preference and enhance learning. The design of the treatments adhered to Mayer’s pre-training, segmenting, and modality principles (Mayer, 2014a) and were learner-controlled, enabling the student to regulate the pace and sequence of the instruction, in contrast with system-controlled materials which automatically manage how and when the instruction was presented (Scheiter, 2014).

As mentioned, this study also investigated student’s perceived self-efficacy, their belief in their ability to understand the subject matter (Bandura, 2006a). The measurement of self-efficacy rarely occurs when assessing student learning in the domain of engineering (Carberry, Lee & Ohland, 2010). Through this study, the intention was to determine the student’s ability to build self-efficacy related to specific engineering tasks during the online presentation. Overall, this study was conducted in order to investigate possible relationships between student’s self-
efficacy and performance, and shed additional light on the apparent discrepancy in the existing literature.

**Purpose**

In response to the conflicting results mentioned above the purpose of this study is threefold: 1) to determine whether students, while learning abstract and complex technical content, chose narration only, or both text and narration; 2) to investigate possible impacts of students’ choices on learning; and 3) to explore possible relationships between students’ self-efficacy and performance.

This quasi-experimental study assigned students to treatment and control groups. The intervention was an online asynchronous tutorial in control systems for a nuclear engineering course. The study collected data on learning through a pre- and post-test (multiple choice), and used Likert scales to assess pre- and post-test self-efficacy. In addition, data collection indicated: where and how often students choose the option to display text and review activity, making it possible to determine how many times each screen was visited during tutorial use. The following research questions guided this study:

RQ1: Does allowing students an option to reveal text enhance performance?

RQ2: Are different patterns of optional text use associated with differences in student performance?

RQ3: Is the student’s use of optional text related to student self-efficacy?

RQ4: Are students’ engineering learning self-efficacy and performance highly correlated?
Significance

Over the past decade, online education in the United States has significantly increased in higher education. As reported in the tenth annual report, *Changing Course: Ten Years of Tracking Online Education in the United States* survey (Allen & Seaman, 2013):

- The number of students taking at least one online course increased by over 570,000 to a new total, 6.7 million.

- The online enrollment is experiencing a growth rate of 9.3 percent per year, which is high, but slower than in previous years.

- The proportion of all students taking at least one online course is at an all-time high of 32.0 percent.

With the prevalence of online education in the United States and the technical content and quantity of information required of upper-level engineering courses, further research into the design of instruction conveying complex content in engineering education could facilitate the creation of custom online tutorials to support a blended learning approach, enhancing student learning. It is important to design online courses to support learner control by segmenting complex content, offering different modes to construct knowledge such as narration and visual (Mayer, 2014a), and enabling learner-controlled movement throughout an online course (Merrill, 1980). Online learning provides the opportunity for students to take control of pace, re-read, and seek additional help as needed.

Furthermore, the expectations of higher education to deliver online learning might necessitate similar learning approached as components of on-campus courses, which could be achieved by a blended learning approach that facilitates the need for specific online tutoring in abstract and complex technical content. This would provide a concentration of focused design and instruction in a specific technical area to support student learning and enable instructors to
use a variety of applications to assist all levels of learners in abstract technical lessons without geographical boundaries.

Definitions

Blended Learning is an approach that combines traditional face-to-face instruction with online learning approaches. It requires the presence of a teacher and student in the same location, as well, as the online component.

Cognitive Load Theory is an instructional theory that considers the human cognitive architecture and the structure of information that will enable a learner to process information. It provides a framework for studies in cognitive processes and instructional design (Paas, Renkl, & Sweller, 2003).

Cognitive Load is the strain on working memory, which has a limited capacity (Moreno & Park, 2010).

Cognitive Theory of Multimedia Learning is a theory about how people learn from words and pictures based on empirical evidence and principles in cognitive science such as multimedia, pre-training, segmenting, and modality (Mayer & Moreno, 2003).

Engineering Learning Self-Efficacy is a student’s belief in his or her own ability to achieve and learn specific engineering tasks during the online tutorial.

Expertise Reversal Effect is the reversal of the effectiveness of instructional techniques on learners that have varying levels of expertise (Kalyuga, Ayres, Chandler, & Sweller, 2003).

Learner-Controlled describes an online tutorial designed to allow the learner to make choices based on his/her learning needs and/or preferences (Merrill, 1980).
MATLAB is a very common mathematics and simulation software package that allows engineers to model a system’s dynamic behavior associated with differential equations and a way to automatically control it – all in one environment. For additional simulation capability, the add-on to MATLAB is Simulink. (https://www.mathworks.com/)

Simulink is a simulation and model-based design package that contains Function blocks. Preconfigured Function blocks are the starting point for graphically defining a function with Simulink blocks (https://www.mathworks.com/).

Modality, for this study, is a particular mode of how instruction is experienced or expressed, such as in the visual or auditory mode.

Modality Effect is a term used in experimental psychology in the fields of memory and learning to indicate when audio-visual information results in superior processing to visual only information such as text (Mayer & Moreno, 2003).

Modality Principle is an instructional guideline to minimize cognitive load in an effort to increase learning by presenting words as narration rather than text on a screen (Mayer, 2014a).

Multimedia Learning is a type of learning that involves processing information through the visual and verbal channels in working memory (Clark & Mayer, 2008).

Multimedia Principle is the premise that using both words and graphics will support a deeper understand of a concept than using only words (Clark & Mayer, 2008).

No Modality Effect is a term used in this study to explain the use of audio-visual (graphics/animation) information in which learners did not show superior processing.

Pre-Training Principle is a design principle that orients the learner to key characteristics, terms, definitions, and/or facts involved in a lesson (Clark & Mayer, 2008).
Reverse Modality Effect is a potentially misleading term in the literature to describe studies in which results are contrary to those anticipated by the modality principle. Although the word “reverse” might be interpreted as implying a significant difference in favor of the treatment designed in ways contrary to the modality principle, the term “reverse modality effect” is commonly used in studies in which the anticipated effect is absent, generally with insignificant differences between treatments. To avoid potential misunderstandings, this study will use the term “no modality effect” in place of “reverse modality effect.”

Self-Efficacy is a person’s belief in her or his own ability to produce or accomplish a task in a certain situation (Bandura, 2006a).

Segmenting Principle is an instructional premise advising that breaking large sections of information into appropriately smaller parts will help a learner understand a concept or skill.

Summary

Based upon the research evidence on the modality principle and a growing body of research involving self-efficacy assessment in engineering, this study was developed to determine whether students, while learning abstract and complex technical content such as mathematics or physics, preferred narration only, or both text and narration. In addition, to investigate the possible effect of students’ choices on learning, and to explore possible relationships between students’ self-efficacy and performance. This study was unlike most others in the literature on multimedia learning because it involved complex engineering content that was relevant to the participants, who were students’ enrolled in a three-credit course.

The following chapter reviews the literature related to the topics described in chapter one on cognitive load, cognitive multimedia principles, blended learning, and self-efficacy.
Chapter 2

Literature Review

This chapter provides a comprehensive literature review that relates to the aims of this study: 1) to determine whether students, while learning abstract and complex technical content, preferred narration only, or both text and narration; 2) to investigate possible impacts of students’ choices on learning; and 3) to explore possible relationships between students’ self-efficacy and performance. Because online students need to learn concepts, knowledge, and skills and how to solve problems related to technical contexts that involve complex systems, the cognitive learning theories most relevant to engineering education are cognitive information processing, cognitive load, and cognitive theory of multimedia learning. These cognitive theories provide a foundation for researchers, designers, and teachers to design, develop and evaluate learning materials with the distinct possibility of informing these theories and contributing to the field of education (Schunn & Silk, 2011).

Learning and Teaching in Higher Education

An online intervention was designed based on established research-based multimedia principles, specifically, the modality condition, to be implemented in a higher education engineering class. Because this study sought to determine if there was an impact on student’s self-efficacy and performance in an online, university-level course, this review of the literature begins with a brief overview of relevant aspects of teaching and learning in higher education.

Despite the technological innovations over the past twenty-years and learners’ continuous engagement with technology, students in higher education are not as comfortable learning
through computer-based delivery systems as they are with information taught through large lectures (Garrison & Vaughan, 2008). Since this study, Garrison and Vaughan (2013) reviewed two case studies that involve blended learning, which combines instructor-led with computer-based learning. There were positive outcomes for both faculty and students in the case studies such as active and engaging study and communication. This approach might be viable for higher education to meet the increase enrollments and, simultaneously, maintain a quality education system. Higher education institutions have been reflecting on how to meet diverse learners’ needs and interests and support faculty who teach today’s multi-generational learners, and in particular, the “Millennial” generation, born since 1982 (Roberts, Newman & Schwartzstein, 2012). According to Novotney (2010), the best way to engage today’s undergraduates is to try new teaching methods, such as multimedia approaches that are interactive and challenging to stimulate the learner’s interest, because learners expect engaging and meaningful learning experiences. In addition, Sorensen, Eichelberger, and Kevan (2016) discuss higher education challenges such as the growth of non-traditional learners and technical advances to support individualize learning, and education costs. The discussion included how competency-based education and blended learning could help overcome these challenges. Almost 70 percent of post-secondary institutions offer online education to support learning because of students’ geographic and work-related constraints (Soares, 2013) which, when taken in the context of the aforementioned challenges, raises the question of how to design multimedia instruction for both faculty and student success in various disciplines.

Although the design of multimedia instruction is important, the affective domain of the learner is equally important. In *Rethinking Engineering Education, The CDIO Approach* (Crawley, Malmquist, Ostlund & Brodeur, 2014), the Conceive-Design-Implement-Operate
(CDIO) document is a very detailed account of the goals of engineering education of which self-efficacy and has been added. In this context, self-efficacy is the self-belief that a student can perform a discreet set of tasks. This belief by the student is context-specific, and is an important factor in the retention of undergraduate engineering students.

**Self-efficacy**

Because learning is complex and based on many factors including how learners feel about the likeliness of their success, this study sought to determine if the student’s use of an option to reveal text influenced self-efficacy. A brief summary self-efficacy is included below.

In the 70s, Albert Bandura introduced self-efficacy into the fields of education and psychology.

Self-efficacy refers to “the strength of people’s convictions in their own effectiveness,” adding that self-efficacy “is likely to affect whether they will even try to cope with given situations. At this initial level, perceived self-efficacy influences choice of behavioral settings. People fear and tend to avoid threatening situations they believe exceed their coping skills, whereas they get involved in activities and behave assuredly when they judge themselves capable of handling situations that would otherwise be intimidating.” (Bandura, 1977, pp. 193-194)

Self-efficacy suggests that humans have an internal system that enables control of their thoughts, feelings, and actions (Bandura, 1986a). This belief system provides humans with the ability to self-regulate and control their capabilities and surroundings. Regardless of prior knowledge, prior accomplishments or skills, a human’s view of his or her ability extremely influences choices made and future courses of action (Pajares, 1996). Bandura (1997) explains that students expect certain results whether participating in a physical, social, or cognitive task but the actual outcomes are the real results. Students’ beliefs in their efficacy can influence their
pursuits, efforts, perseverance, and resilience related to stresses that emerge when realizing accomplishments. A student’s self-efficacy toward an activity tends to correlate positively with increased effort and persistence. In a study with 173 seventh graders, Pintrich and DeGroot (1990) reported a correlation between students’ academic self-efficacy, how they used self-regulation and metacognitive strategies, and academic performance with homework, exams, and quizzes. The students who believed they were capable used more cognitive strategies for their learning and persisted more at difficult tasks.

Bandura (2001) states that a person acquires knowledge based on social interactions with others through observing, modelling, and guidance, internalizing the knowledge but perhaps not showing a change in behavior or performance until later. For example, a student observes how to solve a problem, implements the steps the expert modeled to solve the problem, compares their work and feels confident to take an exam. The exam score would provide verification to the student if the perceived self-efficacy toward solving problems were real. Further, the assumption was the student might use the knowledge gained to solve future problems. The key was to develop self-efficacy within students to bring positive results through their own actions (Ponton, Edmister, Ukeiley, & Seiner, 2001). This affects students’ belief in their ability to perform a given task and provides motivation for them to learn more tasks of the same nature.

Bandura (1986b) proposed that students’ self-efficacy is a better predictor of academic success than objective assessments of their abilities. In essence, if students believe they will not be successful and their grades are above average, their belief can be a better predictor of success than their grades. High self-efficacy and low grades often bring success because the students believe in themselves which results in persistence to overachieve. Many studies show a positive correlation between self-efficacy and academic achievements. A study by Louise and Mistele
(2012) reported that self-efficacy was a good predictor of achievement scores. In academic settings, the study of self-efficacy helps to understand both instructor (Yoon, Evans, & Strobel, 2012) and student self-efficacy (Loo & Choy, 2013) in mathematics and engineering. The importance of measuring self-efficacy is to determine performance based upon students perception of their ability, not prior performance. This core belief or judgement can motivate a person to persevere through difficult events and challenging tasks (Bandura, 2006a).

There are four sources of self-efficacy:

1. mastery experiences - performance accomplishments
2. vicarious experiences - perceptions of your skills based on observing others
3. social persuasion - others’ judgements or support, and
4. physiological reactions - anxiety/fear (Bandura, 1977).

This study focuses on undergraduate students’ mastery experience by providing an active learning intervention (Freeman, et al., 2014), i.e., tutorial with problem solving that is scaffold to build cognitive thinking toward students’ success. If a student is successful in completing a difficult task, then belief in his//her ability will increase resulting in increased or validated self-efficacy. If the performance of the task is unsuccessful, then the converse occurs, lowering self-efficacy. The task alone does not constitute self-efficacy. The cognitive processing, previous beliefs, the perceived difficulty of the task and the help received with the task are all factors (Britner & Pajares, 2006).

In reviewing the self-efficacy scales literature, researchers have identified and described a broad range of scales from general-to-specific (Mamaril, 2014). The *Guide for Constructing Self-Efficacy Scales* (Bandura, 2006b) states that general measurement of perceived self-efficacy due to the “one measure fits all” (p.307) model has limited predictive value. As well, Bandura
(2006b) suggests a self-efficacy scale that is specific to the domain of interest. At varying levels of specificity, engineering studies have measured self-efficacy. However, many did not operationalize the self-efficacy of specific tasks. Self-efficacy measures should include questions that ask what a student “can do” to determine their belief in their capabilities to perform a task (Bong, 2006).

There is value in assessing student’s judgement and cognition to facilitate understanding in engineering education (Carberry et. al., 2010). Understanding students’ affective and cognitive domains of functioning related to a specific engineering task can provide input that will contribute to new guidelines improving the design and development of multimedia instruction (Tait-McCutcheon, 2008). In the future, as students move into the workforce, they will remember the “can do” belief despite the often numerous steps involved in a task, which will strengthen their abilities in completing a novel engineering task in academia, government or industry.

**Engineering Education**

Because engineering education involves many complex and abstract learning outcomes, and may be more demanding than other topics, this literature review provides a summary of relevant literature on engineering education specifically.

In the United States, engineering education is under a major transition to utilize strategies and techniques that will enhance students’ professional skills, aptitudes, and competencies for useful practice in the 21st Century (Gattie, Kellam, Schramski & Walther, 2011). In conjunction with this transition, interdisciplinary fields bringing together researchers in anthropology, computer science, education, and psychology have put forth new ideas about how people learn
that can augment engineering education (Sawyer, 2014). The understanding of how people learn, and traditional instructional design research can provide a foundation for experienced educators who are not experts in psychology or education. These educators desire to understand and use theories, design principles, and lessons learned from these fields to enable their students to be successful (Schunn & Silk, 2011). In February 2012, the report by the President’s Council of Advisors on Science and Technology, *Engage to Excel*, states that better teaching methods in higher education would provide more help for students in engineering. Because engineering is dependent on mathematics and the content is both abstract and complex, this presents challenges for engineering education. Generally, mathematics and engineering are interrelated because of the manipulation of numbers, critical thinking and problem solving (Louis & Mistele, 2012) which makes mathematics a vital component to engineering. To couple mathematics and engineering from a practical aspect in support of engineering competencies, higher education could augment blended learning approaches within courses (Chyung, Moll, & Berg, 2010).

Although, the adoption of eLearning in engineering education is still in the initial stages, the Sloan Consortium does advocate complementing existing instruction on the Accreditation Board for Engineering and Technology (ABET) competencies with online instruction (Bourne, Harris, & Mayyadas, 2005), the focus in engineering education is currently understanding how students learn and how to effectively teach them (Carberry et al., 2010).

**Cognitive Information Processing Theory**

This foundational theory is the basis for the concept of cognitive load and for the cognitive theory of multimedia learning, which are central to this study. Human cognition enables individuals to create new information, and to remember, apply and disseminate this
information (Sweller, Ayres, & Kalyuga, 2011). The cognitive information processing theory analogizes the mind to a computer due to its limited capacity. Based on this model, the notion is that a storage system exists at various stages of memory (Baddeley, 2003). The brain receives information that processes through the sensory memory, working memory, and long-term memory (Driscoll, 2005a). Figure 2.1 depicts how the sensory memory contains the dual channels: visual and auditory (Paivio, 2007). This visual and auditory information “input” is comprised of verbal and nonverbal representations that are recognized and entered into working memory. In this transient holding place, the input might be reasoned and comprehended, if so, encoding has occurred and the input eventually persists as long-term memory where it may be retrieved later by the individual. The understanding of this process provides insight on how an instructor or designer can present information in an efficient and effective manner to support students’ learning.

