
5-2017

Effects of Computer Simulation and Animation (CSA) on Students’ Problem Solving in Engineering Dynamics: What and How

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Recommended Citation

Tajvidi, Seyed Mohammad, "Effects of Computer Simulation and Animation (CSA) on Students’ Problem Solving in Engineering Dynamics: What and How" (2017). *All Graduate Theses and Dissertations*. 5805.
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EFFECTS OF COMPUTER SIMULATION AND ANIMATION (CSA) ON STUDENTS' PROBLEM SOLVING IN ENGINEERING DYNAMICS: WHAT AND HOW

by

Seyed Mohammad Tajvidi

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Engineering Education

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2017

ABSTRACT

Effects of Computer Simulation and Animation (CSA) on Students' Problem Solving in Engineering Dynamics: What and How

by

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Utah State University, 2017

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Department: Engineering Education

The application of Computer Simulation and Animation (CSA) in the instruction of engineering dynamics has shown a significant growth in the recent years. The two foremost methods to evaluate the effectiveness of CSA tools, including student feedback and surveys and measuring student change in performance, suggest that CSA modules improve student learning in engineering dynamics. However, neither method fully demonstrates the quality of students' cognitive changes.

This study examined the quality of effects of application of CSA modules on student learning and problem solving in particle dynamics. It also compared CSA modules with textbook-style problem-solving regarding the changes they cause in students' cognitive process. A qualitative methodology was adopted to design and implement a study to explore the changes in participants' learning and problem-solving behavior caused by using a CSA module. Collected data were coded and analyzed using the categories of cognitive process based on the *Revised Bloom's Taxonomy*.

An analysis of the results revealed that the most significant effects were observed in understanding, analyzing, and evaluating. The high frequency of “inference” behavior after working with modules indicated a significant increase in participants’ understanding activity after working with computer modules. Comparing behavior changes of computer-simulation group students with those who worked with a textbook-style example demonstrated that the CSA modules ignited more analytical behavior among students than did textbook-style examples. This study illustrated that improvement in learning due to the application of CSA is not limited to conceptual understanding; CSA modules enhance students’ skills in applying, organizing, and evaluating as well. The interactive characteristics of CSA play a major role in stimulating students’ analytical reasoning and critical thinking in engineering dynamics.

(212 pages)

PUBLIC ABSTRACT

Effects of Computer Simulation and Animation (CSA) on Students' Problem Solving in Engineering Dynamics: What and How

Seyed Mohammad Tajvidi

Previous studies have shown that in many fields, computer simulation and animation (CSA) improve students' learning and problem solving. However, despite the massive body of research on the role of computers in education, little research has been conducted to qualitatively examine how they affect the learning of engineering students. The purpose of this study was to explore how learning and problem solving were affected by computer modules and what similarities and differences existed between computer representations and paper-based examples.

An analysis of collected data, observations of participants' problem-solving activities, and interviews revealed that computers can enhance students' analytical thinking, organizing, and evaluation. In addition, mindfully designed, effective educational computer animations foster students' critical thinking and help them ask questions and make conclusions which improves their problem-solving.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my major professor, Dr. Ning Fang, for his guidance and supervision for this research during the past several years. Dr. Fang developed the original research idea and the overall plan for the study. He guided me through the entire process of developing the CSA modules and associated research questions, collecting data from student participants, and discussing and analyzing the collected data. Special thanks are also given to the members of my dissertation committee: Dr. Wade Goodridge, Dr. Oenardi Lawanto, Dr. Idalis Villanueva, and Dr. Edward Reeve for their helpful comments and encouraging hints. I want to express my sincere appreciation to Dr. V. Dean Adams for his support and help during my Ph.D. program at Utah State University.

In addition, I would like to thank undergraduate students in Dr. Fang’s research group: Alex Abate, Katie Spendlow, Colleen Kretzer, and Ashton Jessop for their great assistance in transcribing audio files and help with coding collected data. I also thank former graduate students in Dr. Fang’s research group: Dr. Oai Ha and Dr. Yongqin Guo, and undergraduate student, Mr. Jared Lowery, who helped me with the coding process and reviewing the transcripts.

The help and encouragements from Tahmoures Shabanian are greatly appreciated. Finally, I would like to thank especially my wife, Mojgan, and my daughter, Pegah, for their patience, affection and limitless support during this time.

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CHAPTER I

INTRODUCTION

Engineering Dynamics is a high-enrollment, intensive course taken by students in their sophomore year. It is required for several programs including mechanical, civil, environmental, and biological engineering (Fang, 2011; Kumar & Plummer, 1997; Rubin & Altus, 2000). The course is a challenge for many students due to its complexity and diversity of concepts (Cornwell & Fine, 2000; Howell, 1996). Numerous researchers have created innovative educational tools and methods in order to improve students' performance in Engineering Dynamics (Costanzo & Gray, 2000; Grimes, Warschauer, Hutchinson, & Kuester, 2006). The tools and methods include novel pedagogical techniques, instructive and interactive resources and computer modules, and other active learning tools and methods (Stern et al., 2006; Violante & Vezzetti, 2012).

Among all of the instructional tools and techniques, computer simulation and animation (CSA) has drawn significant attention in recent years (Fang, 2011; Fang, Tan, Thwin, Tan, & Koh, 2011). Despite the fact that computer simulation and animation is a term widely used in the literature, an explicit, agreed-upon definition for CSA is difficult to find. As a general title, itis used to describe computer applications that include animated graphics as well as text information to model an actual phenomenon graphically. A computer simulation is characterized by incorporating inputs into calculations or modeling, and presenting functional outputs (Sidhu, Ramesh, &

Selvanathan, 2010; Sidhu & Selvanathan, 2005). Compared to computer animation, computer simulation is usually more calculation-oriented and characterizes the real phenomenon of interest (Sidhu & Selvanathan, 2005).

One important advantage of a CSA application is its capability to be replayed, offering students a replicable, structured, visual experience to acquire information. Mechanical models require considerable time and effort to set up, and once the core process of an experiment begins, there is no “pause” key. In addition, replication and setting up of a physical experiment is challenging. On the other hand, CSA modules can be paused, reset and restarted easily at any time upon the user’s command. Another advantage of CSA is that learners may adjust their learning pace. Change of parameters is another capability of CSA modules that helps students to immediately grasp the results of altering one or more parameter. Such advantages, along with simple installation and the ability to use the feature online, make CSA a strong instructional tool especially in engineering education.

CSA modules are typically characterized by: (1) using animations to illustrate key concepts; (2) interacting with users to enable them to change one or more input parameters to alter animation and/or calculation details; (3) enabling users to navigate through modules to review; and (4) presenting more information to users through clickable pop-up boxes. The last three characteristics refer to students’ active involvement, enabling them to organize their learning process by navigating through modules, changing input parameters, and observing the outcomes. Depending on the technical limitations and CSA objectives, researchers have focused on different aspects of the above-mentioned characteristics (Carbonell & Romero, 2013; Deliktas, 2011; Roselli, Howard, & Brophy, 2006; Rutten, van Joolingen, & van der Veen, 2012; Stern et al., 2006; Violante & Vezzetti, 2012).

Background of the Study

Among the large number of tools developed to improve dynamics learning, CSA modules have several distinct advantages (Deliktas, 2011; Staab & Harper, 2000). In physics and engineering education, CSA modules represent the concepts in a step-by-step fashion, usually accompanied by animations. Solution modules typically contain clickable pop-up hints that appear in the form of static or dynamic boxes. While earlier CSA modules merely included simple animations, the quality of CSA modules has improved substantially. Though researchers have conducted quantitative and qualitative studies to verify the effectiveness of CSA tools, little is known about how CSA modules affect students' problem-solving. In addition, few researchers have focused on the link between the characteristics of CSA modules and students' problem-solving processes.

A review of literature regarding the application of CSA modules shows that most research studies in the field emphasize the results of incorporating the CSA modules developed by the researchers in a general sense. Most current research studies emphasize the technical characteristics of CSA modules rather than the quality of their impact on student learning (Dabney & Ghorbel, 2005; Grimes et al. 2006; Iscoglu & Kale, 2010).

Computer simulation and animation modules, as with any other educational tool introduced to the research society, must be evaluated. Measuring the effectiveness of

CSA modules continues to be a major area of interest in research (Deliktas, 2011; Flori, Koen, & Oglesby, 1996; Ha & Fang, 2013). Currently, most educational CSA modules developed in engineering fields are evaluated through feedback and interviews specified by the end users (Deliktas, 2011; Howard & Brophy, 2006; Montfort, Brown, & Pollock, 2009; Roselli, Violante, & Vezzetti, 2012). In reporting students' experiences with CSA, results often include the frequency of positive feedback made by users, while limited research studies address the quality of the effects in students' problem-solving (Ha & Fang, 2013; Zhu, Aung, & Zhou, 2010). Student feedback is often positively biased and highly dependent on other pedagogical factors such as teacher aesthetics, course content, and student motivation (Ha & Fang, 2013).

Another evaluation method is the quantitative study of learning improvements due to the application of CSA. Such studies establish the CSA module as an educational intervention and measure changes in student performance before and after using it (Deliktas, 2011; Flori, Koen, & Oglesby, 1996; Staab & Harper, 2000). Although the approach is solid and illustrative, it merely reveals the quantity of measured effects of that intervention on learning and does not address the quality of changes that occur in students' learning.

Goals and Objectives

This study investigated the effects of CSA modules on students' problem-solving process in particle dynamics. The method adopted for this investigation was a qualitative inquiry approach. This study involved the "how" question regarding students' cognitive processes throughout their problem-solving activities, which implies the qualitative nature of the findings. Understanding the quality of such changes will lead to the generation of more effective CSA modules and improvement in the quality of instruction in engineering mechanics.

The trend of CSA application in engineering education has shown a significant growth in the recent 20 years (Deliktas, 2011; Sidhu, 2010; Sidhu, Ramesh, & Selvanathan, 2010). Most research studies have suggested that CSA modules improve students' learning in dynamics (Deliktas, 2011; Sidhu, 2010). In addition, student feedback and surveys have been used to support the argument. However, the results of stand-alone surveys do not fully demonstrate either the quality of students' cognitive change or the challenges confronted by them while solving an engineering dynamics problem. Another means of evaluating the effects of CSA is to measure students' change of performance, e.g. changes in grades due to the application of CSA. However, the evaluation involves a similar limitation; namely, a change in grades does not necessarily reflect the quality of a students' learning.

This study examined the quality of changes in a student's problem-solving due to the application of CSA modules. It investigated how students' cognitive process is affected by working with a CSA learning module. The observation of students' problem-solving processes required thorough design, data collection strategy, and data analysis methodology, and resulted in descriptive information. In order to collect more eloquent information about students' learning, observation and recording of their problem-solving processes was used effectively in this study. Interview/questionnaire replies triangulated the outcomes of observation or recording. There were a number of other factors that also guided the qualitative approach such as the nature of the topic and participants' characteristics.

Research Questions

This study was an investigation of the qualitative changes in students' cognitive processes while they solved a dynamics problem. The following two research questions guided the study:

1. How do CSA modules affect students' problem-solving in engineering dynamics from the perspective of cognitive processes?
2. What similarities and differences exist between the effects of CSA modules on students' problem-solving and the effects of textbook-style instruction in engineering dynamics?

The first question addressed the effects of CSA on problem-solving. The second research question identified the similarities and differences in students' problem-solving processes between using CSA modules and using textbook-style-solved problem examples.

Research Design

This study includes three modules about particle dynamics: (1) Newton's Laws of Motion; (2) the Principle of Work and Energy; and (3) the Principle of Impulse and Momentum. For each module, two problems were developed: one solved problem and one assessment problem. Two types of representations were developed for the solved problems, a CSA module representation and a textbook-style paper representation. In this dissertation, the latter is called the Paper Learning Example (PLE). In order to investigate the effects of CSA on students' problem-solving, participants were asked to solve the assessment problem as a pretest, and then to study the CSA module as an intervention. In the next stage or posttest, the participants returned to the assessment problem to solve it a second time, and finally, they participated in an open-ended interview. In order to compare CSA effects with textbook-style problem-solving, a second group of participants worked with the PLE as their intervention stage. Each individual was instructed to perform a "think-aloud" process, i.e. to say aloud whatever he or she thought during the process. Collected data consisted of audio and/or video transcripts of students' speeches throughout the activity, notes created during the activity, and solution notes.

This study intends to investigate the effects of CSA modules on students' learning process. Therefore, the approach and research methodology are based on qualitative research method. Data collection and data analysis also entail qualitative approach mindsets. Researcher's positionality greatly impacts the study design and analysis assumptions in qualitative study. Since the researcher has been an instructor of dynamics course for several years, as well as being a professional practicing engineer, it is likely that the interpretations, assumptions, and designed problems are affected by the researcher's position and background. This issue exists in every qualitative study.

Significance of the Study

In physics education, numerous studies have addressed the problem-solving process while using CSA modules, emphasizing the qualitative investigation of effects of CSA. In engineering education, the major theme pertaining to CSA modules describes the characteristics and quality of the produced modules; however, little is known about how those modules affect problem-solving. This study focused on the quality of effects of CSA modules in a student’s cognitive process in engineering dynamics. Knowing how the CSA modules affect the cognitive aspects of students’ problem-solving processes helps developers of such modules create more effective, engagement-based products. Understanding the quality of CSA effects on cognitive processes will help educators to use CSA modules in their instruction more effectively. Furthermore, developers of educational CSA modules in engineering education will be able to reinforce those characteristics that include the most positive effects on the problem-solving process.

Limitations of the Study

As with any research study, certain limitations were inherent due to the research method or nature of the study. These limitations included:

- Because “think-aloud” was the main data collection technique used in this study, it relied heavily on the participants’ expression of their thoughts. Participants typically do not express all of their thoughts while performing the experience, resulting in moments of silence. Inasmuch as the issue occurs frequently in the “think-aloud” method, researchers have proposed a few helpful solutions to this issue such as video-recording students’ writing, keeping the solution notes and reminding the student to think aloud in some moments (Olk, 2002). Therefore, an attempt was made to record participants’ nonverbal expressions during the process and to incorporate those into the collected data.

- The type and configuration of the technical problem alter the effects of the CSA; the changes depend on the type, difficulty level, and configuration of the problem. As with the learning example problem, the assessment problem included only one dynamics principle to prevent unnecessary complication of the problem.
- Because students with different skills were selected, their problem-solving behavior before being exposed to the intervention depended on their previous knowledge and personal learning styles. Therefore, their pretest results cannot be objectively compared.
- The study design and time frame required that the participants perform all stages. Therefore, there was no means to measure how long the changes in their thinking lasted in their mind. If the participants were given a “forgetting time,” it would be very difficult to attribute their performance to the module or other unknown factors.

Definition of Terms

The following terms were used throughout the study:

- *Assessment problem*: A problem statement was given to each participant to solve. For each module, one assessment problem was developed.

- *Coding table*: The table included the *Revised Bloom's Taxonomy* codes and collected data that were placed in the most pertinent cell based on their meaning.
- *Coding*: The coding technique was used to organize data in order to find common themes.
- *Computer simulation and animation (CSA): CSA* represented the general title used for computer applications that included one or more animation pictures with specific learning objectives.
- *CSA learning group*: The term referred to the participants who studied and worked with the CSA module during their problem-solving activity.
- *CSA module problem:* A solved problem identical to a paper-learning example (PLE) or textbook-style problem represented through the interactive CSA module.
- *Informed consent form*: The form was signed by the researchers and participants, explaining the rights and responsibilities of each party involved in this study.
- *Intervention*: The second step in the problem-solving activity was intervention in which the participant studied a solved problem through either a CSA module or a PLE representation.
- *Interview:* The fourth step in the problem-solving activity was the interview in which the participants talked about their experience with the intervention and expressed their thoughts when solving the problem.
- *IRB*: The Institutional Review Board (IRB) of Utah State University was in charge of reviewing the research study to insure compliance with the institutional code of ethics.