Figure 2.1. The Flow of Information-Progressing Theory


Throughout learning, the information is processed from one memory stage to the next. For example, when a learner reads and hears new information, this involves the sensory memory where processing occurs to determine if the information is recognizable. If there is not full
utilization of sensory memory, this can slow the process of the information reaching the working memory, where coding takes place and the learner makes sense of the information. If the information is encoded (makes sense and connections are formed with prior knowledge), the information is stored in long-term memory. In a complex domain such as engineering, the learner has to solve complex problems. Because of these intricacies, the learner needs to be able to identify and sort the critical aspects of the information to support the process of selecting, coding, and retaining as working memory. Often novices do not know the critical aspects of information to select in a complex problem. Therefore, the instructor and designer should highlight salient features of new information at the right time (Schunn & Silk, 2011).

As an extension of information processing theory, the next section presents cognitive load theory, which relates the cognitive information processing theory and multimedia guidance on designing new information to reduce the burden on working memory for the learner.

**Cognitive Load Theory**

This study explores ways to support learners as they process complex information, or to put it another way, while they grapple with significant “cognitive load,” and cognitive load theory provides a framework for understanding the capacity of learners’ working memory and potential impacts on learning.

Cognitive load theory is heavily concerned with the consequences of how inadequate instructional design of learning material interacts with working memory (Sweller, 1999). The explicit focus of this framework is on the learner’s prior knowledge, not cognitive abilities, motivation, self-efficacy, regulation, or other individual differences (Moreno & Park, 2010). The premise of this theory is that new information can create a cognitive load for a student’s
processing that exceeds working memory capacity, which may compromise the potential to learn. As noted in the research by Sweller (1994), if content or activity elements are highly complex while a learner is learning how to conduct an experiment or interacting with new information, then cognitive load should be a factor in the design. The new information activated as working memory may produce three distinct types of cognitive load: intrinsic, extraneous, and germane (Sweller, 2010). Table 2.1 highlights the cognitive load categories, the definitions, and the multimedia solutions through which the designer can adjust visual and auditory elements and affect the cognitive load experienced by students (Paas & Sweller, 2014).

Table 2.1. Cognitive Load and Multimedia Learning

<table>
<thead>
<tr>
<th>Categories</th>
<th>Definition</th>
<th>Multimedia Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic Load</td>
<td>Level of difficulty of the concept, task, topic, or problem to the learner.</td>
<td>Segment the instructional topic for the learner. Selective use of visual &amp; auditory elements.</td>
</tr>
<tr>
<td>Extraneous Load</td>
<td>Inappropriate elements (visual &amp; auditory) in the instruction that cause learners to process unnecessarily. Does not enhance learning. Distraction. Unrelated to the required learning.</td>
<td>Use visual and auditory options sparingly, avoiding the use of any that distract from the core message.</td>
</tr>
<tr>
<td>Germane Load</td>
<td>Mental processing effort to support the development of connections between prior and new information to support storage in long-term memory.</td>
<td>Employ scaffolding, sequencing practicing, reflecting, and articulating to stimulate appropriate processing. Use visual &amp; auditory elements selectively.</td>
</tr>
</tbody>
</table>


Cognitive load, the effort required by working memory, is the sum of all three loads: intrinsic, extraneous, and germane. The combination of intrinsic and extraneous loads will determine if the cognitive load exceeds the working memory capacity. The goal is to decrease these loads in order to increase working memory resources available to process germane
information, invoking the acquisition of schemas (Sweller, 2010). Germaine load is the mental processing effort that supports the development of a schema or representation in long-term memory (Sweller, 2010). With a sufficient amount of working memory, the mental effort of creating connections between prior knowledge and new knowledge to create a new schema might be more efficient for the learner. The instructor and designer can support this schema development and ease working memory load by using strategies that reduce cognitive load, such as pre-training, segmenting, and appropriate modalities in multimedia learning (Sweller, 2010).

The cognitive load theory was the research-based foundation for the cognitive theory of multimedia teaching (Mayer & Moreno, 2010). During decades of research on multimedia learning, many techniques surfaced to manage intrinsic and extraneous load in multimedia learning. Consideration of the “size” of these loads is important in the instructional design of learning material so students may process the new information effectively.

Like information processing theory, both the cognitive load theory and cognitive theory of multimedia learning hold the underlying assumptions of dual channels, limited capacity, and active processing that provides a strong foundation to support the learning process (Mayer 2014b).

**Cognitive Theory of Multimedia Learning**

This study, based upon twenty-five years of research on the cognitive theory of multimedia learning (CTML) model, has underpinnings from both the cognitive information processing and cognitive load theories. The definition of “multimedia learning” is that individuals are using both visual and verbal senses to process information when presented with a topic area to learn (Mayer & Sims, 1994). Both cognitive load theory and cognitive theory of
multimedia learning assume processing in the sensory channels (verbal/visual), limited processing in working memory, and that learning requires active processing in both channels. These theories provide yet another view to understand the mechanics involved in learning which further supports the use of cognitive approaches to explain how complex learning happens so we can determine the best instructional procedures to enable learning.

The illustration in Figure 2.2 outlines the acquisition of incoming information (input) through spoken and/or printed words and pictures. In addition, how information flows through the sensory, working, and long-term memories to result in learning (output). Allen Paivio’s dual-coding theory derived the dual-channel aspect of the CTML model (Mayer, 2003). This theory assumes that learners process visual (nonverbal) and verbal (language) information in separate cognitive channels in long-term memory (Clark & Paivio, 1991).

As such, animations and static pictures process through the visual/pictorial channel and narrations process through the auditory(verbal) channel. The limited capacity refers to the amount of auditory and verbal processing that can occur in each serial channel during a system-controlled presentation, as illustrated in Figure 2.2. Because a learner has a limited amount of time, it is important to consider the amount of visual and auditory information a learner receives (Mayer, 2003). Lastly, active learning occurs when learners engage and integrate the new information with prior information that supports transfer (Mayer, 2003). This process supports problem solving because there is a coherent structure as a reference (Mayer & Gallini, 1990). When an instructor and designer are aware of this framework and how the processing can affect learning, design features could provide a mechanism for deeper understanding of a concept. An adaptation to the CTML framework in Figure 2.2 is the dash arrow drawn from the “eyes” to “sounds” blocks that signifies how both the visual and spoken words enter into the same auditory
buffer. When a learner reads, the words convert into sounds immediately and become part of the verbal model.

![Diagram of Human Information Processing System: A CTML Framework](image)

*Assumptions underlying CTML*

* These Cognitive Processes must be used for meaningful learning

Figure 2.2. Human Information Processing System: A CTML Framework


In addition, the figure highlights the three assumptions of how cognitive processing works (Mayer, 2014b):

1. Dual Channeling: the message goes through two different channels, visual and auditory,

2. Limited Capacity: there is a limit to the amount of information that can be stored in the working memory at one time, and

3. Active Processing: the learner makes sense of the information.

In addition to the cognitive assumptions, the five cognitive processes in Table 2.2 support multimedia learning: Select Words and Images, Organize Words and Images, and Integrating. This design guidance provides direction while creating multimedia learning solutions.
Table 2.2. Cognitive Processes in Cognitive Theory of Multimedia Learning

<table>
<thead>
<tr>
<th>Process</th>
<th>Words</th>
<th>Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>Attention on relevant words to create sounds in working memory.</td>
<td>Attention on relevant pictures to create images in working memory.</td>
</tr>
<tr>
<td>Organize</td>
<td>Build connections among selected words to create a verbal model.</td>
<td>Build connections among selected images to create a pictorial model.</td>
</tr>
<tr>
<td>Integrating</td>
<td>Build connections between verbal and pictorial models and with prior knowledge.</td>
<td></td>
</tr>
</tbody>
</table>


As seen in Table 2.2, the integration of the cognitive processes into the processing through the memories are guides in the development of a multimedia lesson to enhance learning. The gradual selection of words and images that are organized and integrated supports the learner through multimedia learning. By understanding the human information processing system, instructors and designers can create design methods that promote deep understanding of new information to the learner.

While thinking through the CTML model (assumptions, cognitive processes), the instructional guidelines to support the goal of managing essential information enables an instructor/designer to be “alert” regarding the amount information to be processed throughout the learning experience. During the development of multimedia learning, cognitive load can be reduced by using the appropriate instructional principles of multimedia learning, such as pre-training, segmenting, and modality as proposed by Mayer (2014, p. 319) in Table 2.3.
Table 2.3. Managing Essential Information

<table>
<thead>
<tr>
<th>Over-Load Type</th>
<th>Problem</th>
<th>Load-Reducing Methods</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-training</td>
<td>Visual &amp; auditory channels could be overloaded</td>
<td>Highlight key names and characteristics of components</td>
<td>Learning may occur when there are definitions of key components such as terms and characteristics.</td>
</tr>
<tr>
<td>Segmenting</td>
<td>Content is lengthy or complex.</td>
<td>Allow time for small chunks of information</td>
<td>Learning may occur when information is segmented into manageable chunks versus a continuous flow of information is presented to the learner.</td>
</tr>
<tr>
<td>Modality</td>
<td>Visual channel is overloaded</td>
<td>Move essential from visual to auditory.</td>
<td>Learning may occur when information (words) are spoken versus text on a screen.</td>
</tr>
</tbody>
</table>


By using these instructional principles as a guide when designing multimedia lessons, an instructor/designer can develop instruction that promotes learning by choosing pertinent graphics, video, audio, and text. These three principles for managing essential information processing: pre-training, segmenting, and modality provide guidance to support optimal cognitive load of lessons with complex content.

Pre-training and Segmenting Principles

Based on the studies of Leahy and Sweller (2011, 2016) and Inan, et al. (2015), the pre-training and segmenting principles were applied in the content analysis and design in preparation of the intervention for this study. When applying the pre-training principle, the instructor/designer defines key words and phrases of the main concepts and briefly explains pre-
requisite information needed to understand the concept (Mayer, 2014b). The pre-training occurs prior to the lesson and the information shared with the learner can trigger prior knowledge, gain their attention, and convey the importance of the material. This connection may motivate the learner to seek meaning. As well, this section prepares a learner for deeper meaning by viewing the parts of the concept as a whole, personalizing the concept to own the experience, and understanding the concept at a level to offset cognitive load throughout the multimedia lesson (Gagne, Briggs, & Wager, 1992). This principle is paramount when teaching complex material to beginners because it reduces the amount of essential processing by distributing the information to the pre-training section of the lesson (Clark & Mayer, 2008).

Segmenting occurs when an instructor/designer analyzes the content, sequences the flow of the content, and then divides the content into small chunks. Chunking is the task of breaking complex content into manageable segments so it is easier for the learner to examine and understand (Driscoll, 2005b). When a learner is learning new complex information through a presentation that is continuous and the concepts are unrelated, a cognitive load surfaces and impedes learning. Therefore, breaking the content into bite-size pieces relative to complexity and length can provide a positive psychological approach that effects the learner’s experience. Further research on both pre-training (how extensive should it be?) and segmenting (what is the optimal bite-size in length/time?) needs to be conducted to fully utilize these principles (Clark & Mayer, 2008).

Both the pre-training and segmenting principles were important in the design of this multimedia lesson, as they provided a foundation for the appropriate use of visual (graphs, text) and auditory (spoken text) information that optimizes cognitive load. This leads us to examine
the modality principle and its effect when both audio and visual information were in the design of a multimedia lesson to enhance student performance.

**Modality**

In this study to explore the effects on student performance of text with narration or text only, we reviewed the modality effect that occurs in the working memory as spoken text is processed in the auditory channel and written text and pictures are processed in the visual channel. When both text and pictures are processed in the visual channel, the working memory can become overloaded. The CTML theory claims that when using both channels, the spoken text-auditory channel and the pictures-visual channel, the probability of a cognitive overload that can affect learning is reduced. Exploration of the modality principle within multimedia instruction for complex technical content can provide insight to instructors/designers on effective instruction and can aid in the efficient use of these channels. As (Ginns, 2005) noted, additional research is needed to determine the learning contexts most likely to invoke the modality or reverse modality effects.

According to Mayer and Pilegard (2014), the definition of the modality principle is “people learn more deeply from a multimedia message when the words are spoken rather than printed” (p. 317). This principle provides guidelines for effective instruction, in particular, multimedia instruction (Low & Sweller, 2014). The results in the original study on the effects of modality by Mayer and Moreno (1999) indicate that when designing multimedia presentations about how something works, narrations with animations are more effective than written text with animations. In 2003, Mayer expanded his definition of multimedia messages to include both words and pictures. Words include written or spoken text and pictures include static
representations (chart, diagram, and map) and dynamic graphics (animation and video). When these multimedia messages attend properly to the words and pictures, this reduces competition for resources in verbal and visual working memory.

There has been a plethora of studies demonstrating the modality effect (Brünken et al., 2004; Mayer & Moreno, 1998; Oberfoell & Correia, 2016). However, many studies using self-paced instruction have failed to confirm the modality effect (Tabbers, Martens, & Merriënboer, 2004), Schmidt-Weigrand, Kohnert, & Glowella, 2010). This is most likely due to the control the learner had to move from one concept to another and the significant amount of time for review. Exercising these options would enable the learner to transfer the information from working to long-term memory that may eliminate an overload on working memory.

Replication and augmentation studies on modality have been conducted to determine the effect of using various parameters such as segmenting, pace of the presentation (system versus learner-paced), modality, and written versus spoken text (Cheon, Crooks & Chung, 2014; Leahy & Sweller, 2016). In addition, a study by Leahy and Sweller (2011) discovered two implications. First, technical audio information should be in small chunks along with visuals (graphs, diagrams). Secondly, if the verbal information is lengthy and complex, and not segmented, it should be in written form.

Other modality effect studies place parameters around the effectiveness of modality, investigating static representation, form of presentation, redundancy, expertise reversal, pre-training, segmenting, length of narration or text, and control of pacing.

Table 2.4 provides a summary of the studies conducted by Leahy and Sweller, (2011). The studies distinguish between no modality effect and a modality effect. The intervention was a system-paced power point about temperature graphs with static representations accompanied
with narration or text only. The post-test used for both experiments 1 and 2 consisted of a
temperature graph along with seven test questions asking students to describe certain aspects of
the temperature graph. There were two experiments each consisting of two conditions: Visual
Only and Audio/Visual.

Table 2.4. Modality Effect Study: Reduction in text length of Written and Spoken Text

<table>
<thead>
<tr>
<th>Participants</th>
<th>Outcome</th>
<th>Better</th>
<th>Worse</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age: 11-12 years</td>
<td>No Modality Effect</td>
<td>Visual Only Text</td>
<td>Audio/Visual NO written Text</td>
<td>The transitory auditory text was long and complex not easily processed in working memory, written text better.</td>
</tr>
<tr>
<td><strong>Experiment #1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-instruction, Instruction, Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-112 screens</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Average word count per screen 13.9</td>
<td>M= 58.3</td>
<td>M= 33.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Modification after Experiment #1:
Reduction in statement length and words per screen in instructional material

<table>
<thead>
<tr>
<th>Participants</th>
<th>Modality Effect</th>
<th>Audio/Visual NO written Text</th>
<th>Visual Only Text</th>
<th>Audio/visual instructions proved superior to visual only due to reduced length in text.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment #2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n =64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-instruction, Instruction, Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-112 screens</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Average word count per screen 7.6</td>
<td>M= 51.6</td>
<td>M= 36.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.5 provides a summary of the study conducted by Leahy and Sweller, (2016) five
years after the previous study. In this system-paced intervention, the students read a contour
map with static representations accompanied with visual only or audio/visual modalities.
Table 2.5. Modality Effect Study: Long and Short length of Written and Spoken Text

<table>
<thead>
<tr>
<th>Participants</th>
<th>Outcome</th>
<th>Better</th>
<th>Worse</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age: 14-15 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Experiment #1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n=35$ Pre-instruction, Instruction, Test</td>
<td>No Modality Effect</td>
<td>Visual Only Longer written length Written text</td>
<td>Audio/Visual Longer spoken text NO written text</td>
<td>The auditory text was long and complex not easily processed in working memory, written is better. No significant difference between the two groups.</td>
</tr>
<tr>
<td>9 slides #words per screen (16-to-75)</td>
<td></td>
<td>$M= 5.05$</td>
<td>$M= 2.57$</td>
<td></td>
</tr>
<tr>
<td>$n=36$ Pre-instruction, Instruction, Test</td>
<td>Modality Effect - the audio/visual information results in better processing to visual information (text) only.</td>
<td>Audio/Visual Shorter</td>
<td>Visual Only Shorter written length</td>
<td>Audio/visual only slightly better. Due to shorter text, either mode is effective.</td>
</tr>
<tr>
<td>29 slides #words per screen (10-to-23)</td>
<td></td>
<td>NO written text $M= 5.55$</td>
<td>Written text $M= 5.50$</td>
<td></td>
</tr>
<tr>
<td><strong>Modification after Experiment #1:</strong> Segmentation of the occurred for the Shorter group creating more slide: NO changes to the Longer group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Experiment #2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n=47$ Pre-instruction, Instruction, Test</td>
<td>No Modality Effect</td>
<td>Visual Only Longer written length Written Text</td>
<td>Audio/Visual Longer spoken text NO written Text</td>
<td>The auditory text was long and complex and not easily processed in working memory, written text was better.</td>
</tr>
<tr>
<td>Words per screen, Same as Exp. #1</td>
<td></td>
<td>$M= 5.18$</td>
<td>$M= 4.08$</td>
<td>Audio/visual instructions proved superior to visual only.</td>
</tr>
<tr>
<td>$n=53$ Pre-instruction, Instruction, Test</td>
<td>Modality Effect</td>
<td>Audio/Visual Shorter spoken text NO written text</td>
<td>Visual Only Shorter written length Written text</td>
<td></td>
</tr>
<tr>
<td>46 screens (average 13 words per screen)</td>
<td></td>
<td>$M= 7.53$</td>
<td>$M= 5.52$</td>
<td></td>
</tr>
</tbody>
</table>
In both studies, a modality effect occurred in the NO written SHORT text group and the mean test scores were higher. Due to the segmentation of the content in this study, it was clear the segmenting principle strengthened a modality effect.

Table 2.6 provides a summary of the study conducted by Inan, et al. (2015) one year before the previous study. Unlike the previous studies, this intervention was learner-paced with static representations accompanied with audio or text only. There were two groups each consisting of two conditions: written and spoken text. The learner also controlled the sequence and could review the content within the 10-minute boundary of the instruction. The online intervention displayed a static cross-section representation of the human head with 12 places marked by a small bullet that indicated an articulation point: either an on-screen text description or audio description. The learners in the written text group clicked on each of the 12 articulation markers more frequently than the spoken text group.

Table 2.6. Modality Effect Study: Modality/No Modality Effect

<table>
<thead>
<tr>
<th>Participants</th>
<th>Condition</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduates 17 to 37 years</td>
<td>Written Text group received on-screen text descriptions</td>
<td>No Modality: Written text was superior when learners were in control and learning new complex information. The written text group clicked on markers more frequently possibly due to efficient use of cognitive resources.</td>
</tr>
<tr>
<td>n=79</td>
<td>Spoken Text group received on-screen audio descriptions</td>
<td>Mental effort: No significant differences between the groups. However, the written text group did have a slightly higher mental effort.</td>
</tr>
</tbody>
</table>

n =36
Overall, these three studies indicated that a learner-paced, appropriately segmented (short text) multimedia lesson decreased the perceived cognitive load on the learner and fostered the learning process in multimedia instruction. In some studies, learners’ using written text outperformed those using spoken text while in other studies there was not a statistically significant difference between written and spoken conditions. In general, there is no reason to assume that learning is always optimal with pictures and the spoken word versus written text.

Recently, Schnotz, Mengelkamp, Baadte, and Hauck (2014) conducted a study on the focus of attention and choice of text modality with 120 students in grades 11 and 12 (German advanced grammar school) and first year university students learning about volcanism. The conditions were modality (audio/visual) of content-related paragraphs and modality of picture-related paragraphs. A content-related paragraph described content through a text format such as a paragraph. A picture-related paragraph translated the understanding of this content through a picture that has arrows, text, layers, etc. demonstrating the flow or steps of how something works. There was not a modality effect with the content-related paragraphs because the readers had enough learning time to process the information. With high picture novelty for the learner, the picture-related paragraph had a modality effect regardless of auditory or visual text presentation. This type of research is important in multimedia engineering education because physics is foundational in engineering principles and picture-related paragraphs can enhance learning.

In a study by Schmidt-Weigand et al. (2010), through self-paced instruction, each screen had spoken text with written text visible until the next screen appeared. A limitation of the study was the duration and complexity of the instruction. Tabbers et al. (2004) found no modality effect in a learner-controlled study with the average instructional time of one hour. These studies
suggest future research to examine the amount and complexity of content (audio and visual) to test no modality effect in self-paced instruction (Schmidt-Weigand et al., 2010). Recent research from Cheon, Crooks, and Chung (2014) assessed the relationship between the segmenting and modality principals. They found that segmenting enhances retention and transfer when compared to modality alone.

The differences between this study and the previous studies on modality is that control systems engineering content is a complex topic and an actual course assignment which creates a level of motivation for the students much greater than that found in a typical research study in which the participant does not necessarily have a real need to understand the content. In addition, this intervention focuses on student’s choice of text versus narration as they view the diagrams and equations in the online presentation.

Summary

This chapter reviewed the rise of online learning in higher education and the literature related to relevant concepts, theories and principles that are central to the study’s intent to promote student success in engineering education. In the next chapter, the methodology of the study will be reviewed along with the design of the intervention used in this study.
Chapter 3

Method

Based on principles proposed by Mayer and Sweller to reduce cognitive load, the hypothesis underlying this study was that giving students the option of selecting to expose text explanations in a complex lesson would enhance self-efficacy and performance. Therefore, the treatment group was given the option to reveal text explanations, and this option was not available to the control group. In other words, the purposes of this study were: (1) to determine whether students, while learning abstract and complex technical content in an authentic setting, prefer narration only or text and narration, and (2) to investigate possible relationships between student’s self-efficacy and performance. The study answered the following research questions.

RQ1: Does allowing students an option to reveal text enhance performance?
RQ2: Are different patterns of optional text use associated with differences in student performance?
RQ3: Is the student’s use of optional text related to student self-efficacy?
RQ4: Are students’ engineering learning self-efficacy and performance highly correlated?

This chapter will describe the participants’ characteristics, explain the design and development of the materials, and provide a description of the procedures used in the study.

Participants

There were seventy-four senior undergraduate students and one graduate student enrolled in the course, “Experiments in Nuclear Reactor Physics” at a northeastern research university. Thirty-seven of the students were assigned to the Text (T) group (option to “view or not to view text” on each screen with audio occurring simultaneously) and thirty-seven were assigned to the
No Text (NT) group (audio only with graphics simultaneously-no text choice) based on their alphabetical placement on the class rooster.

Upon completion of the tutorial, it was determined that eight students did not complete the tutorial and seven students did not provide consent. After eliminating these students, thirty remained in the Text group and twenty-nine remained in the No Text group. The academic majors and number of semesters these students had completed are displayed in Table 3.1.

Table 3.1. Participants’ Academic Majors and Semesters Completed

<table>
<thead>
<tr>
<th>Program Plan</th>
<th>Level</th>
<th>Text</th>
<th>No Text</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering - Mechanical Engr (BS)/Nuclear Engineering (BS)</td>
<td>11th Sem (&gt;149.0 Credits)</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10th Sem (134.1-149.0 Credits)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9th Sem (119.1-134.0 Credits)</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8th Sem (104.1-119.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Mechanical Engr (BS)/Nuclear Engineering (BS)/Economics (UMNR)/Entrepreneurship &amp; Innovation (UMNR)</td>
<td>11th Sem (&gt;149.0 Credits)</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (MS)</td>
<td>Engineering - Nuclear Engineering (MS)</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)</td>
<td>11th Sem (&gt;149.0 Credits)</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>10th Sem (134.1-149.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>9th Sem (119.1-134.0 Credits)</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>8th Sem (104.1-119.0 Credits)</td>
<td>7</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>7th Sem (89.1-104.0 Credits)</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Computer Engineering (UMNR)/Engineering Mechanics (UMNR)</td>
<td>8th Sem (104.1-119.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Environmental Engineering (UMNR)</td>
<td>10th Sem (134.1-149.0 Credits)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Engineering Leadership Development (UMNR)</td>
<td>8th Sem (104.1-119.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/History (UMNR)</td>
<td>9th Sem (119.1-134.0 Credits)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Engineering Mechanics (UMNR)/Management (UMNR)</td>
<td>10th Sem (134.1-149.0 Credits)</td>
<td>1</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>
The study contrasted two online control system tutorials: version one allowed the student to select to see the text or not to see the text for each screen and version two did not provide the student with this choice, Table 3.2. Both tutorials were accessed through the university’s learning management system and were available to the students over a forty-eight-hour period. This created an authentic online setting and open book environment.

Table 3.2. Study Parameters

<table>
<thead>
<tr>
<th>Program Plan</th>
<th>Level</th>
<th>Text</th>
<th>No Text</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Engr Mechanics (UMNR)</td>
<td>9th Sem (119.1-134.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Mathematics (UMNR)</td>
<td>10th Sem (134.1-149.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Planetary Sen &amp; Astro (UMNR)</td>
<td>8th Sem (104.1-119.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Nuclear Engineering (BS)/Theatre (UMNR)</td>
<td>9th Sem (119.1-134.0 Credits)</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Students</strong></td>
<td><strong>30</strong></td>
<td><strong>29</strong></td>
<td><strong>59</strong></td>
<td></td>
</tr>
</tbody>
</table>
Material

The online modules built using Storyline Articulate served two purposes: as a tutorial to teach the topic of control systems and as an intervention for this study (see Appendix A). The researcher conducted a thorough content analysis to understand the content and used instructional design principles to create effective instruction to provide a meaningful learning experience for the students. This deep design effort along with the incorporation of multimedia principles had the potential to create a learning solution that would be effective to teach this complex technical information.

The prerequisites for this online tutorial were the ability to use MATLAB/Simulink functionality and experience in solving differential equations. These pre-requisites are standard skills for an engineering student. MATLAB is a technical programming environment used by engineers. For additional simulation capability, the add-on to MATLAB is Simulink that has functions to build a model. The instructor provided instruction on Simulink prior to the delivery of the tutorial. In addition, there had been a few homework assignments using Simulink.

The ADDIE model was the instructional design model used as a guide for creating the tutorials. This provided a foundation that enabled the addition of an element to track time and effort progress. This transformed the original ADDIE model into an enhanced ADDIE model, Figure 3.1. A new phase to the model provided a dedicated timeframe for the research, discovery and collection of information about the content, learner, environment, evaluation, and technology. This deep gathering of information provided a more comprehensive review of these five elements that was helpful in the analysis phase followed by the design, development, implementation, and evaluation phases in the building the online modules. The x-axis shows the time involved in the project and the y-axis shows the amount of effort involved for the
researcher, instructor and multimedia specialist. The workflow for this study was not ideal as shown in the actual workflow (orange dotted line) against the ideal workflow line (black). The first phase, as seen in Figure 3.1, “Investigate,” proceeded on schedule. However, the analysis phase took more time than anticipated because of the breakdown the technical content and cohesive analysis. This caused the actual workflow to be elevated in the design phase that caused a more dramatic increase in the development phase. Because of the nature of the complex technical content, there were more modifications than expected throughout the project. This resulted in content additions and modifications resulting in design changes within the modules. Also important was to design the tutorial to reach low-mid performers and, as well, to avoid creating an expertise reversal with high performers. All of these factors contributed to a heavy iterative process that delayed progress. The entire process ensued a plethora of collaborative face-to-face and email conversations with the instructor. It took time to bridge the understanding between face-to-face instruction and online instruction.

![Ideal Workflow](image)

Figure 3.1. Enhanced ADDIE Model
Enhancement based on the ADDIE model elements (Molenda, 2003).
Another important element was the focus on a systematic approach to the design effort. Based on my experience as a systems engineer and instructional designer, I created a systematic design process based on item complexity. In conjunction with the course professor, I identified content that would most likely be challenging. The verification for this process was derived from the reactions of study team. Overall, the process was functional but supplemental guidance material should be created to aid others in replicating the process. First, it was important to initiate design on the content that would most likely be very challenging to design (teach the student via online) as seen in the order of completion at the left bottom of Figure 3.2. In addition, the subject matter expert was involved at the beginning of each design element as indicated by the blue vertical lines.

The purpose of using the systematic design process was to tackle the most complex design element first (very challenging-orange circle). In this case, the complexity occurred in figuring out how to design in order to teach students what happens when adding a controller to
the water tank model and explaining each part and the impact to the system as a whole. There were four views to show the physical insight into how the liquid height responds with respect to time by applying an equation. In addition, discussions occurred with the instructor to add a fifth view that showed all the cases. The constraint, which compounded the challenge, was the limited space on a screen to hold the diagrams, equation, plots, and text that were required to convey the content. Figure 3.3 shows the final design of five tabs across the screen so the student could view each label to understand at a glance all the potential system responses corresponding to a change in the control system. This is called a gain, “Nominal, Gain=0.1, Gain-0.5, Gain =1, Gain=2 and All Cases,” and each tab is clickable to view the corresponding text and plot for continuity. This was important so the student could appreciate how changing one number effects how a system can respond. Having looked at this component early in the process helped determine whether we were using an appropriate technology/authoring tool to explain the content in an effective manner. If this design was near completion before the technology (training software, Learning Management System, and data tracking) was selected, and the technology was not going to meet the needs of the students and study, a lot of time and effort would have been lost.
Figure 3.3. Very Challenging Design Element

The next step was to identify the challenging content-green circle and continue toward the content considered easiest in the design process. For example, Figure 3.4 was one of the easiest to design “What is a System? This design provided a realistic explanation of a variety of systems by having the student click each picture for a brief definition.
Using this method and including the instructor in the design reviews early in the process were factors that increased the effort and time in the workflow. The assumption is that future use of such a systematic design process would become more fluid as a designer gains experience focusing first on the complex design element and collaborating with a subject matter expert, this proficiency should decrease effort and time. The navigation through the workflow effort should balance with the goals of the learning solution. Simultaneously, the instructor and designer need to consider the quality of the learning solution, effort and time when building multimedia learning products.

During the iterative lesson design process, formative evaluations resulted in constructive feedback. After the completion of the tutorials, a summative evaluation with engineering
students of equivalent development levels provided additional feedback. Lastly, a functionality
test of the system (tutorial interfacing within the learning management system) verified the
timing, operations of the tutorial and the data collection system.

Storyline Articulate 2, a software product used to author online learning modules, was
used to build the two online tutorials. First, the Text-group tutorial was completed, and then
modified and saved to become the No Text-group tutorial. Both tutorials incorporated the
multimedia learning principles of pre-training, segmenting and modality as shown in Tables 3.3
– 3.5.

Table 3.3 describes the pre-training principle use, reason, and consideration for key
information and prior knowledge used throughout the tutorial. This principle guided the front-
end of the lesson that contained definitions, examples, and graphics to provide context on how
control systems fit into the systems approach of engineering. This part of the lesson was a
simple-to-complex approach of delivering the content to the student to build upon each previous
topic within the lesson. For example, the topics of What is a System?, What is a Control
System?, Types of Control Systems, and Design Process: Identify Controls, Model a Control
System, Select a Controller, Determine Parameters, and Test Control System prepared the
student for the lesson on how to build a control system. The pre-training principle application
through definitions, examples and graphics continued throughout the tutorial in conjunction with
the segmenting principle.
Pre-Training Principle
application to Control System tutorial

<table>
<thead>
<tr>
<th>Use</th>
<th>Reason</th>
<th>Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the beginning, present key terms, parts, characteristics and concepts in a logical order.</td>
<td>- This will provide the students without prior knowledge with a baseline of knowledge.</td>
<td>To build this prior knowledge, during content analysis discuss the salient features with the subject matter expert.</td>
</tr>
<tr>
<td>At the beginning, present a succinct system level view of the topic to gain interest and connect with prior knowledge.</td>
<td>A high-level overview of the function and purpose of the &quot;system&quot; that is being taught will prepare the student.</td>
<td>- Think about causes and effects within the system. - Enable the students to learn the relationships of the parts that create the whole.</td>
</tr>
</tbody>
</table>

Table 3.4 describes the segmenting principle use, reason, and consideration for scaffolding and pauses used throughout the tutorial. This principle guided the amount of content on each slide in respect with the diagrams and equations throughout the tutorial. The learner-control navigation enabled movement through the lesson at the students own pace by using the “next” button. This feature supported the design principle of segmentation by dividing a continuous lesson into small chunks of information (Clark & Mayer, 2008). Segmenting was relevant to the complex technical content because all the details needed to be explicit to the learner. Previous studies by Leahy and Sweller, (2011) were used as guidelines when determining the amount of text per segment. Segmenting provided an incremental approach that enabled the student to click forward and backward using the “Back Step” and “Next Step” buttons within each screen to read or hear each segment of text and/or equations. In addition, the forward and backward arrows manipulated the progression of the screens. The segmenting and
modality principles worked in tandem throughout the design of this tutorial. For example, the amount of graphics, equations and text on a screen can affect the modality principle, which is an instructional guideline to minimize cognitive load in an effort to increase learning by presenting words as narration rather than text on a screen.

Table 3.4. Segmenting Principle of Multimedia Learning

<table>
<thead>
<tr>
<th>Segmenting Principle</th>
<th>Use</th>
<th>Reason</th>
<th>Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present key concepts and elements gradually by scaffolding toward the main concept.</td>
<td>This provides incremental knowledge of the main points building toward the main concept.</td>
<td>Through a content analysis, discern the appropriate content and length of each segmentation.</td>
</tr>
<tr>
<td></td>
<td>Create learning pauses and checks to guide the students learning.</td>
<td>These segments provide natural pauses for the learner to absorb the new information.</td>
<td>Count the number of concepts and interactions to determine number of segments.</td>
</tr>
</tbody>
</table>

Table 3.5 describes the modality principle use, reason, and consideration for audio and visuals used throughout the tutorial. This principle guided the use of visuals (diagrams/equations/written text) and narration (spoken text) throughout both tutorials. The text and diagrams/equations were in close proximity on each screen to adhere to the research on segmentation. The written and spoken text were identical to avoid extraneous cognitive load.
Table 3.5. Modality Principle of Multimedia Learning

<table>
<thead>
<tr>
<th>Use</th>
<th>Reason</th>
<th>Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use narration for complex technical content.</td>
<td>With diagrams, equations, text and narration this could overload both the visual and auditory channels.</td>
<td>Enable the student to discern when it is helpful to have text on the screen and when to stop the narration.</td>
</tr>
<tr>
<td>New technical information so both narration and text might support learning.</td>
<td>A learner has limited prior knowledge with content/topic.</td>
<td>Bring together diagrams, equations, and language to support mid-low performers.</td>
</tr>
<tr>
<td>The use of narration, text and visuals is a balanced approach on the screen to support novices yet avoid an expert reversal effect.</td>
<td>The complexity of the content warrants the use of both segmenting and modality to enhance retention and transfer of knowledge.</td>
<td>Expert reversal effect: Enhancements negatively affect high performers.</td>
</tr>
</tbody>
</table>

In addition to applying these principles, the tutorial design considered the possible differences in the experience and knowledge levels among engineering students. The concepts ranged from simple-to-complex by scaffolding the content for the student. Information was in context for less experienced students without producing the expert reversal effect described by Kalyuga, Ayres, Chandler, and Sweller (2003) for other students. For example, an expert reading the same information in written text and diagram format would find the information redundant. However, for a novice, having both the written and diagram formats can be most helpful and can diminish cognitive load. With this in mind, the decision was to create a linear presentation of the content along with formatting that emphasized key points rather than repeating the content in different formats throughout the tutorial.
During project meetings, the instructor described the control system content and relationship to physics. The use of picture-related paragraphs in the design was important to the integration of the concepts throughout the tutorial. Figure 3.5 is an example of a picture-related paragraph as it explains each element, how to identify and develop various performance specifications such as rise time, settling time, and stability boundary separately and, as well, how they integrate.