- *Module-1*: The CSA Module-1 referred to Newton's Laws of Motion and included a step-by-step solution of a problem supported by hints, interactive animation, and figures.
- *Module-2*: The CSA Module-2 referred to the Principle of Work and Energy in particle dynamics. It included a step-by-step solution of a problem supported by hints, interactive animation, and clickable figures.
- *Module-3*: The CSA Module-3 referred to the Principle of Angular Impulse and Momentum in particle dynamics. It included a step-by-step solution of a problem supported by hints, interactive animation, and clickable figures.
- *Participant*: The term referenced each of the 34 students of engineering dynamics who participated in the study by doing the four-step problem-solving activity.
- *Paper Learning Example (PLE),* also referred to as *"textbook-style problem":* The PLE refers to a solved problem that the participants studied during their problem-solving intervention. The representation of the problem was similar to a textbook-style example.
- *PLE learning group*: The learning group was comprised of participants who studied and worked with the PLE during their problem-solving activities.
- *Posttest*: The third step in the problem-solving activity was the posttest in which the participant returned to the initial problem to solve it.
- *Pretest*: The pretest was the first step in the problem-solving activity in which the participant attempted to solve a dynamics problem.

- *Code frequency*: The number of the times that a specific code occurred in a coded student’s transcript (denoted by FC).
- *Code index*: The calculated product of two numbers, sum of code frequencies in a group and the number of students in that group who conducted an activity pertaining to that code (denoted by I, also named as the prevalence index)
- *Revised Bloom’s Taxonomy (RBT)*: The taxonomy of the educational objectives initially developed by Bloom (1956) and revised by Krathwohl (2002).

Assumptions of the Study

The following assumptions were made during different stages of the study including data collection, interview, and data analysis.

- Within the CSA learning group, the CSA module was the only factor which affected a participant’s cognition during the experience.
- Participants were introduced to the topic a few weeks before the experience, although they were taking the course currently and had not yet been tested on the final exam. Therefore, their conceptualization of dynamics had not yet changed because of another more advanced course.
- The participants volunteered to take part in the study and were not under a burden of test anxiety or a challenge problem.

IRB Approval

Because of the involvement of human subjects in the study, the Institutional Review Board (IRB) of the university requires the researchers to protect human subjects and to be committed to the pertinent ethics code. In this regard, an application was made to the IRB describing the study's objectives, characteristics, participants, data collection tools, and procedure. The IRB reviewed and issued the approval letter to Professor Ning Fang as the principal investigator. A copy of that letter is presented in Appendix A of this dissertation. During the data collection phase, the terms and conditions were explained to each participant as well as their rights and our responsibilities regarding their privacy. They were informed about the confidentiality and protection of their identity. As a result, both participants and researchers signed an informed consent form. Each participant was given a copy, and the university copy was reserved by the principal investigator. For the sake of confidentiality, all names given to the participants in this document are pseudonyms. During the problem-solving activities, the participants' faces were not distinguishable in the video recording. All of the data collected were encrypted and reserved securely throughout the research period and thereafter.

Dissertation Outline

This dissertation includes nine chapters**.** Chapter I involves the introduction, presenting the main idea, objectives, background, design, significance, and assumptions of this investigation. Chapter II entails a review of current and past literature on the topic. First, it briefly addresses previous advances in engineering dynamics pedagogy, new tools and techniques in the recent decades. Next, studies which address application of CSA in engineering education and engineering mechanics are addressed. Chapter II also discusses the research gap and reviews previous research studies to evaluate their approach and findings on how CSA effects learning and/or problem-solving theories.

Chapter III describes the process of developing the modules used in this study. Their topic, characteristics, and important issues are explained. Chapter IV describes the research methodology and the study design including participants' background, selection and attrition, as well as assessment problems, a paper-learning problem, data collection procedure, and finally a brief description of the data analysis plan.

Chapter V addresses individual description and interpretation of participants' problem-solving activities, supported by examples of their "think-aloud" transcripts. Chapters VI, VII and VIII discuss the findings for each module based on the coding table. The chapters examine the findings comparing the research questions and the coding methodology as well as the emergent themes from the analyzed data. Finally, Chapter IX summarizes the conclusion and implications of the results and presents recommendations concerning future research. It also discusses how the outcomes can assist developers of educational CSA modules.

CHAPTER II

LITERATURE REVIEW

In most engineering programs, engineering mechanics includes statics, dynamics, and strength of materials, which are required courses in mechanical, civil, environmental, and biological engineering programs (Fang, 2012; Kumar & Plummer, 1997; Rubin & Altus, 2000). The complexity and diversity of the problems and concepts of engineering mechanics are challenging for many students (Carbonell & Romero, 2013; Cornwell & Fine, 2000; Howell, 1996). Specifically, the representation of objects and concepts is complex in many engineering drawing and design courses. In engineering dynamics, mathematical and conceptual analyses in mechanics problems are added to the representation effort making it even more difficult for students to learn (Staab & Harper, 2000).Instructors of engineering typically attempt to represent 2D and 3D motion through static diagrams and explanations. To date, educators and software tool developers have introduced numerous educational tools and methods to improve students’ performance in engineering mechanics (Carbonell, 2013; Costanzo & Gray, 2000; Staab & Harper, 2000). These methods include, among others, novel teaching techniques, instructive and interactive computer modules, and involvement of students in the learning process through a variety of projects and similar activities (Gray & Costanzo, 1999; Grimes et al. 2006).

This chapter reviews the existing literature on engineering education and physics education which were relevant to the focus of this study in order to understand the nature of effects of CSA modules in problem-solving. The review also includes literature that reviews innovative tools or methods in instruction of dynamics. Most of the educational tools and methods attempt to distribute either the content in order to decrease the cognitive load, or to enhance the representation of the content in order to assist students with the geometrical and physical perceptions (Howell, 1996; Kumar & Plummer, 1997). Notable advancements in creating computer simulation and animation (CSA) modules have drawn great attention to CSA as a major educational enhancement tool (Fang, Tan, Thwin, Tan, & Koh, 2011). Nevertheless, most research studies emphasize the technical characteristics of CSA modules, rather than rigorous assessments of its impact on student learning (Costanzo & Gray, 2000; Dabney & Ghorbel, 2005). In reporting students' experiences with CSA modules, results most often refer to the frequency of positive feedback. Limited research studies involve rigorous assessments of the effects of CSA modules on student learning and the problem-solving process (Ha & Fang, 2013; Zhu, Aung, & Zhou, 2010).

The practice of using computer-based tools to enhance learning is widespread. However, using computers merely for the sake of appearing "modern" can be a disadvantage to teaching engineering mechanics (Staab & Harper, 2000). Despite significant progress in computer-assisted teaching, most students need to draw free-body diagrams and write equilibrium equations, kinematic constraints, etc., to grasp the different concepts of engineering mechanics. For this reason, the most successful methods, such as computer-aided instruction problems and interactive computer tutorials, are an augmentation of the traditional context (Deliktas, 2011; Staab & Harper, 2000). In science education, most research studies demonstrate that computer tools improve learning through simulation, better representation, fostering student involvement, and decreasing the instructor’s load (Rutten, van Joolingen, & van der Veen, 2012). The use of CSA in higher education is rapidly increasing and has become a major trend in undergraduate engineering education (Rutten, van Joolingen, & van der Veen, 2012; Smetana & Bell, 2012). This trend explains the abundant literature associated with the research and development of novel tools and methods for teaching engineering mechanics.

This chapter provides a comprehensive and critical literature review of three themes: (1) pedagogical innovations in the instruction of engineering mechanics; (2) using CSA as a learning tool in engineering mechanics education; (3) problem-solving engineering education and engineering mechanics. The themes offer new insights concerning different aspects of CSA in engineering mechanics education and examine the characteristics of CSA that make it a favorite choice for improving engineering mechanics pedagogy. The chapter also deliberates the quality of the relationship between students’ problem-solving and the cognitive process.

A brief review of the literature revealed that a wide range of studies exists regarding the application of computers in all fields of education, ranging from K-12 to postsecondary. The literature review was limited to published studies that focused on engineering mechanics or closely related subjects. A number of references were cited for theoretical or basic research works (Howell, 1996; Ramesh & Selvanathan, 2010; Sidhu, 2010; Sidhu & Selvanathan, 2005). Major characteristics, implications, focused topics, and issues associated with the above-mentioned questions were categorized and presented in a tabular format.

Pedagogical Innovations in the Instruction of Engineering Mechanics

Before the 1990’s, educational research emphasized the improvement of teaching styles, active learning, and facilitation of student conceptual understanding (Felder & Silverman, 1988). In the last two decades, recent developments in computer graphics and web-based tools have reinforced earlier efforts with slight structural changes. A large number of research studies have focused on the overall change in engineering curricula; for example, a new core curriculum design was introduced by Belytschko et al. (1997). This section provides a description of representative pedagogical innovations in three categories: (1) altering engineering mechanics curriculum, (2) active learning strategies, and (3) application of enhancement resources.

Altering the Engineering Mechanics Curriculum

Besides changes to the entire curriculum, improvement strategies for engineering mechanics address other aspects of pedagogy, such as developing new course sequences, creating hands-on simulation tools, and introducing novel instruction approaches. Changing the sequence of topics in engineering mechanics is one means to create more integrity within the engineering mechanics course (Belytschko et al., 1997; Cornwell & Fine, 2000; Rueda & Gilchrist, 2011). In an effort to cover both freshman and sophomore courses, Belytschko et al. (1997) developed a curriculum by integrating a subset of mathematics and science with engineering. It targeted engineering design to foster freshman-year students through a four-course sequence entitled, “Engineering Analysis.” Cornwell & Fine (2000) described a new distribution of topics in mechanics courses and demonstrated that the new sequence improves students’ learning and performance.

Despite the efforts made so far, changes in curriculum face two major challenges. First, it is difficult to assess the impact of curricular changes in a short time, and no pretest/posttest experiments can identify the impact of a curricular change on in a multicourse span. Second, changes in curriculum must engage the parties impacted by the change who are outside academia in order to consider their concerns as well as those of the faculty and departmental leaders (Wormley, 2004). Because curricular changes are related to attitudes and skills as well as to the content materials, not all faculty members accept the intense, yet required integration of new attitudes and skills within the content change. In the recent years, these two challenges have decreased the number of studies which address curriculum change (Wormley, 2004).

Active Learning Strategies

Student involvement is generally accepted as an effective tool in all levels of education (Felder & Brent, 2005; Felder & Silverman, 1988; Howell, 1996; Ramesh & Selvanathan, 2010; Sidhu, 2010; Sidhu & Selvanathan, 2005). Involving students in course activities or active learning necessitates innovative changes to the course examples and problems. Howell (1996) introduced five basic elements to consider in cooperative learning: positive independence, face-to-face interaction, individual accountability, collaborative skills, and group processing. Because there is a large volume of problem-solving in engineering mechanics, cooperative problem-solving practices can be implemented easily. Structuring a lecture class devoted to cooperative learning groups can be overwhelming to many instructors, but studies have shown that introducing cooperative problem-solving receives extensive positive feedback from the students. This phenomenon supports the fact that most novel teaching techniques can reinforce conventional pedagogy, but none can replace cooperative learning completely (Smetana & Bell, 2012).

Incorporating a design challenge, along with altering the sequence of topics and adding group activities with a broader range of resources, is another method that may work to create an innovative teaching style. A more recent initiative, studied over 3 years (2008 to 2011) introduced team-based assignments to students (Rueda & Gilchrist, 2011). In that study, groups of up to five students were given a design challenge directly related to a specific topic in engineering dynamics. The challenges proved to be popular among the students, led to improved learning outcomes, and improved student performance without compromising academic standards (Rueda & Gilchrist, 2011; Wormley, 2004). Utilizing research-led methods in teaching is successful in relating current coursework to actual engineering problems for both undergraduate and postgraduate students.

Most of the methods which claim to improve pedagogy are based on one of the theories of learning, e.g., behaviorist, cognitivist, and constructivist (Sidhu, 2010). Nevertheless, limited number of developers of computer-based learning tools in engineering education include an explicit allusion of the above-mentioned theories. Instead, most of the studies focus on the context of active learning vs. reflective learning.

For example, in his investigation of effectiveness of computer simulation in engineering mechanics, Eronini (2000) combined the active learning strategy method with computer-assisted learning in order to foster engineering students' conceptual understanding; he introduced a simple design project and demonstrated the improvement in student performance due to the intervention. The mechanism of improvement relied heavily on raising motivation and enthusiasm among students by involving them in the course material not only as viewers but also as active players. Students were provided an opportunity to conduct the design. Eronini stated that the introduction of design issues had little impact on the course content and learning concepts. Applications of CSA tools also focus on the "problem representation" dimension of problem-solving (Felder & Silverman, 1988). This group of studies have enhanced problem representation through the instrument to increase its pedagogical effectiveness.

Applying Enhancement Resources

Computer-aided instruction entails developing assignments involving the use of parametric solutions to the problems, thus, guiding students to use computers to reformulate a problem in terms of non-dimensional parameters. In this regard, mediocre-performing students show more interest in computer-assisted problem-solving challenges (Staab & Harper, 2000). Several computer tools have been developed to maintain student involvement in engineering mechanics, combining lab activities with CSA in an authentic project (Bernhard, 2000; Eronini, 2000; Ha & Fang, 2013; Karadogan, Williams, Moore, & Luo, 2012). The main educational advantage of using computer-based labs is the real-time display of experimental results and graphs, facilitating a direct connection between the actual experiment and the abstract representation (Smetana & Bell, 2012). Nevertheless, the acquisition of laboratory skills is often a learning goal in itself which cannot be replaced by simulations.

Streveler, Litzinger, Miller, and Steif (2008) studied learning tools from the point of view of cognitive learning theory. By investigating students’ learning difficulties in engineering dynamics, it was concluded that three issues cause difficulties or misconceptions among students. The first is failure to distinguish properly between different objectives expected from the same phenomena in different discourses. The second issue involves misunderstanding of the meanings of two different concepts due to the closeness of their respective implications, for example, mixing heat and temperature. The third issue is that students often struggle in conceptualizing phenomena that are not directly sensed but rather are mathematically represented and analyzed, for example, the issue of “angular momentum,” a topic covered in engineering dynamics (Streveler et al. 2008).

Focusing on engineering mechanics teaching techniques, concept questioning and scenario building are suitable techniques to create interactive CSA modules with rich graphical content (Gray & Costanzo, 1999). Animation modules created in this way can cover engineering mechanics courses including statics, strength of materials, and dynamics (Belytschko et al., 1997; Muthu & Glass, 1999). By analyzing student feedback through surveys, Sidhu and Selvanathan (2005) concluded that a questioning approach helps students increase their ability to understand dynamics concepts. Deliktas (2011) demonstrated that scenario building through CSA assists instructors in conveying ideas more conveniently. It is important to note that CSA materials and modules cannot replace conventional teaching practices; CSA modules are known to be support material and can merely enhance pedagogy (Deliktas, 2011). Many studies which target improvement of pedagogy involve problem-solving enhancement because of the relationship between problem-solving and learning (Jonassen, 2000).

Computer Applications as a Learning Tool in Engineering Mechanics Education

The application of computers in higher education includes online education, virtual classrooms and e-learning, multimedia, animations and simulations, as well as learning games and online tutoring systems (Muthu & Glass, 1999; Sidhu, 2010; Sidhu & Selvanathan, 2005; Smetana & Bell, 2012). Almost all of these applications have been assimilated for use in engineering mechanics. Although in the early 1990s, when computer-aided instruction tools started to emerge, research studies reported slight positive impacts due to computer applications. However, that situation has now changed drastically (Grimes et al. 2006; Rutten, van Joolingen, & van der Veen, 2012; Zhu, Aung, & Zhou, 2010). The use of modern educational tools, such as simulation software models and visualization techniques, is not only effective but is also often required in engineering mechanics course curricula to assist students in understanding the engineering aspects of dynamics. The following is a list of reasons posited by several researchers:

- Although mechanical models used in either the classroom or the lab are useful, they have little flexibility, and are mostly qualitative, not quantitative. They are not easily repeated, because reinstalling and redoing of the experiments is not simple (Flori, Koen, & Oglesby, 1996).