**Figure 3.5. Picture-Related Paragraph, Performance Specifications**

At the onset of the study the notion was to simultaneously design and develop the tutorial to both create effective instruction for the students and tailor the tutorial (with text option) to evaluate the impacts of the treatment.

The instructor for this course was the content expert. The initial commitment by the instructor was to provide a power point of the lesson and knowledge assessment. This power point initiated the content analysis phase of the project that required frequent sessions with the
instructor to verify the accuracy and flow of the content. This created the first tutorial that consisted of graphics, equations and narration by the instructor. This version was for the No Text group. Next, we used this version of the tutorial and added the text segments. This became the intervention for the Text group. Note for both groups the narration occurred simultaneously as the graphics, equations, and text were displayed on the screen. The instructor provided a sense of efficacy through the narration by providing detailed descriptive examples of concepts and rationale for why certain decisions are made when solving control system design problems.

According to Hoy and Davis (2006), a teacher can influence how well students learn if they have a strong sense of efficacy because they tend to be comfortable using new methods to meet the needs of students. As well, the application of the personalization principle was a guide for the instructor to use an informal yet confident tone during the recording sessions (Clark, 2014).

Upon completion of the tutorial, the instructor recorded the audio for the narration using the audio feature in Articulate. The recording process provided the opportunity for the instructor to read a segment aloud and click to the next segment. The sound of the click was a signal to students to go to the next segment. At the end of the lesson, the instructor also narrated a simulation (video) that demonstrated how to build a model in Simulink. While completing the tutorial, the researcher simultaneously developed the self-efficacy survey and collaborated with the instructor to complete the pre and post-tests. The following describes the survey and tests.

Pre-survey: At the start of the tutorial, each student viewed one screen that comprised five questions regarding their self-efficacy (see Appendix B). The purpose of this self-efficacy assessment was to estimate the level of students’ belief in their ability to perform tasks prior and post lesson in control systems. It was important to know if the lesson itself enabled students to gain self-efficacy related to the engineering activities required to complete the assessment. To
provide an adequate number of responses for variance to support reliability yet maintain individual energy in answering the items, the researcher decided to use a five-point Likert scale to measure self-efficacy (Cox, 1980). In addition, the scale was comprised of “can do” questions to determine the students’ beliefs in their capabilities to perform the tasks associated with the lesson (Bandura, 2006b).

Pre-Test: Each student was shown fifteen multiple-choice test questions (one per screen) to assess prior knowledge of the physics and modelling tasks that would be required to complete the control system lesson (see Appendix C). The instructor provided the test to the researcher. Through reviews, modification of the test occurred to remove ambiguity and emphasize certain points. In addition, an item traceability process ensured each question related to the lesson content. Each item was traced back to the content to ensure the concept was covered in the tutorial with the proper amount of instruction for the learner to answer the question. The purpose of the knowledge tests was to determine students’ knowledge and understanding related to the lesson topic.

Two different tests assessed students’ conceptual understanding and their ability to apply the concepts in the lesson. The pre and post-test assessment of knowledge consisted of 15 multiple-choice items with four alternatives to ascertain the level of prior knowledge and learning related to the topic area of control systems. The pre-test items 1-8 were the same as the post-test. The shuffled items avoided familiarity. Items 9-15 were different in the pre-and post-tests, as the pre-test assessed the student’s knowledge and the post-test assessed the student’s application using Simulink to derive their answers to the items.
Data Log

The purpose of the data log was to discover if there were patterns in the control or treatment groups that might affect students’ motivation or academic performance. For example, if a group showed a significant amount of back button usage or length of time completing the lesson, it might indicate a lack of confidence and/or might improve learning.

The patterns of students’ screen visits, segment visits, and text option selections were collected in the SCORM report. This provided how many clicks per slide, use of text per screen, how many times a screen was visited to measure review cycle, and where and how often students chose the option to display text. In addition, the time stamp for each record showed the amount of time students spent in the tutorial.

The online lesson consisted of forty-three screens. The focus of the lesson was to enable students to understand how to build an automatic controller for a simple system.

Specifically:

- how a control system operates,
- how to design a control system,
- how to build a mathematical model of a system to be controlled,
- how to conduct a sanity check to ensure the model behaves properly, and
- how to apply a controller to a system.

As previously stated, the lesson had a pre-training component that explained the key terms and characteristics to prepare students for the new concepts. The main section used an example graphic of a water tank input and output flow system with and without a controller to demonstrate the operation of a system and application of conservation of mass. The static
visuals were the diagrams, equations, and charts throughout the tutorial. The concepts explained incrementally in the lesson were the:

(a) completion and verification of a control system without a controller,

(b) time constant to gauge how quickly the system responds,

(c) controller and valve resistance to gain insight into how the liquid height responds with respect to time by applying an equation, and

(d) use of a proportional-plus-integral controller.

Specifically, the lesson provided a simple-to-complex flow of information with the learning objective to prepare the student to build a model of a control system in Simulink. Throughout, the students observed a contextual example of using a water tank and basic concepts such as system response characteristics, types of control systems, and typical applications. Next, the students mathematically modelled the water tank system to gain insight on how the specific system responds to input, i.e., input mass flow rate. Upon mathematically modelling the system based upon review of a simulation, the instructor provided the response characteristics for a variety of system input mass flow rates by changing the control system parameters in the system response. The students viewed these effects through diagrams, charts, and equations.

Throughout the lesson, knowledge checks, including multiple-choice and matching activities enabled the student to determine their understanding at that point in time. At the end of the lesson, a video with narration demonstrated how to build and model a control system using Simulink, Figure 3.6. Carlsen and Andres (1992) found that students learning electrical circuits with a simulation led to better conceptual models compared to use of only test-based instruction. Furthermore, a study on the transfer of statistical concepts showed the use of simulation in
training increased undergraduate student performance (Lane & Tang, 2000). In this study, the students reviewed a simulation of building a control system and used Simulink to build their own simulation of a control system to answer the post-test.

![Simulink Review Video Screen](image)

Figure 3.6. Simulink Review Video Screen

Post-survey: After the lesson, the students completed the same 5-point scale to measure self-efficacy.

Post-Test: Students were shown fifteen multiple-choice test questions (one per screen) to assess their prior knowledge of the physics and modelling tasks that would be required to complete the control system lesson (see Appendix D). The first eight items were the same as the pre-test. However, items nine through fifteen were different because they assessed the students’ application of the concepts versus conceptual knowledge, as was the case in the pre-test. The instructor provided this test to the researcher. Multiple reviews modified the test to remove ambiguity and emphasize certain points. In addition, an item traceability ensured each question related to the lesson content.
The researcher proposed using a different pre- and post-test to the instructor, to classify the test exercises using the taxonomies: knowledge, comprehension, application, and analysis (Bloom, 1956/1986). The reason for having the last seven test questions different in the pre- and post-tests was to differentiate between the student’s recall of facts and concepts related to physics and modeling of control systems and their ability to apply what they had learned to interpret and draw a model of their own. As well, in the post-test the students analyzed a physical problem that was a mathematical representation of a water tank and synthesized the controller in Simulink. This provided testing at different levels of expertise for both knowledge (control systems and physics) and skills (use of Simulink).

Procedure

The researcher initiated the study by approaching the instructor of a nuclear engineering course to determine if there was interest in enhancing a particular lesson within the course. The instructor selected a control systems lesson. Based on discussions, the researcher and instructor decided that an online learning approach, adding an online component via this lesson to traditional lecturing would be effective for the control systems lesson. In the past, the instructor had used a Power Point-supported lecture and a multiple-choice test. The dissemination of the online control system tutorial was through the learning management system, resulting in an authentic online and open book environment.

With the interest of the instructor and a plan to disseminate the tutorial, the analysis phase began to determine the feasibility of designing an interactive lesson. The goal was to provide an active learning component for the students to learn and meet the requirements of this research, including the potential for collecting data on the self-efficacy and knowledge gained by the
students during the study. Once this was established, the formation of research study team that comprised the academic advisor, instructor and researcher. All participants on the study team completed the “Protecting Human Subject Participants” training. The exempt determination by the Office for Research Protection allowed for both the recruitment and consent process at the end of the control system tutorial (see Appendix E).

With the research protection approval and the content analysis progressing, we turned to the challenge of creating a system that would compile a data log that would count and collect the number and purpose of selections each student would use on each screen and within the segments within screens. The challenge was to ensure the system would report each student action. Upon research and discussions with technology experts on Articulate (the software tool used to create the treatments), we used a series of variables to store student actions taken, for example, to store which answer was selected for a quiz question. Articulate is compliant with the technical standards of the Sharable Content Object Reference Model (SCORM). This standard for software enables sharing of online information across systems. For example, a SCORM compliant file such as Articulate enables the transfer of data into a Learning Management System such as ANGEL, Blackboard or Canvas. A SCORM 2004 v4 report contained the data collected for this study.

Therefore, upon completion of the module, a SCORM report would display each variable. For example, the recording process for a student's actions from screen-to-screen was as follows. When a student viewed screen number 1.34, and clicked the "next button" to go to the next screen, the value of the variable labeled "NextButtonSlide1.34" increases from 0 to 1. If the user returned to screen 1.34 and clicks the next button again, the variable would increase from 1 to 2. The recording process for a student's actions from segment-to-segment was as follows.
When a student viewed Screen 1.34 that has three text segments for the student to read, and clicked the "Next Step" button to view the first text segment, the value of the variable labeled "NextStepButtonSlide1.34.1" increased from 0 to 1. When they clicked the "Next Step" button to view the second text segment, the value of the variable labeled "NextStepButtonSlide1.34.2" increased from 0 to 1. When they clicked the "Next Step" button to view the third text segment, the value of the variable labeled "NextStepButtonSlide1.34.3" increased from 0 to 1. If the student decided there was too much information on the screen and wanted to focus on a specific segment, they could opt to click the "Back Step" button that removed each text segment. The value of the variable labeled "BackStepButtonSlide1.34.2" increased from 0 to 1.

With the data log system in place, the next step was to contact the Distance Education office located in the College of Engineering. A multimedia specialist from this office worked with us to upload a test version of both tutorials into the learning management system. Once the tutorials were functioning properly, we tested the SCORM report feature. This process took several weeks because of troubleshooting the interface between Articulate and the Learning Management System.

With everything in place, and a week prior to the study, the instructor informed the students of the online tutorial on control systems. The instructor told the students how to access the online tutorial through the learning management system. This tutorial was taking the place of an in-class laboratory and the students had 48 hours to complete the tutorial. The test at the end of the tutorial counted as a homework grade worth 3% of the course grade. At this point, the students did not know this was part of a research study.

In summary, the students took a self-efficacy survey comprised of five Likert scale questions and fifteen multiple-choice questions that assessed prior knowledge. Next, they
completed the control system lesson that included a video simulation that demonstrated by the instructor on how to use physics to build a control system using Simulink functionality. Lastly, the students completed the post-test comprised of fifteen multiple-choice questions (which included using Simulink functionality to answer the last seven questions) and required that the students interact with the software. The students were not able to return to the lesson once they initiated the test. In addition, the same five self-efficacy Likert scale used in the pre-test was administered to assess self-efficacy. In order to have an authentic environment for the study, the consent screen was presented at the end of the lesson before the test, as displayed in Figure 3.7.

Figure 3.7. Consent Screen
At the end of the tutorial, a result screen appeared which displayed the student’s grade for the lesson and expressed appreciation for their participation in the study.

**Experimental Design**

This study examined whether students, while learning abstract and complex technical content, preferred narration only versus text and narration, and investigated possible relationships between students’ self-efficacy and performance. The “narration-only” control group viewed the baseline diagrams and equations and heard the narration,” as depicted in Figure 3.8.

![Mathematical Model](image)

**Figure 3.8.** Screen for the Control Group: Narration Only
Once the tutorial for the control group was complete, this version was the foundation to prepare the tutorial for the treatment group. The treatment group received the baseline diagrams and equations as well as both narration and the option to display supplementary text, that the student could “turn-on” (make visible) for each of the forty-three screens after viewing the diagrams, equations and narration baseline screens. Figure 3.9 shows the screen with the text option box and Figure 3.10 shows the screen with the text. This version provided the student with a graphic narration format and verbal content in a relatively simple and brief manner, designed based on the results from Leahy and Sweller (2016), which suggest that when multiple elements of content are interrelated and not understood in isolation, the shorter, audio-visual format is the best option.

This enables the student to view the content in written form if the complexity and length of the lesson is challenging for the student that may result in a cognitive overload (Leahy & Sweller, 2016). The cognitive load is student dependent; therefore, this written text option will be manipulated by the student in this version of the intervention.
Figure 3.9. Treatment Group Screen: Text Option Box
The overall process for this study, Figure 3.11, displays an outline of the pre-survey and test, lesson, and post-survey and test for this study. The pre-survey was a self-assessment of the student’s self-efficacy in relation to the tasks they would need to use for the lesson and the pre-test was a multiple-choice assessment that measured the student’s prior knowledge of applying physics to an engineering control system problem. Next, the student proceeded to the complete the lesson. Lastly, the post-survey was a self-assessment of the student’s self-efficacy and the post-test was a multiple-choice assessment that measured the student’s new knowledge of applying physics to an engineering control system problem.
The study design in Table 3.6 displays a simple comparative quasi-experimental study with participants assigned to two groups (Creswell, 2014). This table provides further description of the study’s components such as group details, description overview, lesson elements, types of modality effect, number of participants, and list of measurements. Both groups were administered the pre-survey and post-test, and different forms of the treatment were provided to the two study groups. Pre- and post-surveys assessed students perceived self-efficacy before and following the online tutorial lesson. To assess achievement, the pre-test and post-test determined prior knowledge and new knowledge acquired through interaction with the lesson.
Table 3.6. Independent Variable

<table>
<thead>
<tr>
<th>Independent Variable = Treatment (Learner Control of Text)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two levels: Control &amp; Treatment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Groups</th>
<th>Control Group</th>
<th>Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self-Paced</td>
<td>Self-Paced</td>
</tr>
<tr>
<td></td>
<td>Modality-No Text</td>
<td>Modality-Text Option</td>
</tr>
</tbody>
</table>

| Description | An online tutorial where the modality is visual + narration throughout the tutorial. | An online tutorial where the modality is visual + narration throughout the tutorial with the option of exposing written text on each screen, as needed by the student. |

<table>
<thead>
<tr>
<th>Lesson</th>
<th>a. Introduction: Read linear text with graphics</th>
<th>a. Introduction: Read linear text with graphics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b. Simultaneously, watch and listen to the Water Tank animation with differential equations.</td>
<td>b. Simultaneously, watch and listen to the Water Tank animation with differential equations. Upon completion of each screen, the student had the option to turn on the written text which appeared in the appropriate sequence on the screen</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modality</th>
<th>- Static Visuals: Diagrams, Charts, and Equations</th>
<th>- Static Visuals: Diagrams, Charts, and Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Narration</td>
<td>- Narration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Text, Option to reveal written text option on each screen</td>
</tr>
</tbody>
</table>

| Undergraduates | n=29 | n=30 |

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Self-Efficacy Likert Scales (pre/post)</th>
<th>Self-Efficacy Likert Scales (pre/post)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Knowledge Assessment (pre/post)</td>
<td>Knowledge Assessment (pre/post)</td>
</tr>
</tbody>
</table>
Table 3.7 highlights the independent and dependent variables along with the research questions and the analysis that will occur to answer the research questions.

Table 3.7. Research Variable, Research Question and Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Research Question</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent</td>
<td>RQ1. Does allowing students an option to reveal text enhance performance?</td>
<td>To investigate differences between the treatment and control groups, t-tests were used to identify any differences in the pre-test, the post-test, and the change between pre- and post-test scores.</td>
</tr>
<tr>
<td></td>
<td>RQ2. Are different patterns of optional text use associated with differences in student performance?</td>
<td>The data log was mined to identify different patterns of use. The No Text and Text groups’ patterns of use throughout the tutorial were compared.</td>
</tr>
<tr>
<td>Dependent</td>
<td>RQ3. Is the student’s use of optional text related to student self-efficacy?</td>
<td>As might be expected among senior undergraduate engineering students, the data was not normally distributed. The answer to this question was obvious following the observation of the patterns of use.</td>
</tr>
<tr>
<td></td>
<td>RQ4. Are students’ engineering learning self-efficacy and performance highly correlated?</td>
<td>Pearson’s correlation was used to assess the relationship between self-efficacy and performance.</td>
</tr>
</tbody>
</table>
**Measures**

Table 3.8 displays the seven categories of measurements for this study.