- Students' learning styles are different in many ways such as watching and hearing, analyzing and acting, reasoning logically and intuitively, memorizing and understanding and drawing analogies, and building mathematical models. Even one individual may utilize multiple activities while solving a problem (Deliktas, 2011). A CSA module can address multiple aspects and help the user via multiple means such as more clear representation and being interactive.
- In engineering dynamics, most of the content concerns motion, but textbooks, chalkboards, and the traditional classroom teaching tools cannot easily show that motion (Staab & Harper, 2000).
- While working with a computer simulation application, students can adjust the pace of the content representation to the desired level.
- Computer simulation applications can be combined with physical laboratory experiences effectively (Gray & Costanzo, 1999).

Computer Simulation and Animation

Developers of educational animations have focused on the capabilities of user-friendly motion visualizations and the attractiveness of text/animation combinations in order to promote their applications (Gray & Costanzo, 1999; Issa, Cox, & Killingsworth, 1999; Ong & Mannan, 2004; Pinter, Radosav, & Cisar, 2012; Staab & Harper, 2000). More complex capabilities, such as 3D representation and rendering, were added to animations thereafter, which improved the learning impact of animations and simulations

(Ong & Mannan, 2004; Pinter, Radosav, & Cisar, 2012; Sidhu & Selvanathan, 2005). In the past decade, interactive features have been added to CSA modules, which have increased their effectiveness as well as students' involvement. Costanzo and Gray (2000) identified five necessary characteristics for computer-based learning: (1) hands-on laboratory experience, (2) a multidisciplinary approach, (3) a systems perspective, (4) an understanding of information technology, and (5) an understanding of the importance of teamwork.

Visualization characteristics of CSA modules can be associated with cognitive process aspects such as schemata, mental and graphic visualization, situated learning or cognition, and cognitive apprenticeship (Brown & Pollock, 2009; Sidhu, 2010). Brown and Pollock (2009) noted the infrequency of visualizations integrated into classroom instruction. They attributed the infrequency to the lack of sufficient teaching tools. Without exposure to them, students could not experience the benefits of useful CSA tools. In addition, new modules have included more web-based interactive tutoring (Ong & Mannan, 2004; Sidhu, 2010; Sidhu & Selvanathan, 2005). For example, the tutorial package developed by Ong and Mannan (2004) supported students with an interactive feature that had the capability of modifying parameters so that a user could monitor how the solution changes concurrently. In demonstrations of engineering mechanics, changes in input parameters can change the motion of objects or result in pop-up textual or graphical data (Bernhard, 2000; Ong & Mannan, 2004). The interaction features of CSA modules can be developed to introduce problems, give feedback on a user's response, and perform "smart" tutoring by checking different solution scenarios.

In addition to using CSA and multimedia tools, several modules have been developed and tested to build a more effective classroom environment (Deliktas, 2011). Almost all researchers of CSA tools have attempted to measure the efficiency of their represented computer tool. The majority of the developed CSA modules are assessed through feedback and interviews provided by end users (Deshpande & Huang, 2011; Rutten, van Joolingen, & van der Veen, 2012). Feedback is highly biased and dependent on other pedagogical factors, such as teacher aesthetics, course content, student motivation, etc. Nevertheless, in the future, there will be widespread use of virtual classroom computer modules at the college level (Sidhu, 2010).

Comparing students' performance in engineering mechanics with and without CSA modules demonstrates that learning with properly created, interactive animations has positive effects on most students' academic performance (Deshpande & Huang, 2011; Gray & Costanzo, 1999). In addition, CSA can deliver information in an attractive format, which is advantageous in assembling curricula for students who have different skill levels and learning styles. The interactive features of properly developed CSA modules helps learners understand scientific topics. Important conceptual relationships are presented which enable students to become acquainted with the shown system and make changes in input parameters with no additional costs or risks (Deshpande & Huang, 2011). There is no standard procedure for creating successful visual applications. Although, in order to have the desired effect, CSA modules should: (1) cover topics that include dynamic characteristics; (2) comprise a limited multitude of colors; and (3) give an optimal amount of text information. A number of studies have indicated that if the teaching method covers the needs of different types of learners, it is the more likely to become noticed and used (Deliktas, 2011; Deshpande & Huang, 2011). Inasmuch as CSA modules contain a wealth of visual and interactive components, such as pictures, diagrams, clickable hints, interactive animation etc., they are preferred for the visual learning profile, while written and auditory explanations are deemed more effective for the verbal-learning type of student (Deliktas, 2011; Deshpande & Huang, 2011; Pinter, Radosav, & Cisar, 2012).

Learning Games and Virtual Reality

Learning games have also been considered in computer-based learning. Games are interactive, include animations, foster student involvement, and stimulate student motivation. Thus, games are an attractive choice for educators. A comprehensive list, along with the characteristics and challenges of existing game environments, was presented by Deshpande and Huang (2011). In engineering mechanics, there are two game modules for helping students grasp fundamental concepts and basic calculations. Research studies related to the development of games resulted in positive feedback and increased performance from participants in nearly every engineering discipline (Deshpande & Huang, 2011). A major issue in the design of educational games is that a close collaboration between module developers and textbook authors is needed to provide more concrete, consistent material in both products. Instructors with programming knowledge can develop attractive and effective games targeting students' misconceptions. Particularly in engineering dynamics, the games that include calculation challenges can introduce more complex, real-life engineering problem-solving as well as addressing students’ misunderstandings in basic topics such as force, acceleration, and velocity (Coller & Shernoff, 2009).

Another attractive computer tool, virtual reality (VR) simulations enhance a student’s capabilities in programming and operations without the need to work on actual laboratory equipment. Virtual reality simulations also improve a student’s concentration and ability to generate interactions concurrently, similar to simulation practice in authentic trainings, such as flight simulations in pilot training (Ong & Mannan, 2004). Nevertheless, a common weakness among all of the tools is that the procedure of setting up a complex computer simulation or a web-system for e-education requires a significant amount of time (Violante & Vezzetti, 2012). It also requires the use of appropriate pedagogical models along with appropriate means of communication between participants and instructors and deep knowledge of learning theories. Wu and Chen (2012) illustrated participant-researcher communication through the design of the Zaltman Metaphor Elicitation Technique (ZMET), which produced a consensus map of the participants’ concepts. The consensus map contained the links between system attributes, usage consequences, and personal values (Wu & Chen, 2012). Although beneficial to students’ conceptual understanding, VR tools may have limited effects on practices requiring student analysis and synthesizing knowledge (Lipinski, Docquier, Samin, & Fisette, 2012; Pinter, Radosav, & Cisar, 2012).

One notable advantage of virtual tutors is the capability of instant feedback. For example, Roselli, Howard, and Brophy (2006) developed an online “free-body diagram” assistant to help students construct 2D free-body diagrams. The assistant tool provided feedback for a wide range of practice problems, helping improve both learning and assessments. In developing such interactive tools, it is important to use an appropriate software package to develop the learning interface. The interface should consider the students' backgrounds and prior knowledge of the subject (Stern et al., 2006). While lecture and lab teaching are more suitable for courses at introductory and undergraduate levels, multimedia and complex interactive simulation modules perform better for courses at the graduate level.

More rigorous VR simulations are increasingly used for teaching complex 3D design concepts in advanced engineering courses such as machine design (Ong & Mannan, 2004). Stern et al. (2006) designed a semi-structured interview to capture participants' learning experiences with a VR simulation-based learning module. It was shown that the module not only enlivened the learning of machining technology, but it also promoted autonomous learning and mastery. Furthermore, the participants reported that its application impressed their visual experience, helping them to remember the machine processes. The autonomy of using a virtual tool enhances participants' construction of knowledge (Ong & Mannan, 2004; Sidhu, 2010; Stern et al., 2006).

Problem-solving in Engineering Education

Cognitive domain of learning involves six categories: remembering, understanding, applying, analyzing, evaluating, and creating (Krathwohl, 2002). The categories comprise the steps of the learning process in a cognitive domain. Bloom (1956) introduced the taxonomy to categorize the standards of educational objectives.

There are a number of skills or activities which signify learning, students' ability to express acquired knowledge, the ability to make meaningful relevant inferences from the content, and the ability to a solve problem (Mason & Singh, 2010). The latter skill, problem-solving, is the most significant indicator of learning in that it is a measureable activity with tangible results directly related to learning (Litzinger et al., 2010; Taraban, Craig, & Anderson, 2011).

Among several models which describe the problem-solving process, the Polya Theory of Mathematical Problem-solving is widely accepted (Hestenes, 1987; Taraban, Craig, & Anderson, 2011). The theory involves a generic four-step process: (1) representation of the problem, (2) goal setting and planning, (3) execution of the plan, and (4) evaluation of the solution. In physics education, Hestenes (1987) proposed a similar approach for mechanics problems which includes four stages: description, formulation, ramification, and validation. The common problem-solving model used in engineering education involves identifying known and unknown variables, constructing a graphical problem representation, and developing a mathematical model to represent the two preceding steps (Hestenes, 1987; Taraban, Craig, & Anderson, 2011).

In the first step, representation of the problem, the student must read the problem statement and discern the objective. Chi, Feltovich, and Glaser (1981), by comparing the performances of novice and expert problem solvers, showed that there is a relationship between representation of the problem and the quality of problem-solving. In addition to problem representation, there are other factors involved in effective problem-solving. These factors include domain expertise, argumentation skills, metacognition, reasoning

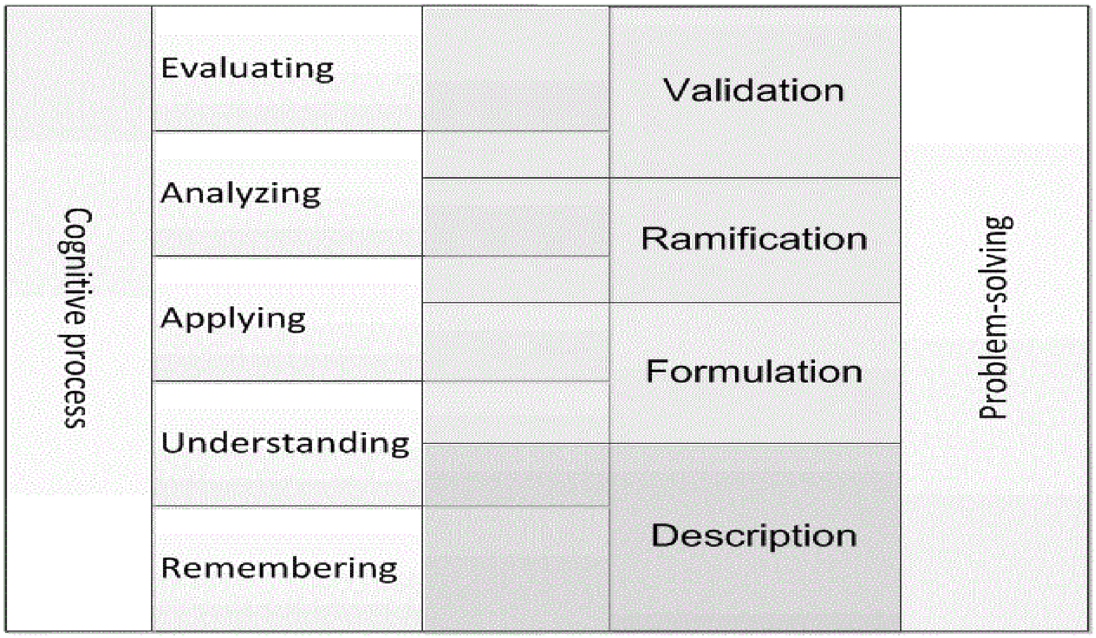


Figure 2-1. Combined cognitive problem-solving model.

skills, and affective variables such as attitudes and emotions. It is not the instructor but the learner who controls most of these factors (Jonassen & Hung, 2008). In mechanics problems, cognitive process categories correlate to the solution process (Douglass et al., 2012). Litzinger et al. (2010) proposed an integrated problem-solving model that explained the relationship between problem-solving phases and the activities which indicate the problem solver's organization of prior knowledge and understanding.

In this section, a model was introduced which combined students' problem-solving steps with the five categories of the cognitive process. In the model, students' learning process was tied to recordable activities in each problem-solving phase, making it possible to attribute a specific activity to a cognitive process category. Combining the five categories of the cognitive process with Hestenes' (1987) problem-solving model, resulted in a cognition problem-solving model to justify the cognitive activities that a student demonstrated throughout a process. Figure 2-1 shows a simple representation of the combined model (Sidhu, Ramesh, & Selvanathan, 2010). In the problem-description stage, the student recalled prior knowledge concerning the problem, understood the problem statement, and set goals. In planning the solution, pattern recognition was also involved, which is also related to recalling prior knowledge. The formulating stage involved understanding the relationship between the parameters and concepts, and applying those concepts to make a mathematical or visual model for the problem. Next, in the ramification stage, the student used the models to solve governing equations and find the problem unknowns. The validation phase was about analyzing the solution, evaluating the answer, and detecting possible errors within the solution.

Relationship Between Learning Theories and CSA Modules

The theoretical framework of a learning tool or model influences its effectiveness. While most instructors emphasize the practical outcomes of CSA modules, cognitive learning theories influence their instructional design significantly. Three learning theories in educational psychology are behaviorism, cognitivism, and constructivism (Sidhu, 2010). The number of studies that address these theories is exceptionally small.

Table2-1displays the reviewed literature which introduce a computer-based pedagogical application and address a theoretical framework. It is shown that only 20% of studies explicitly refer to a theoretical framework while introducing the applications (Sidhu, 2010). Instructional design of a module naturally targets a cognitive skill. However, in order to determine the level of effectiveness of a CSA application, the

Table 2-1 *Theoretical Consideration in CSA Papers*

Course	Number	Percent	Addressing learning theories		
			Explicit	Implicit	None
Dynamics	12	60%	3	7	2
Mechanics of material	2	10%	-	1	1
Statistics and dynamics	1	5%	-	-	-
All three courses	2	10%	-	1	2
Other engineering mechanics	3	15%	1	2	-
Total	20	100%	4 (20%)	11(55%)	5(25%)

associated changes in the student's performance in problem-solving or in exams are measured which fits the behaviorism theory.

Criteria of Effective CSA Modules

Besides improving visualization, most existing CSA modules entail the following characteristics: (1) Interactivity; Because an effective CSA module must be interactive and give a type of autonomy to the user to adjust the pace of navigation with his/her own learning (Gray & Costanzo, 1999; Sidhu, 2010; Staab & Harper, 2000; Stern et al., 2006). (2) Simplicity; an information flood within a CSA module will distract and discourage the user from the intended content, therefore, it should be kept as simple as possible; (3) Appeal; a critical balance between textual and graphical information will facilitate the learning and can be achieved through pop-out boxes (Deliktas, 2011; Roselli, Howard, & Brophy, 2006). If the user needs more explanation on a certain subject, he/she can click on it. Otherwise, the main idea would attract the user through animated or fixed graphical representations.

Assessment of Effectiveness

Table 2-2 depicts assessment methodologies from articles that introduced an innovative CSA module or a computer simulation technique. The table demonstrates that a majority (76%) of studies employed a quantitative approach as the main research method. More than half (56%) of the studies used replies to questionnaires and positive feedback to infer the effectiveness of their modules (Bernhard, 2000; Deliktas, 2011; Eronini, 2000; Boylan-Ashraf, Freeman, & Shelley, 2014; Gray & Costanzo, 1999; Grimes et al. 2006; Karadogan et al. 2012; Koen & Oglesby, 1996; Muthu & Glass, 1999; Roselli, Howard, & Brophy, 2006; Sidhu & Selvanathan, 2005; Stern et al., 2006; Zhu, Aung, & Zhou, 2010;) A small percentage of the studies (9%) used an observation-based qualitative approach as an assessment means.