**Table 3.8. Summary of Measures**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Efficacy Pre</td>
<td>Likert Scale</td>
</tr>
<tr>
<td></td>
<td>-5 item self-efficacy survey</td>
</tr>
<tr>
<td>Self-Efficacy Post</td>
<td>Likert Scale</td>
</tr>
<tr>
<td></td>
<td>-5 item self-efficacy survey (Same as pre)</td>
</tr>
<tr>
<td>Pre Test</td>
<td>Multiple Choice</td>
</tr>
<tr>
<td></td>
<td>-Items 1-8, based on the tutorial, and items (9-15) tested students’ understanding of the concepts</td>
</tr>
<tr>
<td>Post Test</td>
<td>Multiple Choice</td>
</tr>
<tr>
<td></td>
<td>-Items 1-8, based on the tutorial, and items (9-15) tested student’s ability to apply the knowledge they learned using Simulink software. The concepts are the same as the Pre-Test.</td>
</tr>
<tr>
<td>Screen Visits</td>
<td>Data Log maintained by the Learning Management System</td>
</tr>
<tr>
<td>Segment Visits</td>
<td>Data Log maintained by the Learning Management System</td>
</tr>
<tr>
<td>Text Option Selection</td>
<td>Recorded the actions taken by the learners to reveal text explanations.</td>
</tr>
<tr>
<td>(Treatment Group Only)</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 4

Results

This chapter presents the results of the data analyses designed to answer the research questions and support or reject the hypotheses. The following research questions guided this study:

RQ1: Does allowing students an option to reveal text enhance performance?

RQ2: Are different patterns of optional text use associated with differences in student performance?

RQ3: Is the student’s use of optional text related to student self-efficacy?

RQ4: Are students’ engineering learning self-efficacy and performance highly correlated?

Reliability

Self-efficacy

The self-efficacy instrument, consisting of a series of five point Likert scales, provided the pre and post-test data gathered during the study. Cronbach’s alpha determined a reliability of .89.

Knowledge Test

Two of the fifteen multiple-choice questions yielded a correct response of 98%. Therefore, questions #1 and #4 were eliminated from the test. The resulting reliability coefficient was .73. Cronbach’s alpha ranges from 0 to 1.00. For a classroom test, a reliability
coefficient of .70 or higher is considered appropriate (Wells & Wollack, 2003). An item analysis determined the difficulty and reliability of the knowledge test. First, an item-difficulty index was calculated by totaling the number of correct answers for each item divided by the total number of students taking the test. This provided a percentage correct for each item. Through this item-difficulty index, we found the post-test had two multiple-choice questions with correct responses of 98%. These questions were removed in preparation for reliability testing. Because there were modifications to the original test, reliability was unknown, and there was not an opportunity to re-test. Therefore, implementation of Cronbach’s alpha determined the reliability of the post-test. This test correlated each item on the test with every other item to calculate the internal consistency reliability ranging from 0.00-1.00. Since each group viewed a different lesson, there was a Cronbach alpha calculation for each post-test: Text post-test was .71 and the No Text post-test was .75.

**RQ1: Does allowing students an option to reveal text enhance performance?**

**Means**

Table 4.1 shows means and standard deviations for the treatments, no text and text.

Table 4.1. Pre and Post Test Means

<table>
<thead>
<tr>
<th></th>
<th>Knowledge Pre-Test</th>
<th>Knowledge Post-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
</tr>
<tr>
<td>No Text</td>
<td>29</td>
<td>52.8</td>
</tr>
<tr>
<td>Text</td>
<td>30</td>
<td>53.8</td>
</tr>
</tbody>
</table>
Table 4.2 shows no statistically significant difference between the treatments on the pre-tests $t(56) = -0.242, p = 0.405$.

Table 4.2. Pre-Test Differences

<table>
<thead>
<tr>
<th></th>
<th>Pre-Test</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>52.78514589</td>
<td>53.84615385</td>
<td></td>
</tr>
<tr>
<td>Variance</td>
<td>239.7469904</td>
<td>330.5447868</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>29</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-0.241604753</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P(T&lt;=t)$ one-tail</td>
<td>0.404984482</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.672522303</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P(T&lt;=t)$ two-tail</td>
<td>0.809968963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.003240719</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 shows no statistically significant difference between the two treatment post-tests means $t(57) = -0.157, p = 0.437$. We found no evidence that allowing students to reveal text made an impact on performance as measured by a 15-item multiple choice test.
Table 4.3. Post-Test Differences

<table>
<thead>
<tr>
<th>Post-Test</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>75.07161804</td>
<td>75.8974359</td>
</tr>
<tr>
<td>Variance</td>
<td>420.9644679</td>
<td>390.668571</td>
</tr>
<tr>
<td>Observations</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-0.157367735</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.437755586</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.672028888</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.875511171</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.002465459</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4 shows means and standard deviations for the change in score differences.

Table 4.4. Pre and Post Test Difference

<table>
<thead>
<tr>
<th>Pre and Post-Test Difference</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Text</td>
<td>29</td>
<td>22.3</td>
<td>21.5</td>
</tr>
<tr>
<td>Text</td>
<td>30</td>
<td>22.1</td>
<td>21.1</td>
</tr>
</tbody>
</table>
Table 4.5 shows no statistically significant difference between the treatments pre and post-tests. The difference between these means was not statistically significant (t(57) = 0.041, p = 0.483) so the null hypothesis was accepted.

Table 4.5. Change Score Difference

<table>
<thead>
<tr>
<th>Pre &amp; Post Test</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>22.28647215</td>
<td>22.05128205</td>
</tr>
<tr>
<td>Variance</td>
<td>482.8702014</td>
<td>468.2037679</td>
</tr>
<tr>
<td>Observations</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>0.041409859</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.483556933</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.672028888</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.967113865</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.002465459</td>
<td></td>
</tr>
</tbody>
</table>

RQ2: Are different patterns of optional text associated with differences in performance?

Patterns

Out of the 30 students in the Text condition, twenty-seven students in the Text option group chose to view text on all screens, two students chose to view text on all screens after the first, and one student did not select text on any screen. Because there was only one dominant pattern, it was not possible to compare different patterns of use and their potentially differential effects on learning and self-efficacy.
Review

Table 4.6 shows the mean and standard deviation of the frequency of review activity for each group.

Table 4.6. Review Activity Means

<table>
<thead>
<tr>
<th></th>
<th>Review Activity with Outliers</th>
<th>Review Activity without Outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>No Text</td>
<td>29</td>
<td>15.9</td>
</tr>
<tr>
<td>Text</td>
<td>30</td>
<td>22.6</td>
</tr>
</tbody>
</table>

Table 4.7 reveals the comparison between groups on the frequency of review steps. For example, how many times did a learner go back to review the content within each screen, or to the previous screen. No statistically significant differences between the treatments were identified, in the original analysis with outliers (t(45) = -0.690, p = 0.247), nor in an additional analysis that removed one outlier from the Text Option group with two hundred fifty reviews recorded. This additional analysis without the outliers (see Figure 4.8) still showed no statistically significant differences between the treatments (t(45) = -0.689, p = 0.246) so the null hypothesis was accepted.
Table 4.7. Review Step Difference with Outliers

<table>
<thead>
<tr>
<th>Review Activity</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>15.89655172</td>
<td>22.60000</td>
</tr>
<tr>
<td>Variance</td>
<td>628.2389163</td>
<td>2181.8345</td>
</tr>
<tr>
<td>Observations</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>t Stat</td>
<td>-0.689973557</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.246877003</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.679427393</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.493754006</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.014103389</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.8. Review Step Difference without Outliers

<table>
<thead>
<tr>
<th>Review Activity</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>15.89655172</td>
<td>15.1071429</td>
</tr>
<tr>
<td>Variance</td>
<td>628.2389163</td>
<td>358.543651</td>
</tr>
<tr>
<td>Observations</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>t Stat</td>
<td>0.134459208</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.446779276</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.674689154</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.893558552</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.006646805</td>
<td></td>
</tr>
</tbody>
</table>
Time

Table 4.9 shows the mean and standard deviation of the time to complete for each group without outliers. There were two outliers in the Text group (more than two standard deviations from the mean) in terms of time to complete, and no outliers in the No Text group. These anomalies may have represented learners who did not end the lesson properly or did other activities while the lesson was operational.

Table 4.9. Time Mean with and without Outliers

<table>
<thead>
<tr>
<th></th>
<th>Time (min.) with Outliers</th>
<th>Time (min) without Outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>No Text</td>
<td>29</td>
<td>86.0</td>
</tr>
<tr>
<td>Text</td>
<td>30</td>
<td>95.4</td>
</tr>
</tbody>
</table>

Table 4.10 reveals the comparison of each group’s time that shows no statistically significant difference between the treatments with outliers included \((t(56) = -0.720, p = 0.237)\). An additional analysis with the outliers excluded (see Table 4.11) still showed no statistically significant differences between the treatments without outliers \((t(55) = 0.053, p = 0.478)\) so the null hypothesis was accepted.
Table 4.10. Time Difference with Outliers

<table>
<thead>
<tr>
<th>Time (min) with Outliers</th>
<th>Time</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>85.96551724</td>
<td>95.36666667</td>
<td></td>
</tr>
<tr>
<td><strong>Variance</strong></td>
<td>2074.534483</td>
<td>2963.550575</td>
<td></td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>29</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>Hypothesized Mean Difference</strong></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>df</strong></td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t Stat</strong></td>
<td>-0.72035612</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P(T&lt;=t) one-tail</strong></td>
<td>0.237150991</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t Critical one-tail</strong></td>
<td>1.672522303</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P(T&lt;=t) two-tail</strong></td>
<td>0.474301982</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t Critical two-tail</strong></td>
<td>2.003240719</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.11. Time Difference without Outliers

<table>
<thead>
<tr>
<th>Time (min) without Outliers</th>
<th>Time</th>
<th>No Text</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>85.96551724</td>
<td>85.35714</td>
<td></td>
</tr>
<tr>
<td><strong>Variance</strong></td>
<td>2074.534483</td>
<td>1596.386</td>
<td></td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>29</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td><strong>Hypothesized Mean Difference</strong></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>df</strong></td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t Stat</strong></td>
<td>0.053658161</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P(T&lt;=t) one-tail</strong></td>
<td>0.478700974</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t Critical one-tail</strong></td>
<td>1.673033965</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P(T&lt;=t) two-tail</strong></td>
<td>0.957401948</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t Critical two-tail</strong></td>
<td>2.004044783</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RQ3: Is the student’s use of optional text related to student self-efficacy?

Means

Table 4.12 shows means and standard deviations for the self-efficacy change.

Table 4.12. Pre and Post Self-Efficacy Mean

<table>
<thead>
<tr>
<th>Difference</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Text</td>
<td>29</td>
<td>1.96</td>
<td>0.36</td>
</tr>
<tr>
<td>Text</td>
<td>30</td>
<td>1.83</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Comparison of the two treatments on changes in scores on the self-efficacy Likert scale shows no statistically significant difference between the treatments (t(116) = -1.42, p = 0.016) so the null hypothesis was accepted.

RQ4: Are students’ engineering learning self-efficacy and performance highly correlated?

Table 4.13 displays the difference between the pre and post-treatment knowledge test score and pre and post-treatment self-efficacy survey means and standard deviations for each of the treatments. The no text group shows a correlation coefficient of .21, and the text group shows a correlation coefficient of -0.02. Both of these correlations were extremely weak.
Table 4.13. Pre and Post Knowledge and Self-Efficacy Difference

<table>
<thead>
<tr>
<th></th>
<th>Knowledge</th>
<th>Self-Efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Post Test</td>
<td>Pre-Post Test</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>Difference</td>
</tr>
<tr>
<td>n</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>No Text</td>
<td>29</td>
<td>21.80</td>
</tr>
<tr>
<td>Text</td>
<td>30</td>
<td>22.54</td>
</tr>
</tbody>
</table>

Figure 4.1 displays the difference between each student’s pre/post knowledge (dependent variable) and their pre/post self-efficacy (independent variable). The scatterplot shows the weakness of these correlations, we reject the hypothesis that student’s self-efficacy and performance were correlated.
Figure 4.1. Regression of Knowledge and Self-Efficacy
Chapter 5

Discussion

Mayer and Pilegird (2014) state, “further research is needed to determine the conditions for the modality principle and how they relate to cognitive theory” (p. 339). Thus, an intervention based on the theories of cognitive load theory (Sweller, 1999) and cognitive theory of multimedia learning (Mayer, 2014a) was developed and implemented as an online tutorial for a senior-level engineering class. This tutorial was administered in a realistic setting, as part of a course in which the students’ course grades were based partially on the results of the tutorial post-test. In this study, we were able to discover if student’s option to reveal text would enhance performance by asking the question “Does allowing students an option to reveal text enhance performance?” We found no evidence that allowing students to reveal text made an impact on performance as measured by a 15-item multiple-choice test. Since all but one learner chose to reveal text on the screen while simultaneously hearing the narration, this made the treatment, “written text/narration/visuals,” very different when compared to the control group, “no written/narration/visuals.” Therefore, we connect this to the existing literature that discusses modality in relation to “written text/narration/visuals and no written text/narrative/visuals” as reviewed in Chapter 2, Tables 2.4 and 2.5. This research by Leahy and Sweller (2011, 2016) outlines how using various conditions such as self-paced, learner-paced, short text on screen, long text on screen, and complex content with various age groups and how these conditions impacted modality. This study is unique because, we went beyond these conditions in an attempt to look at modality and its effect on learning in real-world conditions. Also in this study, the
treatment group was asked if they wanted written text on each screen rather than the designer/researcher making that decision. Because of the modality principle research, we explicitly asked the learners so we could know their choices. Based on the modality research, we hypothesized that if a learner choose to display text it might be detrimental to their performance. Their choice of displaying text, perhaps because of the open environment and not having a time constraint on the lesson did not seem to affect their performance.

With the next research question, “Are different patterns of use associated with differences in student performance?” we found that all of the learners in the text-option group, except one, choose to view all available text; thereby, demonstrating a choice for text over audio alone. We did not hypothesize that everyone would chose the option to reveal text, and although there was no evidence that selecting the text improved performance, there was also no evidence that it produced the detrimental effect predicted by the modality principle. Because there was only one dominant pattern, it was not possible to compare different patterns of use and their effects on learning.

In a study by Schmidt-Weigand et al. (2010), through self-paced instruction, each screen had spoken text with written text visible until the next screen appeared. A limitation of the study was the duration and complexity of the instruction. Tabbers et al., (2004) study found no modality effect in a learner-controlled study with the average instructional time of one hour. In this study, the learners had two days as much time as they wanted to complete the lesson and post-test (homework). This difference may explain our results, no evidence that either treatment was better or worse. Because this was both a research study and course graded lesson in a course, we did not want to place a tight constraint on the time, which might impede learning. However, based upon the average length of time to complete the lesson and post-test per learner,
a future study with this amount and complexity of content could apply a constraint of 3 hours. These studies suggest future research to examine the amount and complexity of content using audio and visuals to test for modality effects in self-paced instruction (Schmidt-Weigand et al. 2010). Recent research from Cheon, Crooks and Chung (2014) assessed the relationship between the segmenting and modality principals. They found that segmenting enhances retention and transfer when compared to modality alone. For the treatment group in this study, we segmented the text and abided by the recommended number words per screen (10-to-23) based upon the work by Leahy and Sweller (2016). Each screen in this study had narration simultaneous with the written text appear on the screen that was controlled by the learner. Compared to the control group that did not have any written text, there was no evidence of differences between the treatments. Relating back to the Leahy and Sweller (2016) study, the audio/visual with no written text did slightly better than the visual only with written text. We suspect that this may be due to the openness of this study, which removed controls that were used in previous studies.

Lastly, we asked two questions in this study related to self-efficacy (1) Does the student’s use of an option to reveal text influence self-efficacy?, and (2) Are students’ engineering learning self-efficacy and performance correlated? For both questions, we discovered no evidence that differences existed. We anticipated that self-efficacy for both questions would have risen because of the active learning approach in the intervention and the use of principles of pre-training and segmentation. However, in retrospect, it is possible the learner’s self-efficacy as senior undergraduates at this point was high and unlikely to change in the instance of this lesson. There might be a change in self-efficacy if the study was measuring a complete design task that
includes several processes in devising a system (Carberry, et al. 2010), or in longer-term interventions, since self-efficacy is a trait that is developed over time.

Seth, Tangorra, and Ibrahim (2015) suggests, “future work in investigating the gains in self-efficacy and correlations between efficacies in the problem-solving and engineering design” (p.7). This is important because in order to perform at a certain level, an engineer needs a certain amount of self-efficacy. Because of the continuous interest in self-efficacy in engineering education, this study provided the opportunity to understand if there would be an impact to student’s self-efficacy relating to their control system lesson.

This study focused on areas of discussion that surfaced from past research regarding instruction with both visual and auditory text that had been viewed as detrimental when complex content and self-pacing were part of the learning situation.

The first area of focus was modality. In an attempt to verify or challenge previous research on the modality effect conducted in laboratory settings (Mayer, 2014), the premise of this study was that students learning complex technical content, such as engineering content involving mathematics and physics, might perform better when using “text” with graphics and narration instead of having “no text” with graphics and narration. One finding was that given the option of selecting text or no text, students overwhelmingly chose to have the text appear, despite the modality principle’s prediction that this would be detrimental. The absence of evidence of an effect might be related to the fact that senior engineering students are accustomed to relying on reading and active processing to learn, rather than hearing content and viewing graphs and equations. Upon review of the results in this study, there was not a statistically significant difference in performance on the 15-item test. This should not be interpreted as evidence that these treatments are equivalent, but rather there is no evidence, based on this study
that they are different. A study by Tennyson and Park (1980) of learners’ use of learning strategies such as using examples and review in context found the learners who need these strategies the least, tended to use them the most. In addition, learners with low levels of motivation often chose not to use the opportunity to use these learner-controlled strategies to meet their learning needs (Yang, 1987).

The second area of focus was observing students’ patterns regarding choice of text, amount of review activity, and length of time the tutorial was open, and the impact of these variables on student performance. The choices students made when opting for text revealed a single navigation pattern, with almost all students choosing to view all available text. The review activity was defined as the number of times a learner went back to review the content within each screen or to the previous screens. Because there were no different patterns of use, there were not patterns associated with differences in student performance. This finding aligns with the study conducted by Hooper, Temiyakarn, and Williams (1993) that showed no differences between the learner-controlled and program-controlled groups for achievement in relation to length of time.

The last area of investigation was the possible association between the option to reveal text and self-efficacy. There was not a significant difference in the self-efficacy scores between no text and text groups. Therefore, allowing students an option to select text did not have a statistically significant influence on self-efficacy. This is not too surprising as self-efficacy is a trait, which develops over time. Therefore, it is not likely to be influenced by a single lesson. In addition, there was a low correlation between self-efficacy and performance. Neither finding was a surprise as the results of Chyung et al. (2010) were similar. However, they proposed that future studies with a larger sample size might show different results. It would be valuable to
examine students’ self-efficacy in a longitudinal study to determine if they can solve problems similar to the engineering problems that were the focus of this study.

There were several differences between this study and previous studies conducted in classroom environments (Leahy, Sweller, 2011 & 2016). For example, this was (a) complex content involving physics for undergraduate engineering seniors, (b) learner-paced navigation, (c) open environment, and (d) a course assignment.

Based on results from Leahy and Sweller that indicate long and complex written and auditory text was not easy to process, the design of the online intervention for the study incorporated the segmenting principle to ensure both modalities, no text and text, were shorter in length. This design element might have influenced the results of this study if the result was instruction in either treatments, no text or text that provided an instructional challenge that was conducive for learning. Both the size and complexity of information are critical factors in how much information can be stored in working memory. How much is too much for the cognitive load of very capable learners, such as those engaged in engineering majors? This warrants further research.

**Limitations and Recommendations for Future Research**

Several limitations arose throughout the study. Because this was the first application of an online tutorial in an engineering setting for this course and the students’ learning was primary compared to the results of the study, it was decided to deliver the tutorial in an open book format. Based on the average length of completion time of approximately 1 hour and 30 minutes, with 3 hours being the longest for a few students, the suggestion is a time constraint of three hours for a future study. In addition, due to a small population size it was determined to have only two
groups, “no text” and “text option with narration.” A future study adding a third group with “text only” and no narration for comparison could prove informative. Such modifications could surface different results.

The instructor agreed to participate in the study, but his time was limited throughout the study. The time factor is extremely important when designing and developing online material in higher education. Most likely, the notes and PowerPoint from an instructor will need thorough segmenting and sequencing which leads to discussion and communication efforts that are time-intensive.

Lastly, building the tutorial in Storyline Articulate had constraints. For example, the data from the assessments were in a SCORM report that is static and not transferrable to excel for manipulation. The recommendation is to use HTML5 that provides a seamless flow for the content along with the ease of interfacing with a database to collect the data.

Although Mayer found significant differences in modality studies, others found significant difference in another direction, e.g., no modality effect. This study did not find significant differences. Further research on modality in an authentic setting using content that is required for the learner is recommended based on this and previous studies. With an increase in the use of online education in higher education institutions over the past twenty years, the need for effective and efficient multimedia learning is paramount for individuals of all age and performance levels (Allen & Seaman, 2014). It would be valuable to replicate this study using other complex engineering content with more subjects across various courses and levels. In addition, the replication or modification of this study, using different content domains such as chemistry, botany, physics or mathematics could reveal complementary or contradictory results.
A modification could be using interventions with audio and no text and only text to find out if it is necessary to have the audio.

More insight could be obtained by using both qualitative and quantitative assessments that could provide a more in-depth view of what is happening while the learner is interacting with the lesson to understand how people learn. These types of interventions could incorporate cognitive multimedia learning principles in new ways and introduce new methods to contribute to the field of multimedia learning.

In summary, continued research on the modality principle and relationships among the various multimedia learning principles, affects learning design would further help the understanding of how people learn. This type of research might reveal new evidence-based human cognitive learning processes that will support eLearning design and further our understanding of how humans learn rather than focusing on the incorporating the newest technology.
Appendix A
Tutorial Screen Capture

Introduction to the Control System Lesson
Both the No Text (NT) and Text Option (T) group had the “same” screens.

Introduction to Control Systems Tutorial
NucE451
Experiments in Nuclear Reactor Physics
FALL 2016

Please type your first and last name.

Tutorial Content
The contents of this tutorial are:
1. Surveys
2. Control System Lesson
3. Surveys
4. Homework

What will you learn?
The intent of the questions is to inform you of your perceived confidence level with the concepts you will be learning throughout this tutorial.

Content Survey
The intent is for you to understand your level of prior knowledge related to control systems.

Screens 1.6-1.20 displays the Content Pre-Test. The test is available upon request.
Welcome, Student

This tutorial will enable you to understand how to build an automatic controller for a simple system.

Specifically, you will learn...

- how a control system operates,
- how to design a control system,
- how to build a mathematical model of a system to be controlled,
- how to conduct a sanity check to ensure the model behaves properly, and
- how to apply a controller to a system.

---

1.22.1

Physics

The control system model in this tutorial will implement fundamental physical relationships.

Select each button.

- [ ] Conservation of Mass
- [ ] Conservation of Energy
- [ ] Conservation of Momentum

1.22.2

Physics

The control system model in this tutorial will implement fundamental physical relationships.

The force acting on an object is equal to the mass (m) of an object times its acceleration (a).

- [ ] Conservation of Mass
- [ ] Conservation of Energy
- [ ] Conservation of Momentum

1.22.3

Physics

The control system model in this tutorial will implement fundamental physical relationships.

V is voltage, I is current, R is resistance. Voltage equals current times resistance.

- [ ] Conservation of Mass
- [ ] Conservation of Energy
- [ ] Conservation of Momentum

1.22.4

Physics

The control system model in this tutorial will implement fundamental physical relationships.

As Albert Einstein identified, mass (matter) and energy are equivalent, and cannot be created or destroyed only transformed. When energy is in the form of mass, we can use its conservation to develop a dynamic differential equation of a device or system (e.g., a liquid tank).

- [ ] Conservation of Mass
- [ ] Conservation of Energy
- [ ] Conservation of Momentum

1.22.5

Physics

The control system model in this tutorial will implement fundamental physical relationships.

Energy cannot be created or destroyed. It can be transformed to another form of energy. E.g., from Kinetic energy to Potential energy.

- [ ] Conservation of Mass
- [ ] Conservation of Energy
- [ ] Conservation of Momentum
1.22.6

Physics
The control system model in this tutorial will implement fundamental physical relationships.

\[ F = ma \]

\[ \text{Work} \]

Conservation of Mass

Conservation of Energy

Conservation of Momentum

Momentum is a quality of an object, and is equal to its mass times its velocity. When an object is hit by another object, momentum is transferred depending on the masses of the two (or more) objects – but the total momentum of the system of objects is, like its energy, conserved.

1.23.1

In addition, we will be using Differential Equations and MATLAB/Simulink.

Differential Equations

MATLAB/Simulink Software

In addition, we will be using Differential Equations and MATLAB/Simulink.

1.23.3

Differential Equations

MATLAB/Simulink Software

This is a very common mathematics and simulation software package that allows us to model a system’s dynamic behavior associated with differential equations and a way to automatically control it – all in one environment.

1.24.1

What is a System?

A system is a connection of parts that form a complex whole. For example, an airplane and a human are both systems. Many systems contain control systems which provide reliability and precision. Select the graphics to learn more.

1.24.2

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1.24.4

What is a System?

A system is a connection of parts that form a complex whole. For example, an airplane and a human are both systems. Many systems contain control systems which provide reliability and precision. Select the graphics to learn more.

1.25.1

What is a Control System?

A control system manages and regulates the behavior of systems, equipment, and machines. It does this by using sensor measurements, processing these measurements, and changing the position of devices that can physically change the system, known as actuators. An example of an actuator is a valve used to change the rate of fluid flowing in a pipe. The below objects contain control systems.

1.25.2

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What is a Control System?

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![The nuclear reactor contains control systems such as power control, where the control rods get repositioned so the reactor can produce and maintain a specified power level. The feedback sensor is the power measuring device, or nuclear instrument.]

1.25.6

What is a Control System?

A control system manages and regulates the behavior of systems, equipment, and machines. It does this by using sensor measurements, processing these measurements, and changing the position of devices that can physically change the system, known as actuators. An example of an actuator is a valve used to change the rate of fluid flowing in a pipe. The below objects contain control systems.

![Sensors are used to measure quantities of interest, and provide feedback information needed to control a device or system. A thermocouple is an example of a temperature sensor that converts temperature to an electrical signal.]

1.25.7

What is a Control System?

A control system manages and regulates the behavior of systems, equipment, and machines. It does this by using sensor measurements, processing these measurements, and changing the position of devices that can physically change the system, known as actuators. An example of an actuator is a valve used to change the rate of fluid flowing in a pipe. The below objects contain control systems.

![An actuator is a device that changes a quantity necessary to maintain control of a system. An example of an actuator is a motor that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion.]

1.26

Types of Control Systems?

There are two types of automatic control systems: Open Loop and Closed Loop. Within each control system there is a controller that regulates the system.

![Controller Types of Control Systems

<table>
<thead>
<tr>
<th>Controller</th>
<th>Types of Control Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>At a sink, a person turns a single valve so that water flows into a pot.</td>
<td></td>
</tr>
<tr>
<td>Open Loop: manually operates by turning a valve; The temperature is essentially uncontrollable. Not Exact!</td>
<td></td>
</tr>
<tr>
<td>At a sink, a person turns valve(s) multiple times so that water flows into the sink in preparation for dish washing.</td>
<td></td>
</tr>
<tr>
<td>Closed Loop: manually operate the hot/cold water valves multiple times, feeling the water temperature feedback signals to achieve the desired water temperature. Marginally Exact!</td>
<td></td>
</tr>
<tr>
<td>A dishwasher contains a control system which automatically sets temperature, type of wash and dry based on the operator’s selections.</td>
<td></td>
</tr>
<tr>
<td>Automatic: the machine controls the temperature and operation of the dishwasher without any manual input. Exact!</td>
<td></td>
</tr>
</tbody>
</table>

1.27

Activity

Which type of control system utilizes feedback signals to maintain a desired operating point?

- Closed Loop
- Automatic Loop
- Automatic and Closed Loop
- Open Loop

1.28.1

Design Process

Next, we will describe the design process that is used when designing a control system. This is an iterative process which means at any step you might need to repeat previous steps to ensure you are...

- Building the Right system and Building the system Right.

Select each button:

1. Identify Controls
2. Model Control System
3. Select Controller
4. Determine Parameters
5. Test Control System
1.28.2

**Design Process**

Next, we will describe the design process that is used when designing a control system. This is an iterative process which means at any step you might need to repeat previous steps to ensure you are... **Building the Right system and Building the system Right.**

1. Identify what you want to control.
2. Model the system you want to control.
3. Select the type of controller you would like to use to control the system.
4. Determine the control system parameters that will provide the appropriate response.
5. Test the control system to ensure appropriate behavior.

1.29

**Build a Model**

This analysis may use some of the analytical methods you have learned in your courses, e.g., differential equations.

Other times the model may be too complicated and you may have to use numerical methods, i.e., dynamic simulation using a software package such as MATLAB with the add on SIMULINK.

After you have built your model, ask the question: “Does its behavior correspond to reality?”

This “sanity check” requires you to do some analysis of your model. For example, if the physical system is inherently stable and your model is not, you will need to go back and redevelop your model.

1.30

**Select the Controller**

**Step 1 - Select the type of controller** you need to keep in mind that not every problem needs the same type of controller.

**Step 2 - Apply the controller** to your specific problem and perform further analysis with the controller “in the loop.”

A cruise controller maintains the speed of a car without a person adjusting the position of the accelerator petal.

**Step 3 - If the control system does not behave as you have anticipated, you will have to either redesign the controller** (Step 1), refine your mathematical model (Step 2), or you may have to do both several times. This is known as performing design iterations.

1.31.1

**Identify What to Control**

As we build a model for a control system of a water tank, we will identify and develop various performance specifications.

Click each performance specification to learn more.

- **Rise Time**
- **Setting Time**
- **Stability Boundary**

Basically, determine what you want the system to *do* early in the design process by identifying the performance specifications.

Next we will use trial and error to accomplish the final design which will be tested via modeling.

1.31.2

**Identify What to Control**

**Rise Time**

Rise time is defined as the time for the liquid height to go from an initial value to the steady state final value.

**Setting Time**

Setting time is the time required for an output to reach steady state following some input change, i.e., in the case of the water tank a step increase in water flow.
Identify What to Control

Stability Boundary

Determine the Parameters of the Controller

Now that we have the controller, we need to determine the parameters because they will affect the response of the controlled system.

- For example, the parameters in a proportional + integral, controller are \( K_p \) and \( K_i \). If the values of \( K_p \) and \( K_i \) are not correct, the controlled system will not respond as intended.

- The parameters \( K_p \) and \( K_i \) may be accomplished via trial and error or analytical techniques.

_test the Control System

Once you’ve designed and implemented the control system in a modeling and simulation tool (e.g., Matlab and Simulink), you’ll change variables such as the magnitude of the input to the system in your model. In addition, observe the closed-loop response of the automatically controlled system – does the controlled system behave the way you want?

If not, you may have to adjust the controller gains (“tune” the controller gains) and rerun your simulation. You may have to repeat this process several times to get a response that’s acceptable.

Activity

Drag the steps in the design process into the correct order.

1. Model the system you want to control
2. Select the type of controller you would like to use to control the system
3. Identify what you want to control
4. Determine the control system parameters that will provide the appropriate response
5. Test the control system to ensure appropriate behavior

Navigation of the Water Tank

Now that we have learned about the types of Control Systems (Open, Closed, Automatic) and the process to “design and build” a control system, let’s view a control system design for a Water Tank.

This section of the lesson has narration. Turn on your audio.

The following screens will display a step-by-step animation of modeling a Water Tank.

Do Not Forget to Use these Buttons.
At this point, the No Text (NT) and Text Option (T) group had “different screens.”
NT1.37.2

Mathematical Model of the Water Tank - Applying Conservation of Mass

\[ \frac{d m_{\text{Tank}}(t)}{dt} = \dot{m}_1(t) - \dot{m}_2(t) \]

NT1.38.1

Mathematical Model - Applying Conservation of Mass (cont.)

\[ \frac{d m_{\text{Tank}}(t)}{dt} = \dot{m}_1(t) - \dot{m}_2(t) \]

NT1.38.2

Mathematical Model - Applying Conservation of Mass (cont.)

\[ \dot{m}_2(t) = K \sqrt{\Delta p} \]

\[ \dot{m}_1(t) = K' \sqrt{h(t)} \]

T1.37.2

Mathematical Model of the Water Tank - Applying Conservation of Mass

At the moment, we'll only concern ourselves with gaining some physical insight into the dynamic behavior of our system - so we'll neglect the control input and just keep mass as input mass flows.

\[ \frac{d m_{\text{Tank}}(t)}{dt} = \dot{m}_1(t) - \dot{m}_2(t) \]

Now draw a control volume around the system like you typically do in fluids and apply conservation of mass...

T1.38.1

Mathematical Model - Applying Conservation of Mass (cont.)

\[ \frac{d m_{\text{Tank}}(t)}{dt} = \dot{m}_1(t) - \dot{m}_2(t) \]

T1.38.2

Mathematical Model - Applying Conservation of Mass (cont.)

In general, the mass flow leaving the tank is related to the pressure across the valve...

\[ \dot{m}_2(t) = K \sqrt{\Delta p} \]

Given that the tank is open to the atmosphere and the pipe at the bottom of the tank empties to atmosphere, we can express the mass flow in terms of the tank height...

\[ \dot{m}_1(t) = K' \sqrt{h(t)} \]

To use some of the solution methods you studied in your differential equations class, we'll have to linearize this expression which gives...

\[ \dot{m}_1(t) \approx \frac{h(t)}{R_{\text{valve}}} \]
NT1.39.1

Mathematical Model - Applying Conservation of Mass (cont.)

Substitution of:

\[ m_{\text{Tank}}(t) = p_{\text{Tank}} \cdot \text{Volume}_{\text{Tank}}(t) \]

and \( h_{\text{i}}(t) = \frac{h_0}{R_{\text{tank}}} \)

\[ \rho_{\text{Tank}} \cdot A_{\text{Tank}} \cdot \frac{dh(t)}{dt} + \frac{h(t)}{R_{\text{tank}}} = -\bar{m}_i(t) \]

Validation of Mathematical Model - Applying Conservation of Mass

T1.39.1

Mathematical Model - Applying Conservation of Mass (cont.)

Substitution of:

\[ m_{\text{Tank}}(t) = p_{\text{Tank}} \cdot \text{Volume}_{\text{Tank}}(t) \]

and \( h_{\text{i}}(t) = \frac{h_0}{R_{\text{tank}}} \)

\[ \rho_{\text{Tank}} \cdot A_{\text{Tank}} \cdot \frac{dh(t)}{dt} + \frac{h(t)}{R_{\text{tank}}} = -\bar{m}_i(t) \]

Validation of Mathematical Model - Applying Conservation of Mass

NT1.40.1

Validation of Mathematical Model - Applying Conservation of Mass

T1.40.1

Validation of Mathematical Model - Applying Conservation of Mass
NT1.40.2

**Validation of Mathematical Model: Applying Conservation of Mass**

\[
\frac{dh(t)}{dt} = \frac{\dot{m}_i(t)}{\rho \cdot A_{\text{tank}} \cdot R_{\text{cable}}} - \frac{h(t)}{\rho \cdot A_{\text{tank}} \cdot R_{\text{cable}}}
\]

A step increase in \( \dot{m}_i(t) \) gives a positive \( \frac{dh(t)}{dt} \) and \( h(t) \) increases.