Regarding developments in teaching engineering mechanics, i.e., statics, dynamics, and strength of materials, efforts made to improve student performance are grouped into three major categories: (1) altering the engineering mechanics curriculum, (2) active learning strategies, and (3) the application of enhancement resources. The first category addresses combining topics of instruction, changing the course sequence/design, and introducing problem/project-based learning in engineering mechanics. The second

Table 2-2 *Assessment Tools in CSA Papers*

Field	Assessment method			
	Questionnaire	Observation	Learning-gain comparison	No assessment
Statics and dynamics	1	1	1	-
Dynamics	10	-	4	4
Mechanics of materials	2	2	2	-
Other engineering mechanics	5	-	-	1
Percentage	55%	9%	21%	15%

category involves students in the learning process through hands-on projects, fostering problem-based learning, and teamwork. The third category, introducing lab experiences, integrates authentic design projects and fosters mastery of concepts through video or CSA modules.

The Research Gaps

A review of the existing literature regarding CSA applications in engineering mechanics education showed that the main objective of CSA modules is to help students visualize key concepts (Deshpande & Huang, 2011; Sidhu, 2010). From the Bloom taxonomy viewpoint, visualization is associated with the understanding category (Krathwohl, 2002). The textual information that helps students remember basic concepts or confirm their previous knowledge may be linked to the remembering category (Stern et al., 2006). The Interaction features enable students to engage in the solution process and observe the changes they make. Although few studies have associated this feature with the cognitive domain level of application (Sidhu & Selvanathan, 2005; Stern et al., 2006; Violante & Vezzetti, 2012), a large percentage of studies have addressed the interaction features from the practical point of view. Interaction features also enable the user to repeat a specific part any number of times with different input parameters. The next category in the revised Bloom's taxonomy of educational objectives is evaluation (Krathwohl, 2002). Attributing the interactive feature in CSA modules to the "application" category entails that instant feedback to the student would address the "evaluation" category. Therefore, like many CSA applications currently used in science education (Rutten, van Joolingen, & van der Veen, 2012), future CSA modules in engineering mechanics will generate feedback regarding the user's solution to problems.

This review revealed three major gaps in the current literature. First, very few studies have explicitly addressed a theoretical framework or have explained how that framework should be used to develop CSA modules. Second, there was a lack of a systematic approach for selection of disciplinary topics used to design CSA modules. Except for the studies covering all concepts in a particular course, only two papers addressed the selection methodology of topics for CSA modules (Boylan-Ashraf, Freeman, & Shelley, 2014; Montfort, Brown, & Pollock, 2009). Almost all of the papers reviewed focused on the difficulty or importance of their selected topics based on the researchers' experience. Finally, evaluation of CSA modules is primarily based on students' feedback and comments. Few studies employed a qualitative approach to address how student cognitive skills can be improved by CSA modules. Thus, the question of “how does CSA help students with learning?” remains unanswered. Focusing on CSA and other pedagogical innovations in engineering mechanics education, we observed that:

- Engineering dynamics is suitable for introducing CSA modules as pedagogical tools because of the number of concepts as well as the high level of complexity. Particularly in engineering dynamics, CSA modules can demonstrate motion of particles and rigid bodies through computer animations, therefore, helping students figure out learned concepts. (Sidhu, 2010; Sidhu & Selvanathan, 2005)
- Most studies suggest that interactive features, animation, and problem-solving are the main characteristics of effective CSA. Although learning theories affect the instructional design of CSA modules, they are not often addressed in published research papers.
- Most researchers state that CSA modules cannot be considered as the sole pedagogical tool and that CSA modules cannot replace conventional classroom instruction. Ideally, traditional, face-to-face or online classes combined with novel improvements, such as peer help or group problem-solving, can be complemented by CSA modules (Schmidt, 2011).
- While it is common to use students’ performance change and self-reported questionnaires to evaluate the effectiveness of CSA modules, the features cannot express the quality of CSA effects on the students’ learning process. Overall evaluation results may be subject to the Hawthorne effects, which means that

students’ responses may be affected by the attention they received as study participants.

CHAPTER III

DEVELOPMENT OF CSA MODULES

In most engineering programs, a dynamics course includes two main sections: particle dynamics and rigid body dynamics. Particle dynamics deals with the motion of mass particles without dimension. Rigid body dynamics addresses the motion of bodies whose dimension affects that motion. Particle dynamics starts with kinematics of particle, continues with particle kinetics (Newton’s Laws of Motion), work and energy, and finally concepts of impulse and momentum. This study addressed students’ problem-solving in particle dynamics and focused on the three topics mentioned above. Because particle kinematics is the simplest topic and most students learned it in high school or college physics, we focused on particle kinetics (Newton’s Laws of Motion), work and energy, and concepts of impulse and momentum which require more effort by the instructor and student.

For each of the three topics, one CSA module was developed to investigate how working with the modules affects students’ problem-solving. Each CSA module included one solved problem represented through a number of interactive slides. The design of the CSA modules followed the design initially proposed by Fang (2012), which included several features. For example, a detailed solution of mathematical equations was included in the CSA modules, so students could follow the solution steps of a dynamics problem as well as the physical phenomenon. Another problem called an “assessment problem” functioned as a benchmark to evaluate the effects of the module. For those students who worked on a paper representation of the solved problem, another representation of it, called a textbook-style problem or paper learning example (PLE) problem was developed which illustrated the solution in a traditional fashion, i.e., problem statement, problem diagrams, solution steps, complimentary diagrams, equations, and final answer.

After preparing a draft design of the textbook-style problem, assessment problem, and the CSA module, the research team made necessary improvements to the problems and modules. The following criteria guided the design of the assessment and solved problems. The problems:

- addressed only one topic,
- included all relevant concepts within the topic,
- were clear and concise,
- had a moderate level of difficulty, and
- featured a clear, attractive diagram to facilitate the student’s understanding of the problem statement.

The two problems pertaining to each topic were similar, though not the same, so that the student could use the principles and ideas of the solved problem in the assessment problem, but the solution procedure was not exactly the same. The level of difficulty for the assessment problem was slightly lower than the learning solved example. None of problems included ill-structured, combined topics, or required innovative solutions. The mathematical knowledge required for the solution was not designed to be complex or rigorous. As a general principle, the problems were intended to reflect the students’ understanding of the relevant topic in engineering dynamics. In addition, the solved problem which was used in the CSA module was to have concise yet sufficient explanation, clear figures and diagrams, enough (but not boringly long) text explanation, and an attractive layout. A typical student participant needed approximately 10 to 15 minutes to solve the assessment problem. It was determined that a longer solution time was likely to create exhaustion among the participants and loss of concentration during the process.

Module-1: Newton's Second Law of Motion

The first module addressed Newton's Second Law of Motion. Two learning objectives guided the development and design of the module. After working with the module, students' were expected to be able to (1) develop free-body diagrams for particles in a relative motion and (2) apply Newton's Second Law to determine forces and accelerations of particles in a relative motion. The module consisted of the following sections: title page (one slide), learning objectives (one slide), problem statement (one slide), animation page (one slide), and solution (five slides).

The title page and learning objectives provided needed information to the student about the topic before being exposed to the problem and animation. Figures 3-1 shows the problem page and animation pages of the module. The animation page contained a dynamic animated representation of the problem. The animation illustrated the motion of the blocks on the ramp and had the capability to start and pause upon the user's command. The solution was presented in a step-by-step manner through multiple pages, enabling the user to navigate back and forth. As shown in Figure 3-2, there were clickable links on specific words to transport the user to more descriptive figures. In order to achieve the learning objectives, each module had four features, as initially proposed by Fang (2012):

(1) navigation over the slides,

(2) play-pause-reset buttons in the animation,

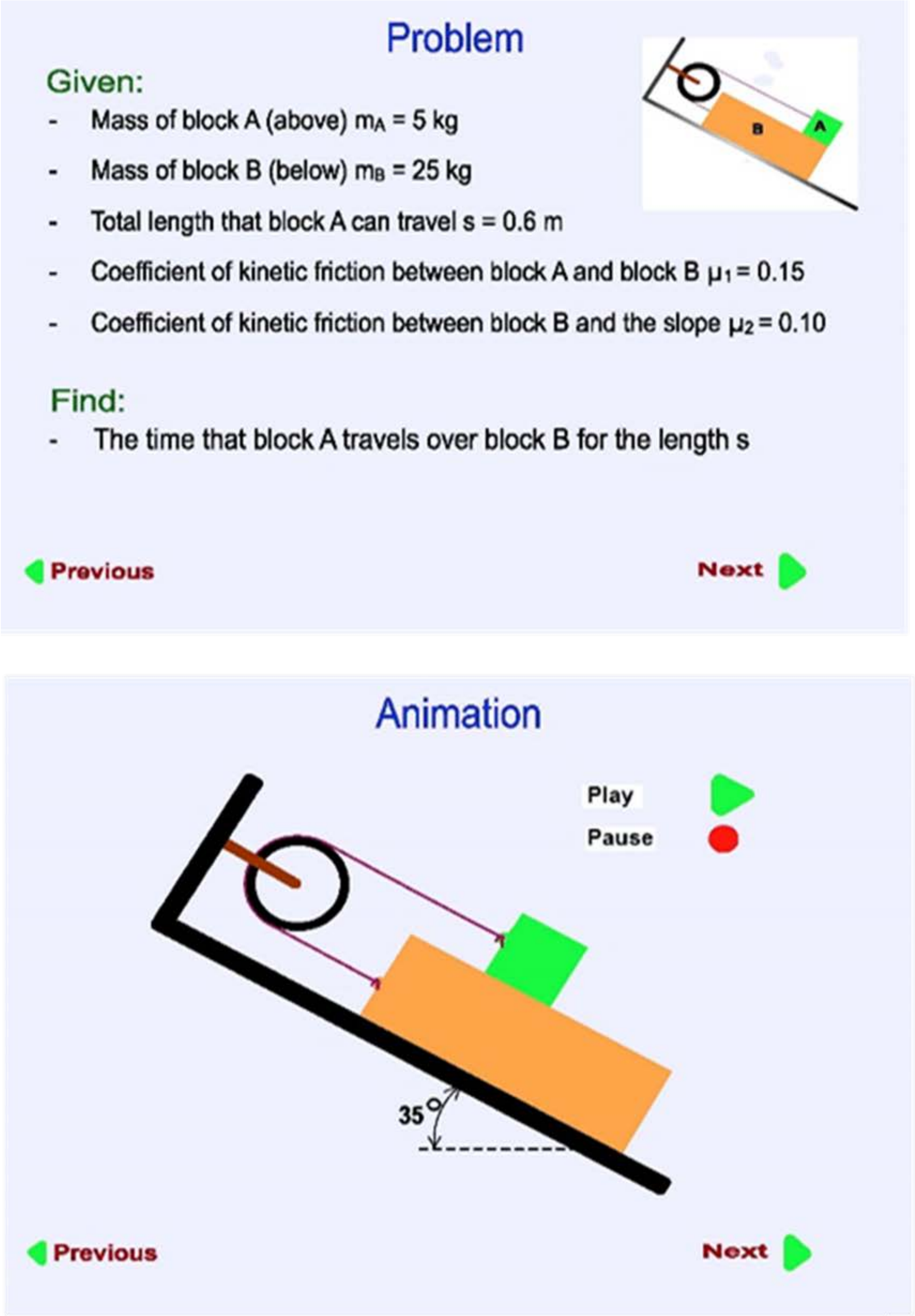
(3) dynamic parameter change

(4) graphical pop-up hints.

The first feature, navigation, was common among all modules of this type by adding “next,” “previous,” and “return” buttons on all pages. It gave the user the opportunity to decide the amount of time he/she wanted to spend on a specific slide before continuing to the next slide. The user could also scroll to the first slide. In the second feature, the user controlled the animation by pausing, replaying, or resetting it.

The second feature was similar to the navigation feature in helping the user. The user could watch the animation as many times as needed.

It was especially important that real physical models not be paused while functioning because restarting them took a long time. The third feature involved changing one or more parameters in the solution which immediately affected the values in the solution and final answer. In this way, the user could follow how altering a parameter changed the numerical results. Pop-up hints, or the last function, appeared upon clicking the “hint” button. Some students felt that they needed more explanation, so they clicked it, while others bypassed such hints.



Problem

Given:

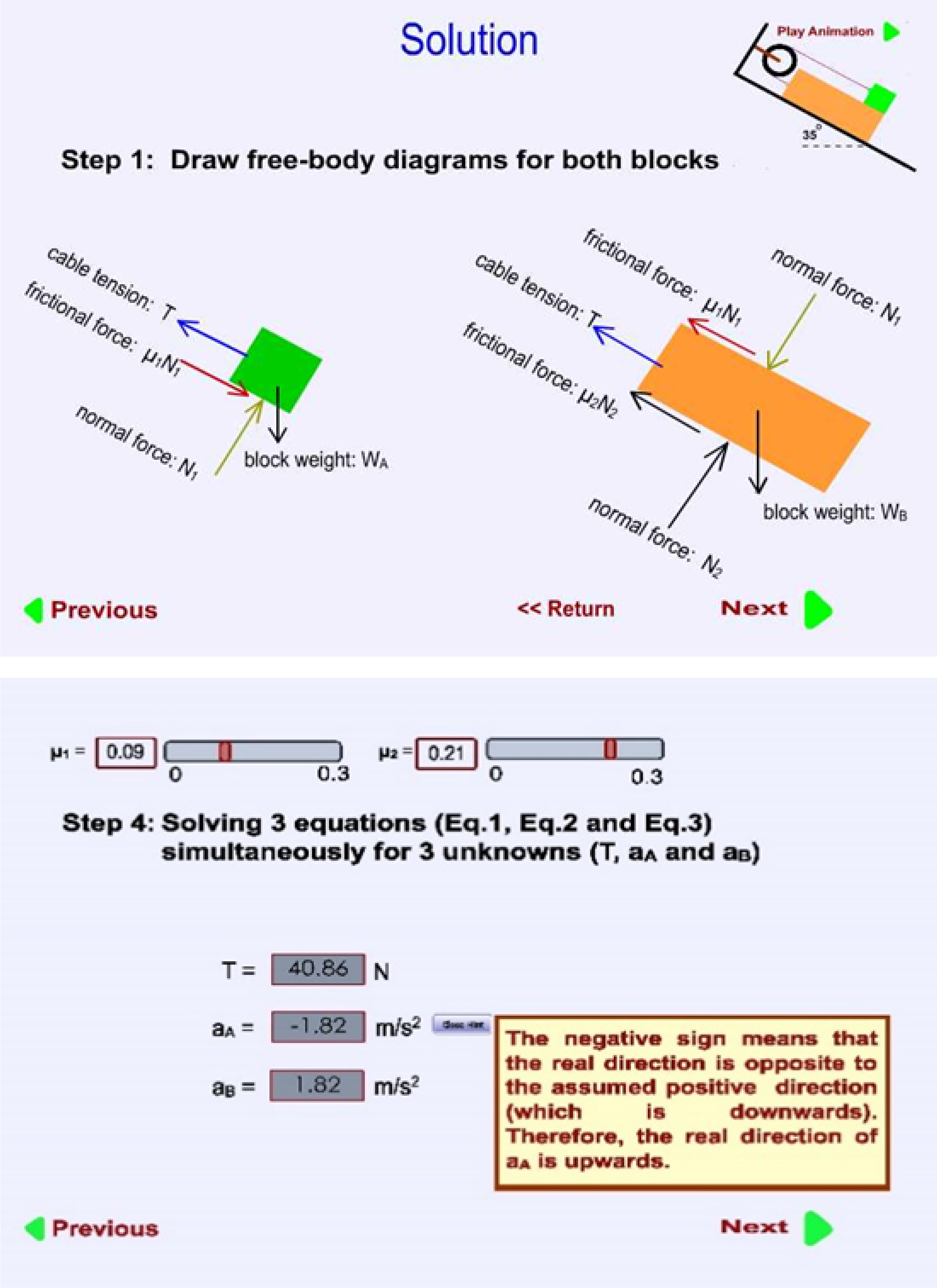
- Mass of block A (above) $m_A = 5$ kg
- Mass of block B (below) $m_B = 25$ kg
- Total length that block A can travel $s = 0.6$ m
- Coefficient of kinetic friction between block A and block B $\mu_1 = 0.15$
- Coefficient of kinetic friction between block B and the slope $\mu_2 = 0.10$