A step change in \( h(t) \) increasing \( A_{\text{tank}} \) tends to decrease \( \frac{dh(t)}{dt} \)

A step increase in \( h(t) \) along with closing the valve \( A_{\text{tank}} \rightarrow 0 \) to infinity results in a positive \( \frac{dh(t)}{dt} \) and \( h(t) \) increases indefinitely.

T1.40.2

**Validation of Mathematical Model: Applying Conservation of Mass**

We need to look at the model and verify if things "go in the right direction." For our simple example, we can take the differential equation model and change some of the system parameters...

\[
\frac{dh(t)}{dt} = \frac{\dot{m}_i(t)}{\rho \cdot A_{\text{tank}} \cdot R_{\text{cable}}} - \frac{h(t)}{\rho \cdot A_{\text{tank}} \cdot R_{\text{cable}}}
\]

Here are some examples of "quick and dirty" model checks...

A step increase in \( \dot{m}_i(t) \) gives a positive \( \frac{dh(t)}{dt} \) and \( h(t) \) increases. ✓

A step change in \( \dot{m}_i(t) \) increasing \( A_{\text{tank}} \) tends to decrease \( \frac{dh(t)}{dt} \)

A step increase in \( h(t) \) along with closing the valve \( A_{\text{tank}} \rightarrow 0 \) to infinity results in a positive \( \frac{dh(t)}{dt} \) and \( h(t) \) increases indefinitely. ✓

NT1.41.1

**Let’s find a Solution for Specified Mass Flow Input**

\[
\dot{m}_i(t) = M_i
\]

T1.41.1

**Let’s find a Solution for Specified Mass Flow Input**

\[
\dot{m}_i(t) = M_i
\]

NT1.41.2

**Let’s find a Solution for Specified Mass Flow Input**

\[
\dot{m}_i(t) = M_i
\]

T1.41.2

**Let’s find a Solution for Specified Mass Flow Input**

If the mass flow in increases as a constant, say \( M_i \), then using the method you learned in your Differential Equations class, we can find the height as a function of time \( h(t) \).

1. Rearrange the differential equation and insert the change in the mass flow \( \dot{m}_i \).

\[
\frac{dh(t)}{dt} = \frac{\dot{m}_i - M_i}{\rho \cdot A_{\text{tank}} \cdot R_{\text{cable}}}
\]

2. Assume solutions for the transient and forced components of the total response \( h(t) \).

3. Apply initial conditions to obtain the total response. Does it make sense?
NT1.42.1

\[ \tau \frac{dh(t)}{dt} + h(t) = A \dot{m}(t) \]

T1.42.1

\[ \tau \frac{dh(t)}{dt} + h(t) = A \dot{m}(t) \]

Would you like to try this solution?

Yes  No

NT1.42.2

\[ \tau \frac{dh(t)}{dt} + h(t) = A \dot{m}(t) \]

\[ \tau = \rho ARy \]

T1.42.2

A characteristic of the response is the time constant, \( \tau \), which is often used to "gaug e" how quickly a system responds, and to understand how system parameters affect the system's response.

The time constant, \( \tau \) (sec), is the time the system takes to get to 63% of the steady-state value after a step change in the input (in the case of the water tank). \( \tau \) is used to characterize the response characteristics of systems described by first-order differential equations (like the water tank).

\[ \tau = \rho ARy \]

In the case of the water tank, the time constant \( \tau \) is equal to: \( \tau = \rho ARy \)

and can be identified in the level response of the tank when we graph it.

NT1.43

Time Constant

T1.43

Time Constant

Would you like to try this solution?

Yes  No
NT1.45.3

No Control - Change Valve Resistance

\[ h(t) = M_r R_{\text{valve}} (1 - e^{- \frac{t}{R_{\text{valve}}}}) + h(t = 0) \]

50% decrease in Valve Resistance

NT1.45.4

No Control - Change Valve Resistance

\[ h(t) = M_r R_{\text{valve}} (1 - e^{- \frac{t}{R_{\text{valve}}}}) + h(t = 0) \]

Factor of 2 increase in Valve Resistance

NT1.45.5

No Control - Change Valve Resistance

\[ h(t) = M_r R_{\text{valve}} (1 - e^{- \frac{t}{R_{\text{valve}}}}) + h(t = 0) \]

Comparison of 3 Cases

T1.45.3

No Control - Change Valve Resistance

Let's decrease the valve resistance by 50% - the red is how the liquid height in the tank would respond - note that it takes less time for the height to reach its final value. This system responds more quickly and has a shorter time constant.

T1.45.4

No Control - Change Valve Resistance

Let's increase the valve resistance by a factor of 2 - the black is how the liquid height in the tank would respond - note that it takes more time for the height to reach its final value. This system responds more slowly and has a longer time constant.

T1.45.5

No Control - Change Valve Resistance

Here's a comparison of all 3 cases. We see that changes in the design characteristics of the outlet valve (i.e., the valve resistance) affect how quickly the output of this system (the tank height) responds to changes in outlet valve position.
NT1.46.1

No Control - Change Cross-Sectional Area

\[ h(t) = M(RV)_{\text{final}} (1 - e^{-\frac{t}{\text{time constant}}}) + h(t = 0) \]

T1.46.1

No Control - Change Cross-Sectional Area

\[ h(t) = M(RV)_{\text{final}} (1 - e^{-\frac{t}{\text{time constant}}}) + h(t = 0) \]

Would you like to test this idea?

Yes  No

NT1.46.2

No Control - Change Cross-Sectional Area

\[ h(t) = M(RV)_{\text{final}} (1 - e^{-\frac{t}{\text{time constant}}}) + h(t = 0) \]

T1.46.2

No Control - Change Cross-Sectional Area

We found that changing the valve resistance, which is an aspect of the valve design, changed how the liquid height in the tank responded to changes in mass flow input. Now, let's:

- decrease the tank cross-sectional area by 50%.
- increase the tank cross-sectional area by a factor of 2.

\[ h(t) = M(RV)_{\text{final}} (1 - e^{-\frac{t}{\text{time constant}}}) + h(t = 0) \]

Height versus Time: 50% change in Cross-Sectional Area

Now let's decrease the tank cross-sectional area by 50%. The new height in the tank would respond as if it were to reach its final value. We say that this system responds more quickly and has a shorter time constant.

NT1.46.3

No Control - Change Cross-Sectional Area

\[ h(t) = M(RV)_{\text{final}} (1 - e^{-\frac{t}{\text{time constant}}}) + h(t = 0) \]

T1.46.3

No Control - Change Cross-Sectional Area

We found that changing the valve resistance, which is an aspect of the valve design, changed how the liquid height in the tank responded to changes in mass flow input. Now, let's:

- decrease the tank cross-sectional area by 50%.
- increase the tank cross-sectional area by a factor of 2.

\[ h(t) = M(RV)_{\text{final}} (1 - e^{-\frac{t}{\text{time constant}}}) + h(t = 0) \]

Factor of 2 increase in Cross-Sectional Area

Now let's increase the tank cross-sectional area by a factor of 2. The liquid height in the tank would respond as if it were to reach its final value. We say that this system responds more slowly and has a longer time constant.
NT1.46.4

No Control - Change Cross-Sectional Area

\[ h(t) = M \cdot \frac{R_{\text{in}}}{V_{\text{in}}} \cdot (1 - e^{-\frac{t}{\tau_{\text{in}}}}) + h(t = 0) \]

NT1.47.1

What does Height versus Time look like?

NT1.47.2

What does Height versus Time look like?

T1.46.4

No Control - Change Cross-Sectional Area

We found that changing the valve/resistance-which is an aspect of the valve design-changed how the liquid height in the tank responded to changes in mass flow input. Now, let's:

- decrease the tank cross-sectional area by 50%.
- increase the tank cross-sectional area by a factor of 2.

\[ h(t) = M \cdot \frac{R_{\text{in}}}{V_{\text{in}}} \cdot (1 - e^{-\frac{t}{\tau_{\text{in}}}}) + h(t = 0) \]

T1.47.1

What does Height versus Time look like?

T1.47.2

What does Height versus Time look like?

We found that changing the \( R_{\text{in}} \)--which is an aspect of the valve design-changed how the liquid height in the tank responded to changes in mass flow input. We observed how changing a system parameter can change a system's response time.

We reviewed tank height response with:

- decreasing \( R_{\text{in}} \) by 50%.
- increasing \( R_{\text{in}} \) by a factor of 2.
- increasing the water tank cross-sectional area by a factor of 2.
- decreasing the water tank cross-sectional area by 50%.

In summary, changes in system design parameters may affect how the system responds. The control engineer needs to understand this prior to designing and building a control system.
Now let's add a "controller" to the Water Tank system. We'll need something that will open/close the control valve based on "how far" the tank level is from where we want it, i.e., the target.

We'll use something fairly simple, a float-lever mechanism.

The lever reproduces the valve. The amount the valve position changes relative to the change in height is determined by the location of the pivot point.

The pivot closer to the float results in the controller being more sensitive to changes in height. The pivot closer to the control valve results in the controller being less sensitive to changes in height. This pivot location may be considered to set the gain of the controller.
Controller Design: Float-Lever Mechanism

\[ \Delta h(t) = k_0 \cdot h(t) - 0 \]

\[ \Delta V_{\text{position}}(0) \]

\[ \Delta h(t) = h(t) - h(t - 0) \]

\[ \Delta V_{\text{position}}(0) = \frac{L_2}{L_2} \Delta h(t) \]

Controller Design - Block Diagram

A useful tool for presenting and analyzing the complete, closed-loop system. The block diagram, for now, will just look at an example of a block diagram applied to our tank controller closed-loop system.

\[ \Delta h(t) = h(t) - h(t - 0) \]

\[ \Delta V_{\text{position}}(0) \]

\[ \Delta h(t) = h(t) - h(t - 0) \]

\[ \Delta V_{\text{position}}(0) \]

The float-lever mechanism is an example of a "proportional-only" controller. We modify the error in the tank level, \( \Delta h(t) \), by a constant or gain.

The method of enhancing the Proportional-only controller is the Proportional-Plus-Integral controller which will be discussed later.

Controlled Behavior

\[ h(t) = M_0 R_{\text{valve}}(1 - e^{\frac{-t}{T_{\text{on}}}}) + h(t - 0) \]
NT1.51.2

**Controlled Behavior**

\[ h(t) = M_R R_{\text{tank}} (1 - e^{-\frac{t}{\tau_{\text{tank}}}}) + h(t = 0) \]

---

**NT1.51.3**

**Controlled Behavior**

\[ h(t) = M_R R_{\text{tank}} (1 - e^{-\frac{t}{\tau_{\text{tank}}}}) + h(t = 0) \]

---

**NT1.51.4**

**Controlled Behavior**

\[ h(t) = M_R R_{\text{tank}} (1 - e^{-\frac{t}{\tau_{\text{tank}}}}) + h(t = 0) \]

---

**T1.47.1**

**Controlled Behavior**

Now let's build our model with a controller. Let's view plots to gain some physical insight into how the liquid height responds with respect to time by applying this equation throughout this section.

\[ h(t) = M_R R_{\text{tank}} (1 - e^{-\frac{t}{\tau_{\text{tank}}}}) + h(t = 0) \]

---

**T1.51.3**

**Controlled Behavior**

Now let's build our model with a controller. Let's view plots to gain some physical insight into how the liquid height responds with respect to time by applying this equation throughout this section.

\[ h(t) = M_R R_{\text{tank}} (1 - e^{-\frac{t}{\tau_{\text{tank}}}}) + h(t = 0) \]

---

**T1.51.4**

**Controlled Behavior**

Now let's build our model with a controller. Let's view plots to gain some physical insight into how the liquid height responds with respect to time by applying this equation throughout this section.

\[ h(t) = M_R R_{\text{tank}} (1 - e^{-\frac{t}{\tau_{\text{tank}}}}) + h(t = 0) \]
NT1.51.5

Controlled Behavior

\[ h(t) = M_R v_{lim} \left( 1 - e^{-\frac{t}{\tau_R}} \right) + h(t = 0) \]

Tank Level Response with Controller Gain = 1

Gain = 0.1 | Gain = 0.5 | Gain = 1 | Gain = 2 | All Cases

NT1.51.6

Controlled Behavior

\[ h(t) = M_R v_{lim} \left( 1 - e^{-\frac{t}{\tau_R}} \right) + h(t = 0) \]

Tank Level Response with Controller Gain = 2

Gain = 0.1 | Gain = 0.5 | Gain = 1 | Gain = 2 | All Cases

NT1.51.7

Controlled Behavior

\[ h(t) = M_R v_{lim} \left( 1 - e^{-\frac{t}{\tau_R}} \right) + h(t = 0) \]

Tank Level Response with Increasing Controller Gain

Gain = 0.1 | Gain = 0.5 | Gain = 1 | Gain = 2 | All Cases

T1.51.5

Controlled Behavior

Now let's build our model with a controller. Let's view plots to gain some physical insight into how the liquid height responds with respect to time by applying this equation throughout this section.

\[ h(t) = M_R v_{lim} \left( 1 - e^{-\frac{t}{\tau_R}} \right) + h(t = 0) \]

Tank Level Response with Closed-Loop Proportional Control 1. Response of the tank height with respect to time when the mass flow into the tank is doubled. The closed-loop proportional controller has the pivot point on the lever mechanism so that L1 = L2.

Gain = 0.1 | Gain = 0.5 | Gain = 1 | Gain = 2 | All Cases

T1.51.6

Controlled Behavior

Now let's build our model with a controller. Let's view plots to gain some physical insight into how the liquid height responds with respect to time by applying this equation throughout this section.

\[ h(t) = M_R v_{lim} \left( 1 - e^{-\frac{t}{\tau_R}} \right) + h(t = 0) \]

Tank Level Response with Closed-Loop Proportional Control 2. Response of the tank height with respect to time when the mass flow into the tank is doubled. The closed-loop proportional controller has the pivot point on the lever mechanism so that L1 = L2.

Gain = 0.1 | Gain = 0.5 | Gain = 1 | Gain = 2 | All Cases

T1.51.7

Controlled Behavior

Now let's build our model with a controller. Let's view plots to gain some physical insight into how the liquid height responds with respect to time by applying this equation throughout this section.

\[ h(t) = M_R v_{lim} \left( 1 - e^{-\frac{t}{\tau_R}} \right) + h(t = 0) \]

Tank Level Response with Increasing Controller Gain

Gain = 0.1 | Gain = 0.5 | Gain = 1 | Gain = 2 | All Cases
**NT1.52.1**

**Proportional-plus-Integral (PI) Controller**

\[
\text{Controller Output} = K_P e(t) + K_I \int e(t) \, dt
\]

- \(e(t)\) - The difference between where you want the system output to be and where the actual system output is.
- \(K_P\) - Proportional Gain (can be tuned)
- \(K_I\) - Integral Gain
- \(K_P e(t)\) - Proportional Control Action
- \(K_I \int e(t) \, dt\) - Integral Control Action

**T1.52.1**

**Proportional-plus-Integral (PI) Controller**

\[
\text{Controller Output} = K_P e(t) + K_I \int e(t) \, dt
\]

- \(e(t)\) - The difference between where you want the system output to be and where the actual system output is.
- \(K_P\) - Proportional Gain (can be tuned)
- \(K_I\) - Integral Gain
- \(K_P e(t)\) - Proportional Control Action
- \(K_I \int e(t) \, dt\) - Integral Control Action

**NT1.52.2**

**Proportional-plus-Integral (PI) Controller**

\[
\text{Controller Output} = K_P e(t) + K_I \int e(t) \, dt
\]

- \(e(t)\) - The difference between where you want the system output to be and where the actual system output is.
- \(K_P\) - Proportional Gain (can be tuned)
- \(K_I\) - Integral Gain
- \(K_P e(t)\) - Proportional Control Action
- \(K_I \int e(t) \, dt\) - Integral Control Action

**T1.52.2**

**Proportional plus-Integral (PI) Controller**

Proportional plus-Integral (PI) Controller is an improved type of proportional controller that provides integral action. PI controllers provide the low sensitivity necessary to produce stable control as well as the small drift characteristic of a high sensitivity instrument.

On a PI controller, when using a combination of calculations on the difference between where you want the system output to be and where the actual system output is, you can obtain a quick response and \(e(t) = 0\), so that the controller gives you exactly what you want.

\[
\text{Controller Output} = K_P e(t) + K_I \int e(t) \, dt
\]

- \(e(t)\) - The difference between where you want the system output to be and where the actual system output is.
- \(K_P\) - Proportional Gain (can be tuned)
- \(K_I\) - Integral Gain
- \(K_P e(t)\) - Proportional Control Action
- \(K_I \int e(t) \, dt\) - Integral Control Action
Post- Control System Lesson
Both the No Text (NT) and Text Option (T) group had the “same” screens.

Activity
A controller gain is...
- a variable that is dependent on how quickly the process changes.
- the amount of time it takes for a system to respond.
- a constant that can be tuned to affect the response of a closed-loop control system.
- a term used to describe the upper limit of a process variable.

MATLAB/Simulink Review
Demonstration of creating a model of a closed-loop system in MATLAB/Simulink.
- This video will be helpful when completing the homework in this tutorial.