Find:

- The time that block A travels over block B for the length s

Animation

Figure 3-1. Selected graphic user interface screen shots of Module-1(a) and (b)



Solution

Step 1: Draw free-body diagrams for both blocks

Step 4: Solving 3 equations (Eq.1, Eq.2 and Eq.3) simultaneously for 3 unknowns (T, a_A and a_B)

T = 40.86 N

a_A = -1.82 m/s^2

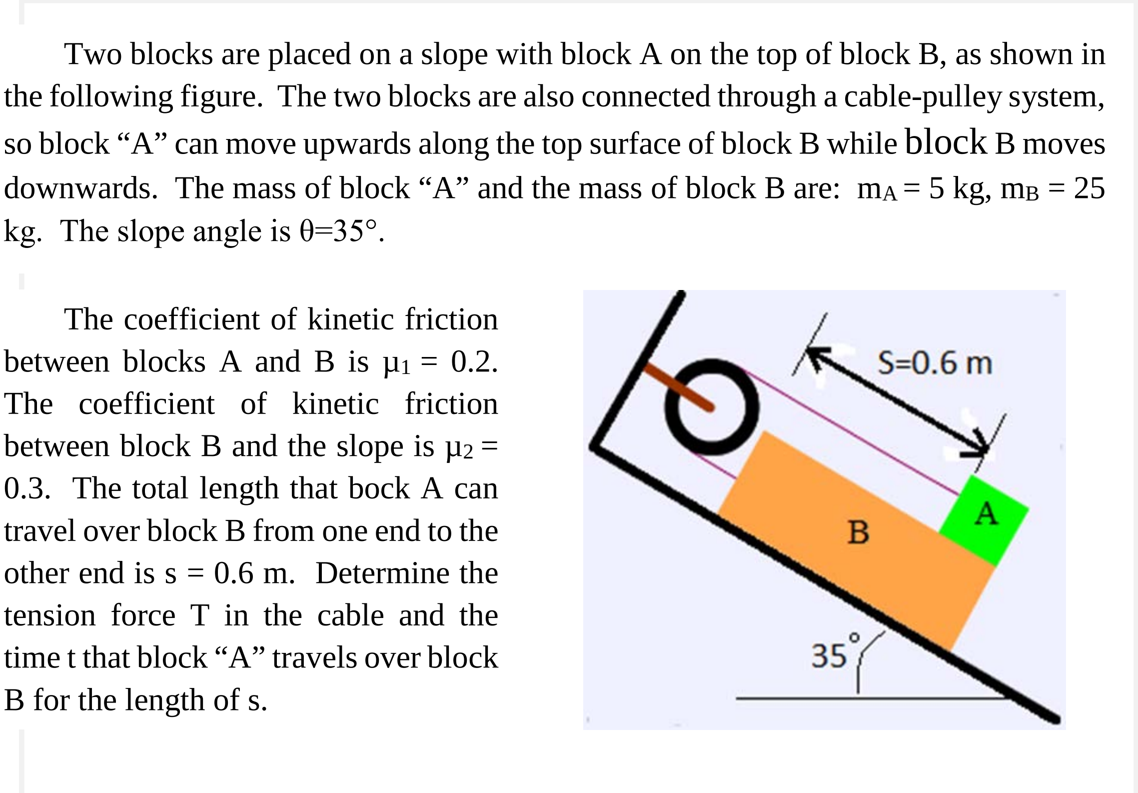
a_B = 1.82 m/s^2

The negative sign means that the real direction is opposite to the assumed positive direction (which is downwards). Therefore, the real direction of a_A is upwards.

Figure 3-2. Selected graphic user interface screen shots of Module-1(c) and (d).

Textbook-style Problem

The solved problem used for PLE representation entailed the motion of two blocks on an inclined surface in which the surface supported the blocks. The smaller block moved on the larger block and the two blocks were connected together with a cable-pulley system. Friction between the surfaces and the relative motion of the blocks played a major role in the topic. The student needed a basic knowledge of kinematics to solve the problem although they were allowed to use the textbook to look up the formula. Figure 3-3 shows the solved problem statement and diagram. The problem asked the user to find one “T” unknown, but it actually had two objectives: finding the acceleration from the kinetics and finding the time parameter from kinematics.



Two blocks are placed on a slope with block A on the top of block B, as shown in the following figure. The two blocks are also connected through a cable-pulley system, so block “A” can move upwards along the top surface of block B while block B moves downwards. The mass of block “A” and the mass of block B are: $m_A = 5$ kg, $m_B = 25$ kg. The slope angle is $\theta=35°$.

The coefficient of kinetic friction between blocks A and B is $\mu_1 = 0.2$. The coefficient of kinetic friction between block B and the slope is $\mu_2 = 0.3$. The total length that bock A can travel over block B from one end to the other end is s = 0.6 m. Determine the tension force T in the cable and the time t that block “A” travels over block B for the length of s.

*Figure 3-3.*Textbook-style problem of Module-1.

Assessment Problem

According to the research design, the assessment problem was developed to be used for the pretest and posttest phases. It was similar to the PLE problem in topic and solution, with small differences in configuration and level of difficulty. The assessment problem had a straightforward solution procedure, did not contain an "ill-structured" component in the solution, and did not require complex mathematical or trigonometric calculations. As shown in Figure 3-4, the problem involved a horizontal surface which did not need calculation of reaction on an inclined surface.

As shown in the following figure, block A is placed on the top of block B. While a tension force P of 300 N draws block B to the left, block A moves to the right through a cable-pulley system that connects the two blocks. The mass of block 'A' and the mass of block B are: $m_A = 15$ kg, $m_B = 30$ kg. The total length that bock A can travel over block B from one end to the other end is s = 0.6 m. The coefficient of kinetic friction between block A and block B is 0.4 and the coefficient of kinetic friction between block B and the ground surface is 0.5. Determine the time that block A travels over block B for the length of s.

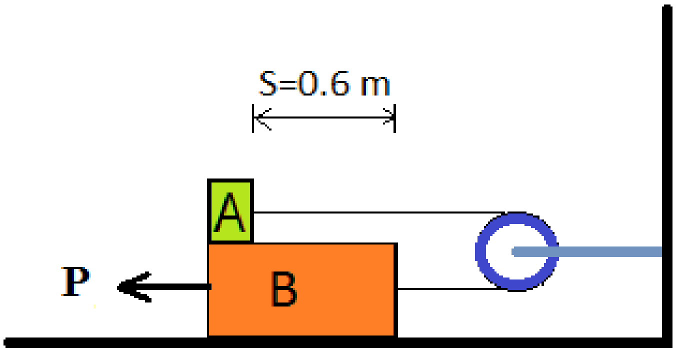


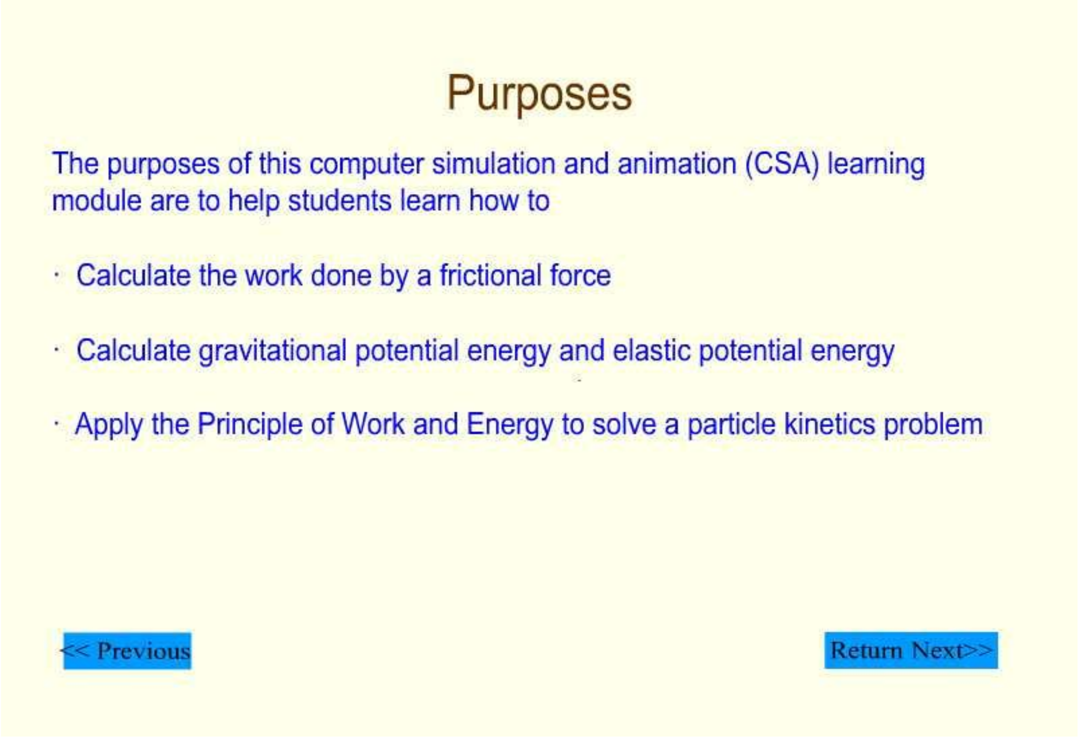
Figure 3-4. Assessment problem of Module-1.

Module-2: Principle of Work and Energy

The second module covered the Principle of Work and Energy. The learning objectives of the module were to help students learn how to (1) calculate the work done by a frictional force, (2) calculate gravitational potential energy and elastic potential energy, and (3) apply the Principle of Work and Energy to solve a particle kinetics problem. This module also included four learning features (Fang, 2012):

(1) Step-by-step navigation throughout the module
(2) Interactive animation with the capability of parameter change which affects the motion
(3) Clickable graphical hints throughout the solution process
(4) Clickable pop-up diagrams

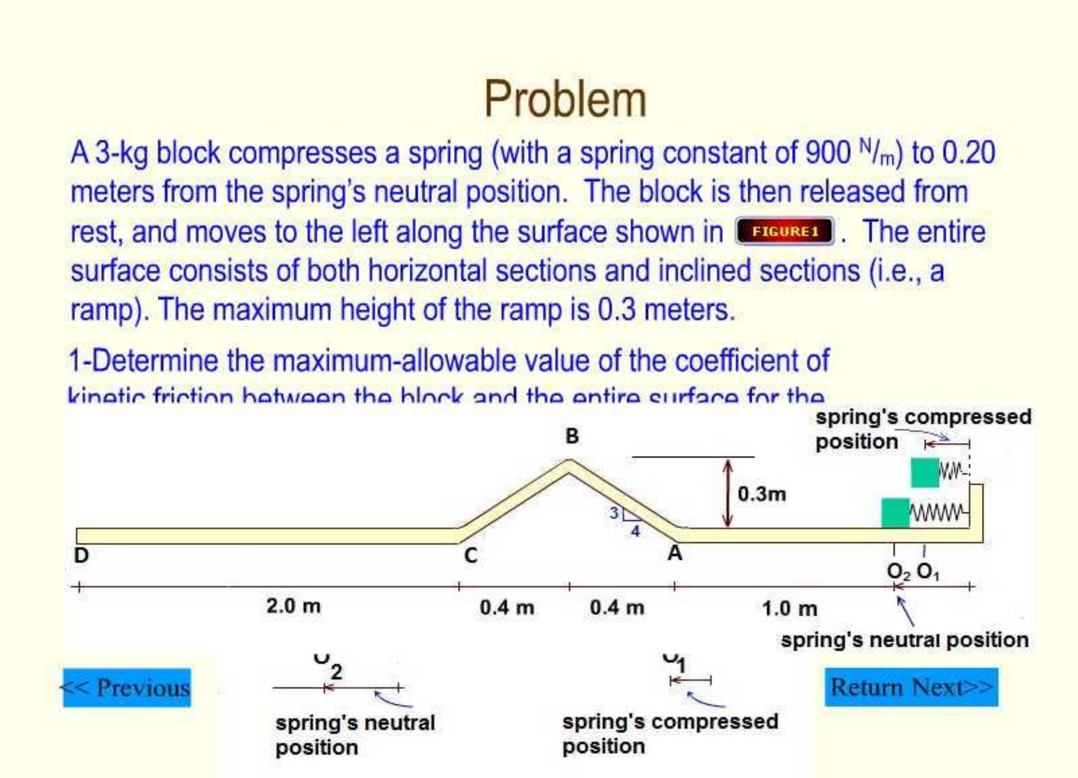
Figure 3-5 illustrates the sample slides from the learning module showing the above-mentioned learning features. One important characteristic of the Module-2 was the step-by-step solution by which the users could navigate through the solution at their own pace. In addition, all diagrams in the modules are pop-ups with clickable buttons. The user has access to the button in each solution slide to see the problem diagram as needed. The user could also click the figure to see it in more detail. Interactive animation means that the user can change an input parameter, the coefficient of friction which affects the animation speed and the path at which the block moves. If the coefficient of friction is set to a high value, the block will stop before the ramp, decreasing that coefficient will allow the block to move up the ramp and return. Setting the value to a minimum will allow the block to pass the tip and descend downward. The user could change the parameter with a



Purposes

The purposes of this computer simulation and animation (CSA) learning module are to help students learn how to

- Calculate the work done by a frictional force
- Calculate gravitational potential energy and elastic potential energy
- Apply the Principle of Work and Energy to solve a particle kinetics problem

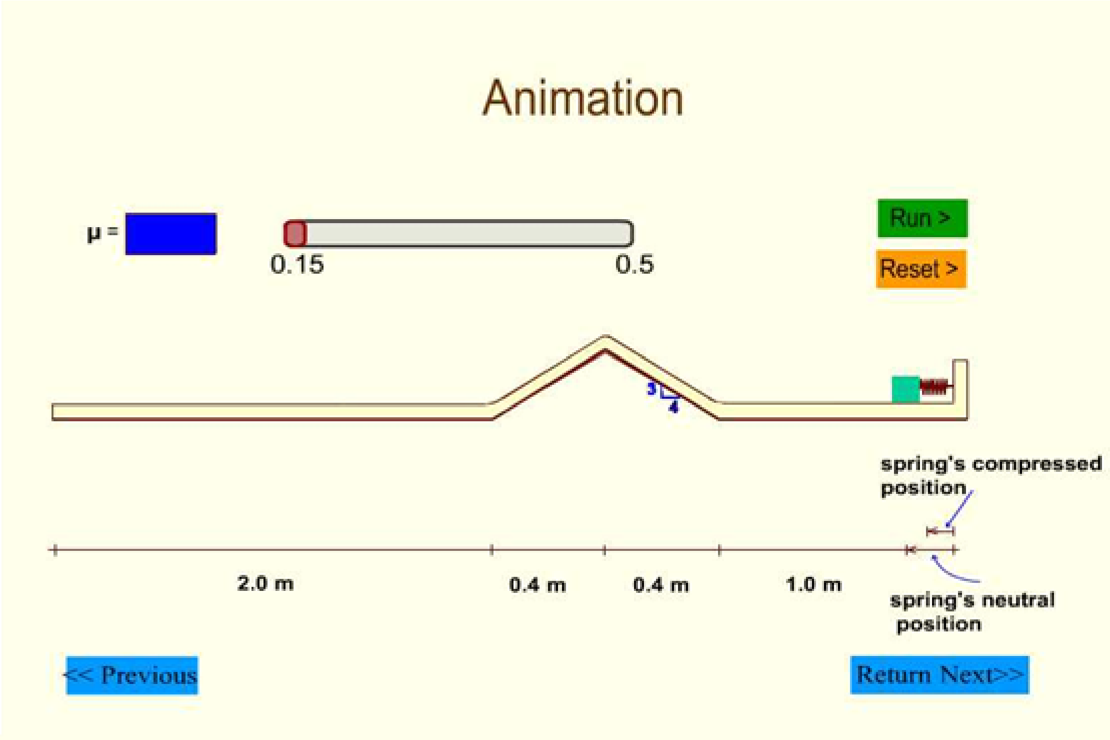


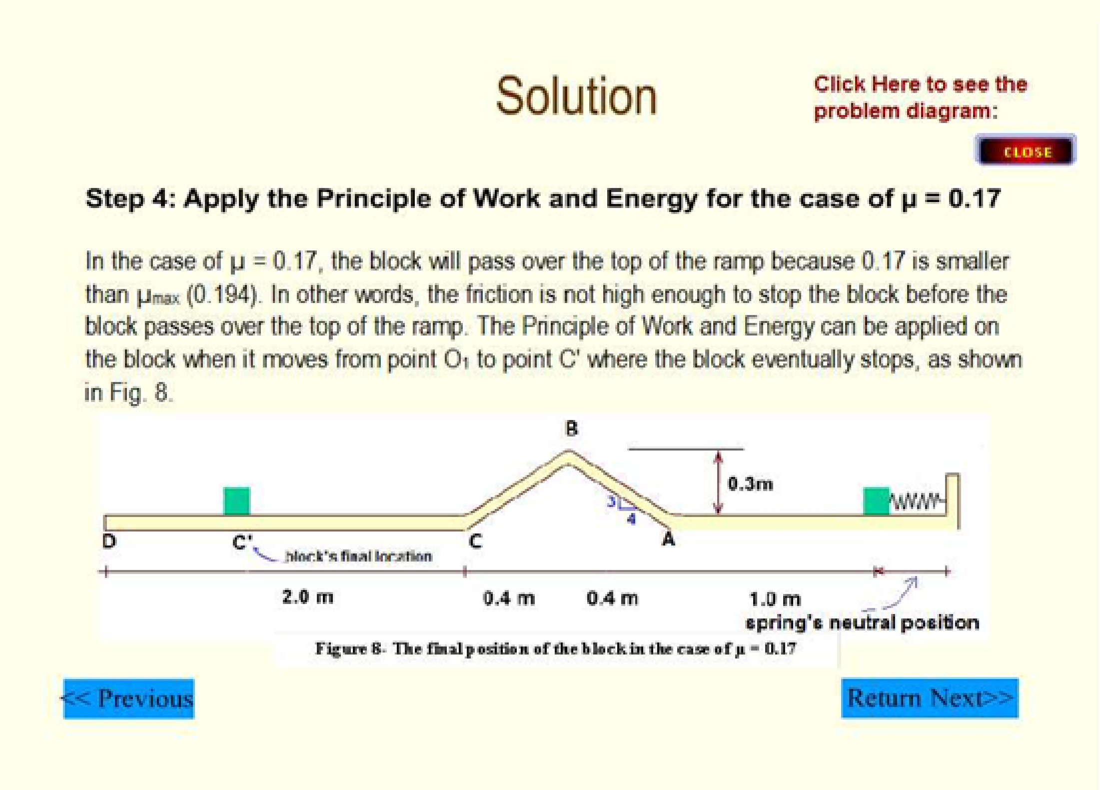
Problem

A 3-kg block compresses a spring (with a spring constant of 900 $^{N}/_{m}$) to 0.20 meters from the spring's neutral position. The block is then released from rest, and moves to the left along the surface shown in FIGURE1 . The entire surface consists of both horizontal sections and inclined sections (i.e., a ramp). The maximum height of the ramp is 0.3 meters.

1-Determine the maximum-allowable value of the coefficient of kinetic friction between the block and the entire surface for the

Figure 3-5. Selected graphic user interface screen shots of Module-2 (a) and (b).





Step 4: Apply the Principle of Work and Energy for the case of μ = 0.17

In the case of μ = 0.17, the block will pass over the top of the ramp because 0.17 is smaller than μ_{max} (0.194). In other words, the friction is not high enough to stop the block before the block passes over the top of the ramp. The Principle of Work and Energy can be applied on the block when it moves from point O_1 to point C' where the block eventually stops, as shown in Fig. 8.

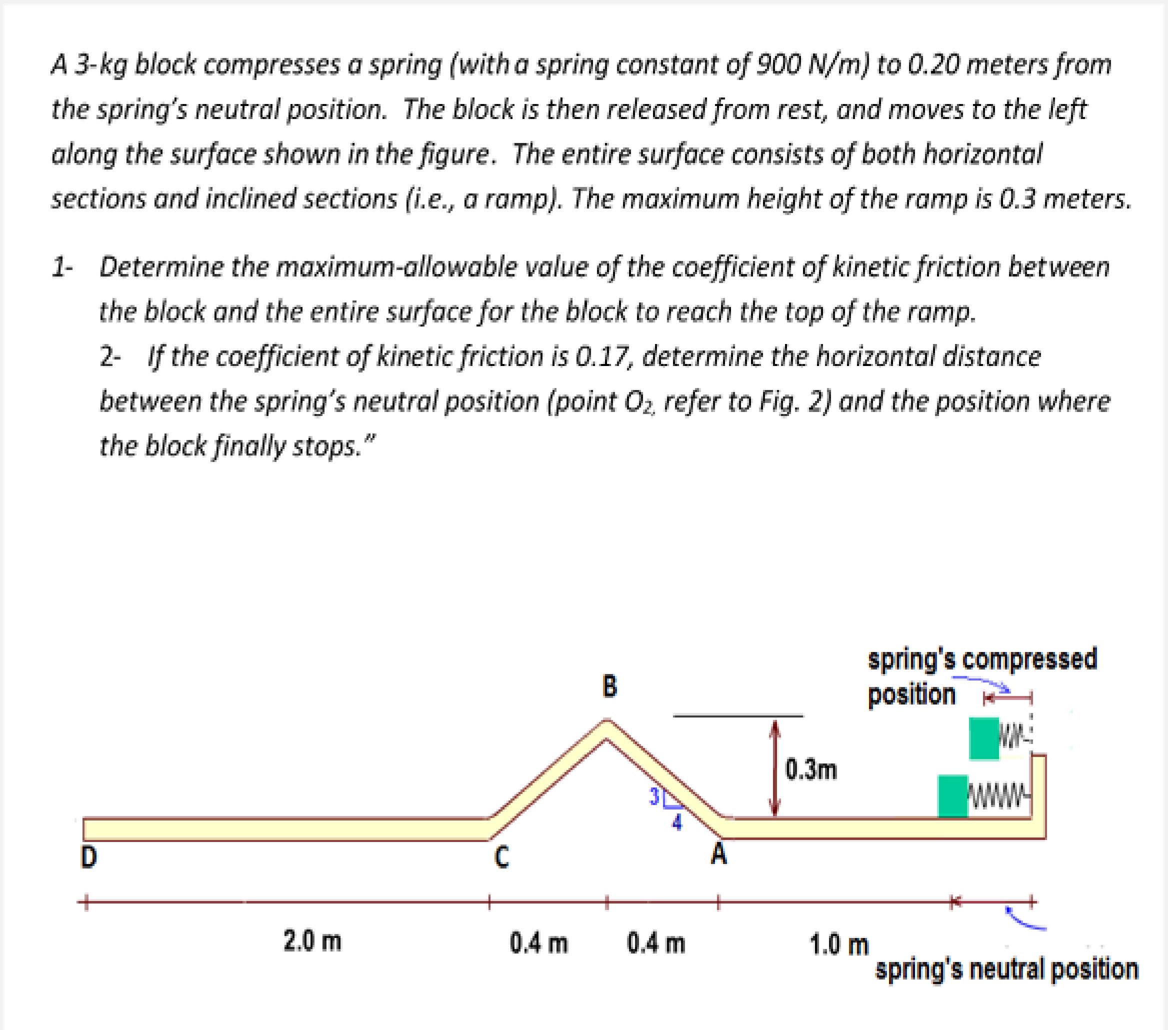
Figure 8- The final position of the block in the case of μ = 0.17

Figure 3-6. Selected graphic user interface screen shots of Module-2 (c) and (d).

slider, pause, reset, rerun the animation, and observe the changes in the motion regime and speed.

Textbook-style Problem

The solved problem used in Module-2 involved application of the Principle of Work and Energy to a block moving on a surface with a bump. The problem solution had three main steps and required the participant to distinguish between different scenarios



A 3-kg block compresses a spring (with a spring constant of 900 N/m) to 0.20 meters from the spring's neutral position. The block is then released from rest, and moves to the left along the surface shown in the figure. The entire surface consists of both horizontal sections and inclined sections (i.e., a ramp). The maximum height of the ramp is 0.3 meters.

1- *Determine the maximum-allowable value of the coefficient of kinetic friction between the block and the entire surface for the block to reach the top of the ramp.*
   2- *If the coefficient of kinetic friction is 0.17, determine the horizontal distance between the spring's neutral position (point O_2, refer to Fig. 2) and the position where the block finally stops."*

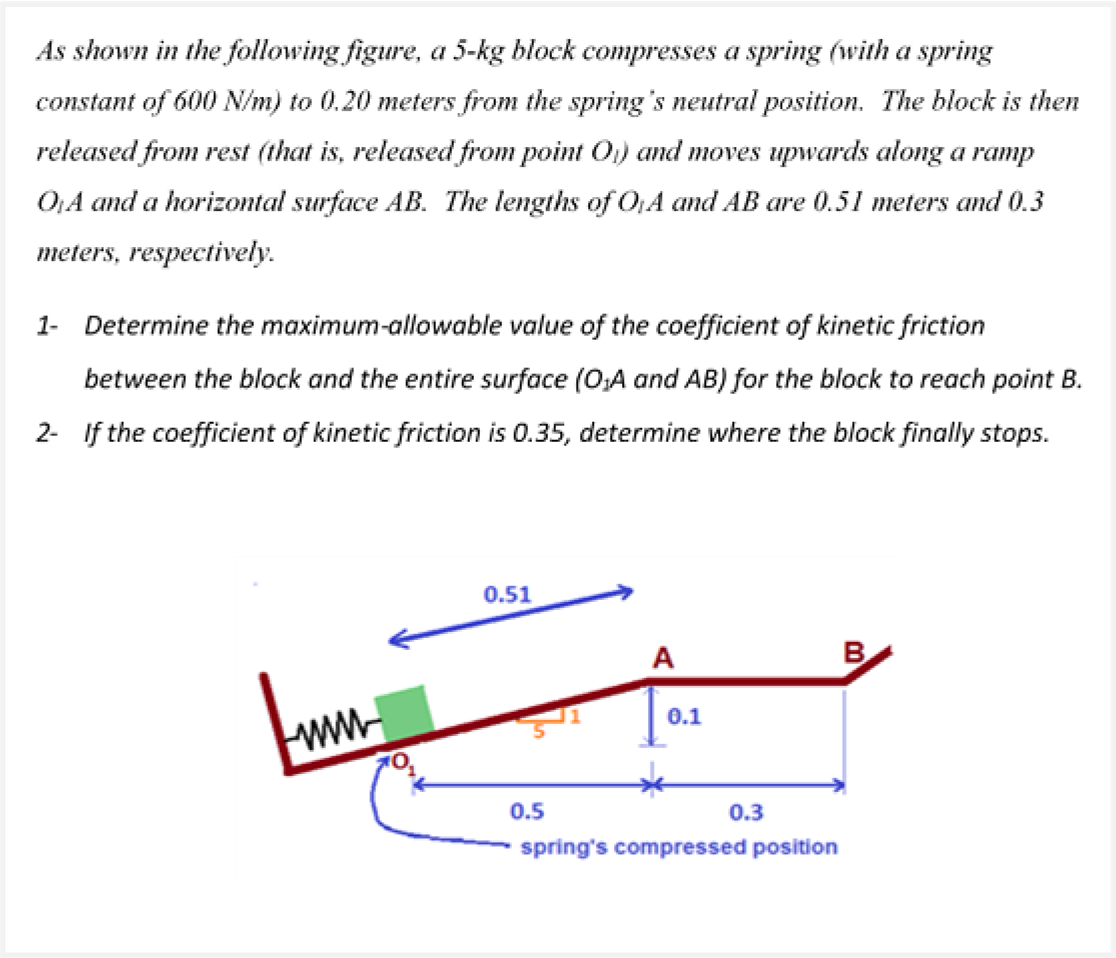
Figure 3-7. Textbook-style problem of Module-2.

that can occur depending on the coefficient of friction parameter. It also required the participant to make a major conclusion to find the correct case. The problem statement and diagram are as follows.

Figure 3-7 illustrates the statement of the PLE problem. The problem was identical to the modules-solved problem. It included a bump on which the block moves, and depending on the value of friction factor, the block may or may not pass the tip of the bump. The student observed the solution for the coefficient of friction satisfying a specific condition described. The possibility of different scenarios by changing the friction factor enabled the user to observe how friction changes the motion and how it is calculated in the solution.

Assessment Problem

An assessment problem was developed to explore how students solve it initially and how they use their findings after they work with the CSA module. Figure3-8 shows the problem statement and diagram of the assessment problem used in this study. As shown in Figure 3-8, in order to avoid an ill-structured problem, it was well-defined with enough input information, no redundant confusing input, explicitly prescribed goals, and one correct answer (Jonassen, 2000). The unknown problem was clearly stated in order that the objects and situation presented in the problem be simple, idealized, and decontextualized, and the problem addressed only the “work and energy” topic. In addition, the solution involved no additional assumptions or implicit input parameters. In both problems, there was a possibility of pass-or-stop which in the assessment problem required the participant to make an assumption, try a solution, check correctness of that assumption, and verify the correct answer. It was deliberate because the CSA learning-solved problem included three scenarios which affected the path of motion of the block. The intent was to determine if the participant would notice different scenarios. While it was intended to maintain the similarity in the concept in both assessment and learning problems, the configuration of the assessment problem was changed in order to observe how participants use their knowledge about major concepts, e.g., friction, definitions of work and energy, and principle of work and energy, when they return to solve the "assessment problem."



As shown in the following figure, a 5-kg block compresses a spring (with a spring constant of 600 N/m) to 0.20 meters from the spring's neutral position. The block is then released from rest (that is, released from point O_1) and moves upwards along a ramp O_1A and a horizontal surface AB. The lengths of O_1A and AB are 0.51 meters and 0.3 meters, respectively.