Reaction to the Tutorial
The following questions will not impact your grade.

- The intent is to provide feedback on this tutorial to the instructor for future educational purposes.

Throughout this tutorial, approximately how often did you use the "text button" on each screen to read the text?
- All the time, 100%.
- Majority of the time, 75%.
- Most of the time, 50%.
- Sometimes, 25%.
- Never.

List the three most important things you learned in this tutorial?

What would you recommend “keeping” in this tutorial?

This question will not affect your grade – it is meant to improve the quality of the control tutorial and homework.

Type your text here
1.59

This question will not affect your grade - it is meant to improve the quality of the control tutorial and homework.

What would you recommend “deleting” from this online tutorial?

Type your text here

1.60

Self-Efficacy Survey

The following self-efficacy questions do not impact your grade.

- The intent of the questions is to inform you of your perceived confidence level with the concepts you covered in this tutorial.

1.61

Rate your degree of confidence by selecting 1 to 5 using the scale.

1 = Cannot do  
2 = Maybe can do  
3 = Most likely can do  
4 = Fairly certain can do  
5 = Positively can do

How confident are you that you can apply differential equations to developing a model using software?

1 2 3 4 5

How confident are you that you can learn how to design a control system?

1 2 3 4 5

How confident are you that you can build models using the software package Matlab with the add-on functions of Simulink?

1 2 3 4 5

How confident are you that you can analyze data resulting from a model?

1 2 3 4 5

How confident are you that you can provide adequate and relevant data to communicate your results in writing?

1 2 3 4 5

1.62

Thank You

Thank you for completing this survey.

1.63

Consent

We would like to use the data generated by this tutorial, for education and research purposes.

The intent is to discover in an authentic setting “how students learn best in an online environment” so that future tutorials may be improved to facilitate students’ learning performance.

1.64

Comment

Protocol Title: The effects of student control of modality on learning and self-efficacy in engineering education
Principal Investigator: Denise Turino, 814.865.7419
Academic Advisor: Dr. Kyle Hek, 814.865.7380

You are being invited to volunteer to participate in a research study.

Purpose: The researcher and instructor would like to use the data generated by this tutorial, survey data and homework data for education and research purposes.

Procedure: The student survey and homework data will be collected by the researcher.

Confidentiality: All data will be de-identified by the researcher. The consent information will be released to the instructor, after this semester.

If you have any questions or concerns, you should contact Denise Turino at 814.865.7419. If you have questions regarding your rights as a research subject or concerns regarding your privacy, you may contact the Offices for Research Protections at 814.865.1775.

Your participation is voluntary. You do not have to share any data. If you would like to meet with the PI to discuss the results of the data in general terms, please call 814.865.7419.

Select “consent” to participate in this study.

Select “no consent” if you do not participate in this study.
Homework Instructions

1. You will answer a series of multiple choice questions.
2. Note: you will need to use Simulink to answer some of the questions.
3. Take care in answering each question, you will not be permitted to go back after clicking "submit."

Screens 1.67-1.80 displays the Content Post-Test. The test is available upon request.

Thank You for completing the Control System Tutorial.
Appendix B
Self-Efficacy Likert Scale

Rate your degree of confidence by recording a number from 1 to 5 using the scale

1  2  3  4  5
Cannot do  Maybe can do  Most likely can do  Fairly certain can do  Positively can do

1. How confident are you that you can apply differential equations to developing a model using software?

1  2  3  4  5

2. How confident are you that you can learn how to design a control system?

1  2  3  4  5

3. How confident are you that you can build models using the software package MATLAB with the add-on functions of Simulink?

1  2  3  4  5

4. How confident are you that you can analyze data resulting from a model?

1  2  3  4  5

5. How confident are you that can provide adequate and relevant data to communicate your results in writing?

1  2  3  4  5
Appendix C
Pre-Test Multiple Choice

(Answer key: boldface option)

1. Development of differential equations used to describe dynamic physics systems typically start with:
A. a balance of quantities that equate to the time-rate-of-change of the variable of interest
B. conservation of mass, energy, neutrons, etc.
C. conservation of mass, energy, neutrons, etc. and a balance of quantities that equate to the time-rate-of-change of the variable of interest
D. none of the selections

2. In the development of a liquid tank model, \( \dot{m}_{\text{out}}(t) = K' \sqrt{h(t)} \) was simplified to \( \dot{m}_{\text{out}}(t) = \frac{h(t)}{R_{\text{valve}}} \) (i.e., an Ohm’s Law analogy) in order to:
A. allow for the student to calculate the mass flowing into the tank
B. to simplify the final differential equation so that methods can be used to obtain a solution from your differential equations class
C. none of the selections
D. eliminate the differential equation describing tank water height with respect to time

3. Prior to designing and implementing a control system on a physical device, one should:
A) perform a sanity check on a mathematical model of the device.
B) implement a controller, using trial and error, on the actual device so as to get a feel for how the device responds under automatic control.
C) develop a mathematical model of the system to gain insight as to how the uncontrolled system responds.
D) perform a sanity check on a mathematical model of the device and develop a mathematical model of the system to gain insight as to how the uncontrolled system responds.

4. When performing a “sanity check” on a mathematical model of a component or system, if the system behaves counter-intuitive (e.g. responds in the wrong direction), one likely cause could be:
A) a sign mistake.
B) an aspect of the physical system was omitted or incorrectly modeled.
C) your modeling assumptions were incorrect.
D) all of the selections.

5. The simple controller for tank level presented in the tutorial was an example of:
A) on/off control like the thermostat in your house.
B) integral control to eliminate steady-state error between the actual tank level and the set-point level.
C) a controller that would not eliminate steady-state error between the measured tank level and the set-point level.
D) proportional-plus-integral control.

6. By sliding the pivot point on the float-lever control mechanism, one would:
A) potentially over-compensate for small changes in tank level so the control valve would have large changes in opening for relatively small changes in level.
B) create a gateway into another dimension.
C) incorporate a negative gain into the control system.
D) none of the selections.

7. The float in the float-lever type controller described in the tutorial plays the role of:
A) a gain adjustment.
B) none of the selections
C) a means to measure water density.
D) a feedback signal used to measure current water level.
8. Recall from laboratory session lecture that differential equations, for example \( \tau \frac{dh(t)}{dt} + h(t) = A \dot{M}_{\text{in}}(t) \) (where \( \tau \) is the time constant describing the speed of system response) may be represented by Laplace Transforms. A liquid tank model has a transfer function with the following form \( \frac{\text{Output}(s)}{\text{Input}(s)} = \frac{\text{Height}(s)}{\dot{M}_{\text{in}}(s)} = \frac{2}{2.5s + 1} \). The time constant for this system is:
   A) 2.5
   B) \( \rho A_{\text{tank}} \)
   C) \( \rho A_{\text{tank}}R_{\text{valve}} \)
   **D) 2.5 and \( \rho A_{\text{tank}}R_{\text{valve}} \)**

9. For a proportional controller and a step change in the controller setpoint, the error signal is:
   A) the final steady-state value of the system output.
   B) equal to the controller gain multiplied by the feedback signal.
   **C) the difference between the controller setpoint and the feedback signal.**
   D) none of the selections.

10. For a proportional controller and a step change in the controller setpoint, resulting time to reach steady-state is:
    A) the time constant.
    **B) the time it takes for the system transients to die out.**
    C) independent of the controller gain \( K_p \).
    D) none of the selections.

11. For a proportional controller and a step change in the controller setpoint, the error signal:
    A) increases with increases in controller gain.
    **B) decreases with increases in controller gain.**
    C) controller gain has no effect on the error signal.
    D) increases with decreases in controller gain.

12. As the proportional gain of a controller increases for a step change in controller setpoint, the resulting time to steady-state:
    A) increases
    B) stays the same
    **C) decreases**
    D) changes incrementally

13. Increasing the gain of a proportional controller provides a:
    A) slower response and more error.
    B) slower response and less error.
    C) faster response and more error.
    **D) faster response and less error.**

14. For Proportional-plus-Integral control on a system like the water tank and a step change in setpoint, the steady-state error signal:
    A) goes negative.
    B) gets amplified.
    **C) eventually goes to zero.**
    D) goes positive.

15. Increasing the integral gain of a Proportional-plus-Integral controller:
    A) **potentially causes oscillation.**
    B) result in a more sluggish system response.
    C) have little or no effect if there is no proportional gain.
    D) none of the selections.
Appendix D
Post-Test Multiple Choice

(answer key: boldface option)

1. Development of differential equations used to describe dynamic physics systems typically start with:
   A) a balance of quantities that equate to the time-rate-of-change of the variable of interest
   B) conservation of mass, energy, neutrons, etc.
   C) conservation of mass, energy, neutrons, etc. and a balance of quantities that equate to the time-rate-of-change of the variable of interest
   D) all of the selections

2. In the development of a liquid tank model, \( m_{\text{dot\_out}}(t) = K' \sqrt{h(t)} \) was simplified to \( m_{\text{dot\_out}}(t) = \frac{h(t)}{R_{\text{valve}}} \) (i.e., an Ohm's Law analogy) in order to:
   A) allow for the student to calculate the mass flowing into the tank
   B) to simplify the final differential equation so that methods can be used to obtain a solution from your differential equations class
   C) all of the selections
   D) to eliminate the need to solve a differential equation for \( h(t) \)

3. Prior to designing and implementing a control system on a physical device, one should:
   A) perform a sanity check on a mathematical model of the device.
   B) implement a controller, using trial and error, on the actual device so as to get a feel for how the device responds under automatic control.
   C) develop a mathematical model of the system to gain insight as to how the uncontrolled system responds.
   D) perform a sanity check on a mathematical model of the device and develop a mathematical model of the system to gain insight as to how the uncontrolled system responds.

4. When performing a “sanity check” on a mathematical model of a component or system, if the system behaves counter-intuitive (e.g. responds in the wrong direction), one likely cause could be:
   A) a sign mistake.
   B) an aspect of the physical system was omitted or incorrectly molded.
   C) your modeling assumptions were incorrect.
   D) all of the selections.

5. The simple controller for tank level presented in the tutorial was an example of:
   A) on/off control like the thermostat in your house.
   B) integral control to eliminate steady-state error between the actual tank level and the set-point level.
   C) a controller that would not eliminate steady-state error between the measured tank level and the set-point level.
   D) proportional-plus-integral control.

6. By sliding the pivot point on the float-lever control mechanism, one would:
   A) potentially over-compensate for small changes in tank level so the control valve would have large changes in opening for relatively small changes in level.
   B) create a gateway into another dimension.
   C) incorporate a negative gain into the control system.
   D) none of the selections.

7. The float in the float-lever type controller described in the tutorial plays the role of:
   A) a gain adjustment.
   B) none of the selections
   C) a means to measure water density.
   D) a feedback signal used to measure current water level.
8. Recall from laboratory session lecture that differential equations, for example \( \frac{\text{dh}}{\text{dt}} + h(t) = A \cdot M_{\text{dot in}}(t) \) (where \( \text{tau} \) is the time constant describing the speed of system response) may be represented by Laplace Transforms. A liquid tank model has a transfer function with the following form: \( \frac{\text{Output}(s)}{\text{Input}(s)} = \frac{\text{Height}(s)}{M_{\text{dot in}}(s)} = \frac{2}{2.5s+1} \). The time constant for this system is:

A) 2.5
B) \( \rho \cdot A_{\text{tank}} \)
C) \( \rho \cdot A_{\text{tank}} \cdot R_{\text{valve}} \)
D) 2.5 and \( \rho \cdot A_{\text{tank}} \cdot R_{\text{valve}} \)

For questions 9-13, base your answers on a Simulink model you develop using the below instructions.

From the Continuous library in Simulink use a transfer function block.

From the Mathematics library, use a gain and a summation. Also use a step input from the Source library – this will be your control system setpoint.

You may need a scope and a digital output from the Sink library.

Arrange your model so that it is a closed-loop system, i.e., with the gain and transfer function in the forward loop (transfer function after the gain) and a unity feedback loop.

Note that for all good control engineers go to a “better place” when they pass away, they need to have negative feedback as part of the loop – implement this as a negative input in your simulation.

9. For a proportional gain of 1.0, and a step change from 0 to 5 at 5.0 seconds, the resulting error signal is (choose the closest answer):

A) 0
B) 1.2
C) 1.675
D) 2.3

10. For a proportional gain of 1, and a step change from 0 to 5 at 5.0 seconds, the resulting time to reach steady-state is (choose the closest answer):

A) about 1 second
B) about 3 seconds
C) about 0.1 seconds
D) about 42 seconds

11. For a proportional gain of 100, and a step change from 0 to 5 at 5.0 seconds, the resulting error signal is (choose the closest answer):

A) 5
B) 0.025
C) 0.004
D) 2

12. For a proportional gain of 100, and a step change from 0 to 5 at 5.0 seconds, the resulting time to reach steady-state is (choose the closest answer):

A) about 1 second
B) about 3 seconds
C) about 0.1 seconds
D) about 42 seconds

13. Increasing the gain of a proportional controller provided:

A) slower response and more error
B) slower response and less error
C) faster response and more error
D) faster response and less error

For questions 14-15, base your answers on your Simulink model with the following modifications. Add integral action to your controller so that you have proportional-plus-integral control. For the integral action of the controller, use the integrator block you have been using all semester. Use a proportional gain of 1.0 and an integral gain of 0.1.

14. For the same setpoint change used previously, the error signal:
   A) went negative
   B) eventually went toward zero
   C) went positive
   D) became an imaginary number

15. Increasing the gain of the integral action from 0.1 to 10 provided:
   A) a quicker response and no overshoot
   B) a slower response and no overshoot
   C) a peak value of the system output of approximately 5.5 to 6.0, no oscillation, and some steady-state error
   D) a peak value of the system output of approximately 7.5 to 8.0, damped oscillation, and approximately zero steady-state error.
Appendix E
Consent for Exemption

EXEMPTION DETERMINATION

Date: October 17, 2016
From: Joyel Modler, IRB Analyst
To: Denise Turso

<table>
<thead>
<tr>
<th>Type of Submission:</th>
<th>Initial Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title of Study:</td>
<td>The effects of student control of modality on learning and self-efficacy in engineering education.</td>
</tr>
<tr>
<td>Principal Investigator:</td>
<td>Denise Turso</td>
</tr>
<tr>
<td>Study ID:</td>
<td>STUDY00005837</td>
</tr>
<tr>
<td>Submission ID:</td>
<td>STUDY00005837</td>
</tr>
<tr>
<td>Funding:</td>
<td>Not Applicable</td>
</tr>
</tbody>
</table>

- [ControlSystem_MultimediaLearning_28_IRB.pdf](#), Category: Other
- [Turso_HRP-591 - Protocol for Human Subject Research_V2.pdf](#), Category: IRB Protocol
- [Turso_Prc_Post_Test_NucE451_Turso.docx](#), Category: Data Collection Instrument

The Office for Research Protections determined that the proposed activity, as described in the above-referenced submission, does not require formal IRB review because the research met the criteria for exempt research according to the policies of the institution and the provisions of applicable federal regulations.

Continuing Progress Reports are not required for exempt research. Record of this research determined to be exempt will be maintained for five years from the date of this notification. If your research will continue beyond five years, please contact the Office for Research Protections closer to the determination end date.

Changes to exempt research only need to be submitted to the Office for Research Protections in limited circumstances described in the below-referenced Investigator Manual. If changes are being considered and there are questions about whether IRB review is needed, please contact the Office for Research Protections.

Penn State researchers are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within CATS IRB (http://irb.psu.edu).

This correspondence should be maintained with your records.
References


Curriculum Vitae

Denise L. Turso
denise.turso@gmail.com

A researcher with a balance of higher education and industrial experience in the areas of learning science, systems engineering, technology, program development, and project management.

EDUCATION
Ph.D. Candidate, Learning, Design, and Technology, Penn State University (expected 2017)
Research Study: The effects of student control of modality on learning and self-efficacy in engineering education. Dissertation study relates to how people learn in relation to STEM education, in particular, application of mathematics in engineering. Research interests include adaptive and innovative creative problem solving for teams and individuals, organizational process improvement and optimization through integration and interoperability, and instructional design based on the areas of cognitive and education psychology and problem solving. She has developed formal and informal education programs; online training and blended learning; and organization system processes for academia, museums, and industry emphasizing that efficient and engaging programs in any environment require a focus on the human element.

M. S., Systems Engineering Management, Naval Postgraduate School, Monterey, CA
B.S. Education, The Pennsylvania State University

CERTIFICATION
Certified Systems Engineering Professional (CSEP). This certification incorporates both professional project management (PMP) and systems engineering management (SEM) toward a cohesive systems approach to planning and executing multiple projects throughout the lifecycle.

PROFESSIONAL EXPERIENCE
Writes grants and selects research-based and evidence-based frameworks and principles to support the initiation and production of learning materials such as Face-to-Face, Hybrid, and E-Learning. As content developer of training for military clinicians across the services in the areas of child abuse and neglect and domestic abuse. Manage various research programs that require in-depth content and instructional design analysis and continuous research of the literature to select the most effective human-centered design features to use in support of the learning goals. Experience in academia, industry and non-profit.

SERVICE
Center for Online Innovation in Learning (COIL) Reviewer for Research Initiation Grant
Society for Public Science, International Science & Engineering Fair, Washington, DC
Systems Engineering Advisory Group – Northrop Grumman Corporation
INCOSE Technical Paper and Tutorial Review Committee

AWARDS
The Wayne E. Meyer Award for Excellence in Systems Engineering, Naval Postgraduate School,
Partnership Award. Pittsburgh Society of Mining, Metallurgical, and Exploration.
Achievement Award. Science Service, Inc., Washington, DC