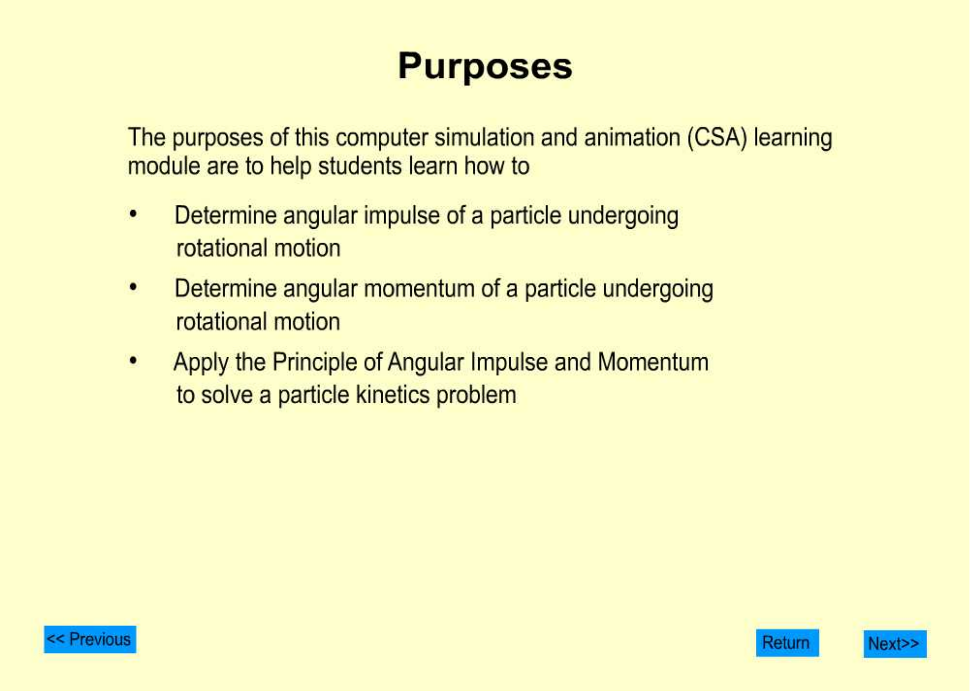
1- *Determine the maximum-allowable value of the coefficient of kinetic friction between the block and the entire surface (O_1A and AB) for the block to reach point B.*
2- *If the coefficient of kinetic friction is 0.35, determine where the block finally stops.*

Figure 3-8. Assessment problem of Module-2.

Module 3: Principle of Impulse and Momentum

Module-3 involved the Principle of Impulse and Momentum topic, and addressed both linear and angular definitions for impulse and momentum. Because angular impulse and momentum is more abstract, the research team used the angular case for the CSA module. In addition, students were introduced to the topic for the first time. After studying this module, the students were expected to be able to: (1) determine the angular impulse of a particle undergoing rotational motion, (2) determine angular momentum of a particle undergoing rotational motion, and (3) apply the Principle of Angular Impulse and Momentum to solve a particle kinetics problem. Based on student feedback on Module-2, some of the features of the third module were changed. For instance, one change involved altering the parameter slider to an editable box in order that the user could input a value with desired precision. Another feature was dynamic 3D diagrams added to the module, along with more mathematical hints. Other items, such as navigation over slides, dynamics interactive animation, and clickable pop-up hints and clickable figures were maintained.

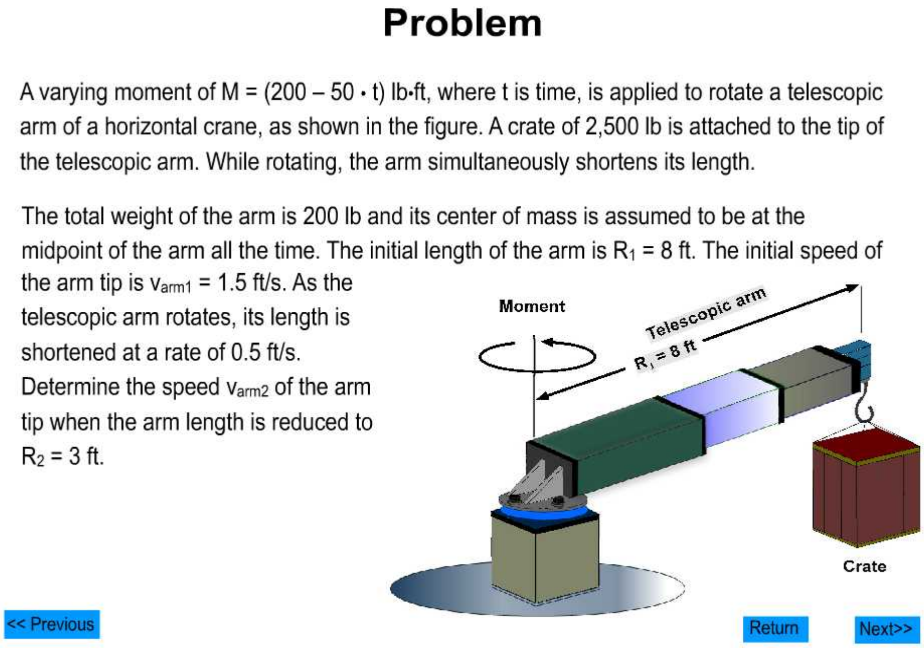
The module included the title page, learning objectives page, problem statement, guidelines for working and navigation in the module, and one animation page followed by a step-by-step solution. Mathematical clickable pop-up hints helped the user follow the calculations in detail. Figure 3-9 includes the learning objectives and problem statement, and Figure 3-10 shows animation and solution slides, respectively.



Purposes

The purposes of this computer simulation and animation (CSA) learning module are to help students learn how to

- Determine angular impulse of a particle undergoing rotational motion
- Determine angular momentum of a particle undergoing rotational motion
- Apply the Principle of Angular Impulse and Momentum to solve a particle kinetics problem

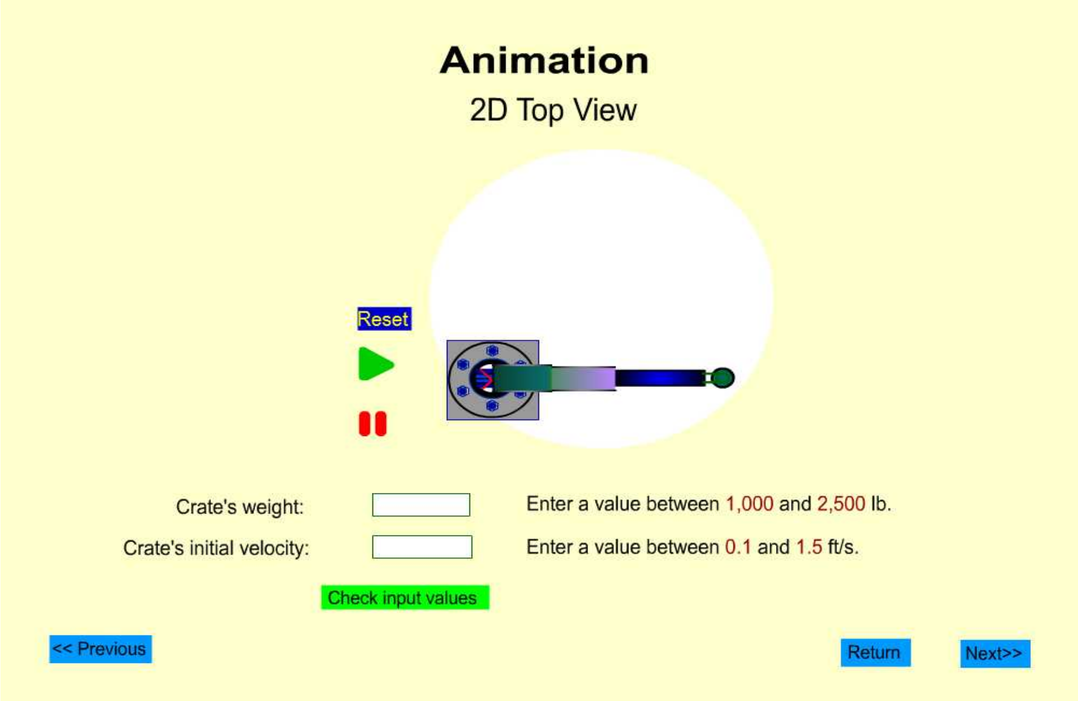


Problem

A varying moment of M = (200 – 50 • t) lb•ft, where t is time, is applied to rotate a telescopic arm of a horizontal crane, as shown in the figure. A crate of 2,500 lb is attached to the tip of the telescopic arm. While rotating, the arm simultaneously shortens its length.

The total weight of the arm is 200 lb and its center of mass is assumed to be at the midpoint of the arm all the time. The initial length of the arm is R_1 = 8 ft. The initial speed of the arm tip is v_{arm1} = 1.5 ft/s. As the telescopic arm rotates, its length is shortened at a rate of 0.5 ft/s. Determine the speed v_{arm2} of the arm tip when the arm length is reduced to R_2 = 3 ft.

*Figure 3-9.*Selected graphic user interface screen shots of Module -3 (a) and (b)

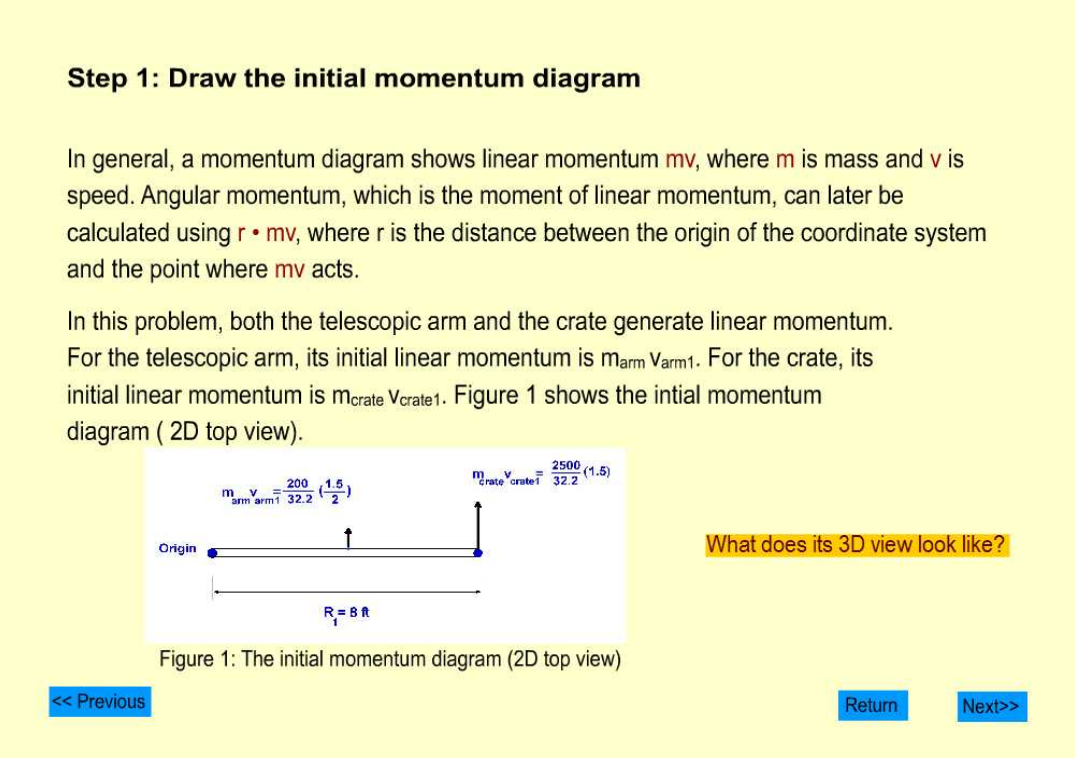


Animation

2D Top View

Crate's weight: Enter a value between 1,000 and 2,500 lb.

Crate's initial velocity: Enter a value between 0.1 and 1.5 ft/s.



Step 1: Draw the initial momentum diagram

In general, a momentum diagram shows linear momentum mv, where m is mass and v is speed. Angular momentum, which is the moment of linear momentum, can later be calculated using r • mv, where r is the distance between the origin of the coordinate system and the point where mv acts.

In this problem, both the telescopic arm and the crate generate linear momentum. For the telescopic arm, its initial linear momentum is m_{arm} v_{arm1}. For the crate, its initial linear momentum is m_{crate} v_{crate1}. Figure 1 shows the intial momentum diagram (2D top view).

Figure 1: The initial momentum diagram (2D top view)

Figure 3-10. Selected graphic user interface screen shots of Module-3 (c) and (d)

Textbook-style Problem

CSA problem characteristics involve the rotation of two masses about the origin. It is essentially a particle dynamics problem. The problem statement stipulated this point. Focusing on angular impulse and momentum, the problem involved a telescopic crane which rotated about its basepoint. During the rotation, the arm length of the crane shortens. This type of crane is used commonly in storage yards and warehouses. The crane settings were introduced to demonstrate the applications of the topic.

The 3D diagram was intended to help the students understand the problem clearly. The problem could not be solved by the previous topics, such as Newton's Second Law or the Principle of Work and Energy. Nevertheless, the solution was relatively simple if the student could conceptualize the problem motion and apply the Principle of Impulse and Momentum correctly.

Assessment Problem

In order to simplify the problem and focus on the topic, the problem assumed the frictional force to be negligible. Also, the student did not need to calculate of normal reaction either. As soon as the student could identify the dynamics principle and understood which forces contributed to the angular impulse, the solution was straightforward. This problem had a capability to add more assumptions in case the student could solve it completely in the pretest. In such a case, during the posttest the participant was asked to apply the frictional force. Frictional force does not participate in the solution but the students need to conceptualize the principle of impulse and momentum to prove that.

A varying moment of M = (200 – 50·t) lb·ft, where t is time, was applied to rotate a telescopic arm of a horizontal crane, as shown in the figure. A crate of 2,500 lbs. was attached to the tip of the telescopic arm. While rotating, the arm simultaneously shortens in length.

The total weight of the arm is 200 lb., and its center of mass was assumed to be at the midpoint of the arm at all times. The initial length of the arm is R_1 = 8 ft. The initial speed of the arm tip is v_{arm1} = 1.5 ft/s. As the telescopic arm rotates, its length is shortened at a rate of 0.5 ft./s. Determine the speed v_{arm2} of the arm tip when the arm length is reduced to R_2 = 3 ft.t

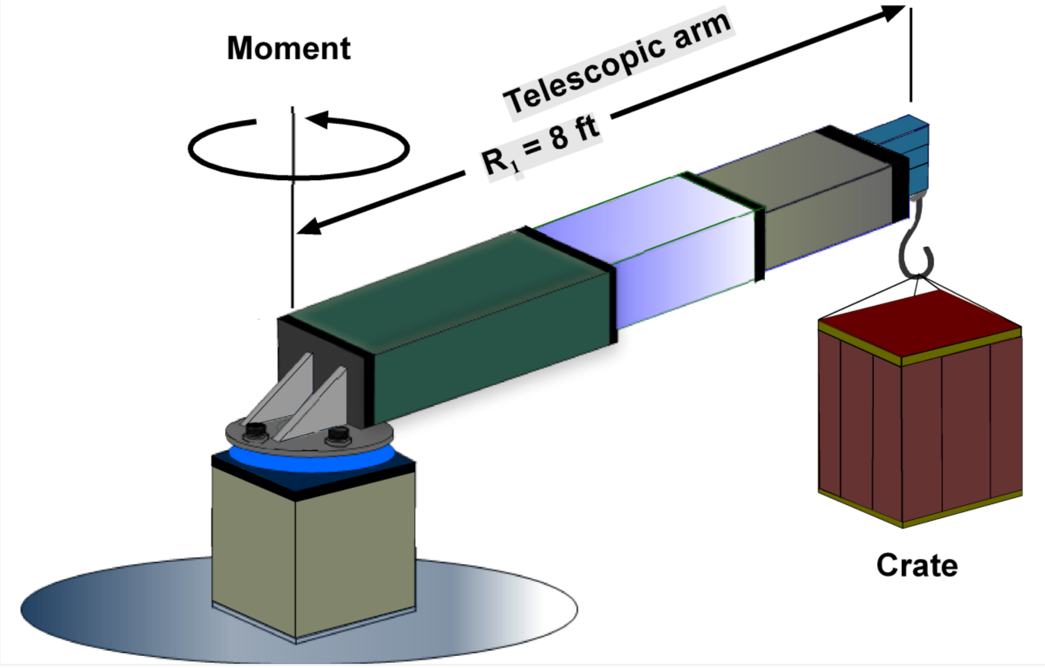


Figure 3-11. Textbook-style problem of Module-3.

As shown in the following figure, a cable going through the inside of a pole is attached to a 1.5 kg sphere. The cable shortens with a constant rate of 0.05 m/s to drag the sphere, so the sphere slides along the pole. At the same time, a varying moment of $M = 0.02\cdot t^2$ (where t is time in seconds) is applied on the pole to rotate the pole.

The sphere starts from rest, with the initial distance of the sphere to the rotating center being 0.35 m. The friction between the sphere and the pole, and the mass of the pole are both neglected. Determine the speed of the sphere after 3 seconds when the distance of the sphere to the rotating center is reduced to 0.24 m.

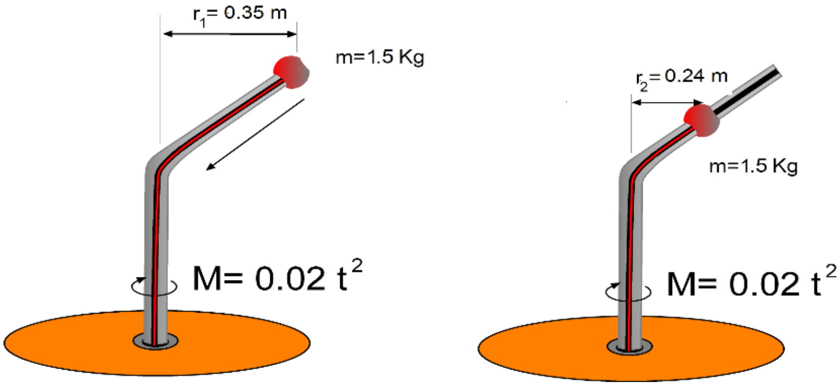


Figure 3-12. Assessment problem of Module-3.

CHAPTER IV

RESEARCH METHODOLOGY

The research process started with developing three CSA modules in particle dynamics, meeting the minimum criteria for educational CSA modules. The changes in students' problem-solving were characterized by the differences in their behavior before and after working with the modules. For this purpose, an assessment problem was developed which was to be solved by the participant twice, once before and once after working with the CSA module. The first and second attempts were called pretest and posttest, respectively. In the design, working with the CSA module was defined as intervention. Data from participants' thoughts and reactions during the process were collected to identify the changes that the CSA modules were expected to make. Qualitative analysis of the collected data were used to find the answer to the first research question, which addresses the changes in students' problem solving due to the application of CSA module. Replicating the process, that is, replacing the CSA module with a textbook-style-solved PLE representation and comparing the CSA effects with PLE, leads to an answer to the second research question, which focuses on comparing the effects of CSA modules and paper representation on students' problem-solving.

Qualitative Inquiry Method

Qualitative inquiry involves studying the quality of social or individual behavior. For this reason, participants' behavior during the problem-solving activity and interaction with CSA modules were observed. An interview followed the activity in which participants spoke about their thoughts and replied to a number of open-ended questions about the activity. The effects of the CSA modules in students' problem-solving formed the main theme of this dissertation. The research questions characterized the qualitative content of the study. A qualitative inquiry approach is favored increasingly in engineering education research (Borrego et al., 2009; Koro-Ljungberg & Douglas, 2008). A qualitative approach is defined as an interpretive, realistic approach to the world in which something is studied in its natural setting, and an attempt is made to interpret phenomena in terms of the meaning that people bring to them. In comparing qualitative and quantitative methods, (Denzin & Lincoln, 2011) qualitative data include mainly details, interpretations, and observations, while quantitative data tends to make objective inferences from explicit data. Furthermore, quantitative methods often involve few variables and numerous cases. On the other hand, qualitative methods typically address many variables and a limited number of cases. (Leydens, Moskal, & Pavelich, 2004). As a general conclusion, qualitative research is more painstaking theoretically and methodologically in comparison to quantitative methods (Borrego et al., 2009; Koro-Ljungberg & Douglas, 2008).

Most researchers combine a qualitative approach with a quantitative method. For engineering education researchers, qualitative methods have been utilized increasingly, and their value of offering deeper insights into human behavior increases their potential application in the future (Borrego, Douglas, & Amelink, 2009; Koro-Ljungberg & Douglas, 2008). In order to draw the most benefit from qualitative research, researchers must adopt an attitude of change and discovery (Douglas et al., 2010). In a literature review paper, Borrego et al. (2013) addressed the methods adopted in engineering education research. With no attempt to favor any one particular method, Borrego et al. highlighted the distinct features of qualitative, quantitative, and mixed-research methodology with respect to engineering education research. An important difference between qualitative and quantitative approaches is the assessment issue. Researchers differentiate the evaluation terminology by using “reliability” for quantitative results, and “trustworthiness” for qualitative research outcomes (Borrego et al., 2009). Many researchers in the field of engineering education are not yet confident enough to accept the qualitative method as a reliable approach, which, according to the authors, is due to the traditional training, exposure, experience, and perspectives of reviewers. (Borrego et al., 2009; Douglas et al., 2010). The challenges of introducing the qualitative research tradition into engineering education seem to result from the epistemological diversity in qualitative research methodology and the dominant nature of the quantitative method paradigm in engineering education (Douglas et al., 2010).When adopting a qualitative approach, an engineering education researcher should specify the basic philosophical differences between qualitative and quantitative approaches. The differences affect the method, data collection and analysis, and conclusions significantly (Baillie & Douglas, 2014).

Similarly, qualitative data analysis is also impacted by the epistemology and theoretical framework of the approach. Considering the question of the trustworthiness of collected data and the appropriateness of measures and interpretations, the researcher must gain an awareness of the participants' preconceptions about the research context (Smetana et al., 2012). The succeeding data analysis stage contains the steps of developing a coding table, identifying major and minor themes, clustering them, and making structural descriptions from the themes (Creswell, 2013). Even when validated instruments are employed, they may not adequately probe students' concepts. It would be helpful to consider the validity of the interview/observation as a major issue. In order to cope with the validity issue, Smetana and Bell (2012) recommended that research studies utilize a combination of quantitative and qualitative methods.

Protocol Analysis

Analysis of protocols is the main tool in qualitative data analysis. Protocol analysis is defined as "analysis of the time-ordered description of activities." Among existing protocols, verbal, also called "think-aloud," are the most widely used protocols used in qualitative method (Hayes, 2013). "Think-aloud" was also called "talk-aloud" in earlier references, although in this study the more common "think-aloud" term is used. Participant-based methods, e.g., case study and phenomenology benefit the "think-aloud" technique due to ease of employment despite its limitations (Ericsson, 1998). It usually takes some time for participants to get used to it, and initially they may need to be reminded to think aloud, which distracts them from the activity. This happens especially on crucial occasions when a participant experiences a higher level of mental load. Follow-up interviews are often used as a complement to "think-aloud" data to study the participants' experiences more deeply (Koro-Ljungberg et al., 2013). Although the “think-aloud” technique may be effectively used to observe simple cognitive processes, it should be supplemented by other protocol analysis tools in complex situations. For example, in “hard-thinking” moments when the participant is solving a problem, the participant may fail to “think-aloud” even if reminded by the interviewer/observer. Other protocol analysis tools such as follow-up interviews and observational recording or noting may supplement the collection of data. Some students may exhibit anxiety when approaching the “think-aloud” sessions as if they are in a testing situation, even though grades are not ascribed for performance on the problems (Koro-Ljungberg et al., 2013).

Description of CSA Modules and Problems

Three topics in dynamics guided this study: Newton’s Laws of Motion, the Principle of Work and Energy, and the Principle of Impulse and Momentum. For each topic, two problems were designed and developed. Chapters III, IV, and V describe the characteristics of the problems and relevant modules. The first problem, called the “assessment problem” was given to each participant unsolved; the participant was asked to solve it in two subsequent efforts. The second problem, termed the “textbook-style paper learning example” (PLE) included a solution represented by textbook-style paper representation. The participant first tried to solve the assessment problem, and then studied the learning example, and finally returned to the assessment problem to resolve it. Table 4-1 illustrates the problem topics and resources used for each module. The changes in the participant’s problem-solving process before and after reviewing the learning example were observed.

Table 4-1 *Description of Modules*

Module number	Topic covered	Problem description	Important concepts
Module 1	Newton's Second Law	Sloped surface	Friction force
Module 2	Work and Energy	Spring and ramp	Work done by different forces
Module 3	Impulse and Momentum	Rotating crane arm	Angular impulse and angular momentum

Participants, Site, and Selection Procedure

Research participants were sophomore-year mechanical, civil, environmental, or biological engineering students who were taking a dynamics course. All of the participants were engineering students at Utah State University, and the study was conducted in the university's main campus in Logan. For each of the three topics, after the corresponding topic was taught in the class, an invitational email was sent to each student. The participants were selected among the volunteers who responded to the email. Based on their grades on the first midterm exam, both higher and lower groups were invited to participate in the study. In the case where a participant declined to take part in the experience, that person was substituted with another volunteer from the list with an equal performance level.

In total, 34 students (8 female and 26 male students) participated in the study, 10 students in Module-1 and 12 students in each of modules 2 and 3. They were all sophomore year students and were taking the dynamics course for the first time. Twenty-four students were white and ten students were from Hispanic origin. They were split into two groups of six, one PLE group and one CSA group. Every group included high-, medium- and low-performance students. The problem-solving activity took place in an independent, quiet room to minimize ambient noise and distractions.

Every participant was given a consent form indicating that the researchers will protect their privacy and confidentiality and that all personal information would be kept confidential. The consent form was also signed by the researchers. In addition, each student who completed a problem-solving activity was paid with a $25 gift card as an incentive for participating in the research. In the invitation email, the incentive was mentioned.

Data Collection Procedure

For each individual, the problem-solving activity consisted of four stages: (1) a pretest: solving the assessment problem; (2) an intervention: studying a solved problem given in either of the CSA or PLE; (3) a posttest: solving the first assessment problem again; and (4) an interview: talking about the problem-solving process with the researcher in the form of an open-ended interview. Table 4-2 illustrates the design of the activity, a short description of each stage, instruments used, recording methods, and problem topics for each module.

Pretest Stage

In the pretest stage, the participant was asked to solve the assessment problem. In order to reduce the inevitable test stress, they were told that they could use their class notes, textbook, and calculator. Also, they were reminded that it was not a test exam and that their answer would not affect their course grade. The solution process was recorded by a video camera recording their voice and their paper. An audio recorder also recorded the process.

Before starting the observation, the students learned to perform the “think-aloud” technique for 2 to 4 minutes. For this purpose, they were asked to work on a voluntary problem and try to verbalize whatever occurred to them. It prepared them to perform “think-aloud” during the experience. During their problem-solving time, each participant was reminded to say what he/she was thinking.

Intervention

The CSA module was the main element of this stage. The CSA group participants studied the solved problem through the module. They could talk about the problem or the solution, ask questions, and were allowed to note everything that they were thinking that might be interesting in the solution. The PLE group worked with the textbook-style, solved problem representation. Throughout the second example, a comprehensive solution was shown to help the students apply the points they learned in solving the first problem. For each participant in the CSA group, a computer screen record was also created which illustrated his/her mouse motion and data entered.

Posttest Stage

The assessment problem was given to the participants after they reviewed the solved example. In their second attempt, they tried to solve it, and their think-aloud was recorded once again. Sometimes, they completed the solution with the assistance they received during the posttest. The change in their behavior was the key point in examining the effects of the intervention, which could be the CSA module or the PLE representation. The focus of concern was the actions that were different. Obviously, they repeated some behaviors from the pretest, which were recorded, but were not considered as important unless they indicated a different cognitive category.

Interview

The participants talked about their experiences with the process in open-ended, semi-structured interviews. The interview questions consisted of four major categories. The first category dealt with factual and conceptual knowledge; the questions were intended to determine if the participant remembered and understood basic and advanced concepts. The second category was about the design of the module. It entailed how a participant perceived the CSA module and what components they deemed more important. The third category addressed the problem-solving process, i.e., the strategy that the participant adopted, whether the participant discovered the relationship between interim unknowns in the solution procedure, and how they evaluated their solutions.

The questions regarding the first group of problems focused on the process of problem-solving: “How did you construct the equation?” or “Which concept did you forget while solving the problem?” The second group of problems addressed each participant’s evaluation of the module and how he/she observed it. The participants talked about the parts in the CSA module or the paper problem that were more clear, attractive, or informative. The third group of questions addressed the participant’s feeling or evaluation of the process as a whole, the problem-setting environment, general settings of the process, activity sequence, etc. The second group of questions was different for paper-solution and CSA-solution participants. The research group discussed the questions to develop a final version of the interview questions. The questions were designed to encourage the participants to explain their responses, and their answers were used to triangulate the data collected from observations. Occasionally, a question was added to the initial set by the researcher, for example, “When you were solving the friction, you looked in the book, why didn’t you use . . . etc.”– Thereby encouraging the participant to talk about his/her thoughts in more detail.

Data Collection Instruments

The process of data collection was audio and video recorded. A video camera recorded what was written by the participants, and an audio recording was used for checking the voices on the video file. After recording the problem-solving process and interview, audio and video files were saved in a separate folder for each student participant. Each participant’s solution notes and the researcher’s notes collected during the process were attached to the data.

Table 4-2 *Research Design*

Stage		Tools available	Recording method	Problem given
		PLE group		
1	Pretest	- Paper/pencil - Calculator - Textbook	- Video record - Audio record	Assessment problem (ASP)
2	Intervention	- Paper/Pencil - Calculator	- Video record - Audio record	Paper learning example (PLE)
3	Posttest	- Paper - Pencil	- Video record - Audio record	Assessment problem (ASP)
		CSA group		
1	Pretest	- Paper/Pencil - Calculator - Textbook	- Video record - Audio record	Assessment problem (ASP)
2	Intervention	- Paper/Pencil - Computer	- Video record - Screenshot record - Audio record	CSA learning module
3	Posttest	- Paper/Pencil	- Video record - Audio record	Assessment problem (ASP)

Organization of Collected Data

At the end of each problem-solving activity, three sets of data were collected: visual observations of the video recording of the student problem-solving process, audio recordings of each student’s “think-aloud” monologue, and the response of the student to the open-ended interview questions. The audio files were stored in a protected location, tagged for pseudonyms, and transcribed. These transcripts were compared to the students’ solution notes and notes taken by the interviewer to confirm their correctness.

The differences between the CSA and textbook-style group’s problem-solving were assumed to be due to the application of an interactive CSA module to a group of students. The students who worked with the textbook-style, paper solution were compared to those who used the animated, step-by-step solution (CSA module). Collected data included audio, screen and video recordings, interviews, and solution manuscripts. Audio recordings were transcribed and checked with video records for more accuracy. Additional nonverbal information derived from video recordings, such as silent moments and the motion of a mouse on the module was incorporated into the transcripts. The hand notes made by the researcher during the process helped to record the activities missed by the video records or the expressions or gestures made by the participant, e.g., looking confused, distracted, looking for something, etc. The notes were time-marked while incorporating them into the audio/video data. The notes made by the participant helped to reinforce the primary data. For instance, when a word or figure in the participant’s notes was difficult to perceive in the video footage, the solution note added clarity.

Data Analysis and Coding

Collected qualitative data were processed to illustrate the major harmonies, grounded themes, and discrepancies. The transcripts of recordings and interviews were compared and synthesized with the participants' solution notes and the notes taken by the researcher during the problem-solving activity. For categorizing, a coding table covering various aspects of the cognitive process was developed. Table 4-3 illustrates the summarized coding table used for all modules. Detailed coding tables for each category are presented in Appendix C. For each module, necessary adjustments were made in the level-3 codes considering the content of the dynamics topic. For example, "remembering Newton's Second Law" in Module-1, was changed to "remembering the Principle of Work and Energy" in Module-2. Thus, the structure of the table was maintained while the pertinent contextual changes were applied.

A coding activity was conducted primarily by the researcher. A second coder watched the videos, read the transcripts, and coded them independently. Before starting the process, he was trained for the research and was previously a member of Dr. Fang's research team. Also, he was trained for qualitative research and was familiar with the coding process, objectives of the study, and similar coding examples in other studies by the research team. After both coders completed their tasks, they compared their results, discussed the differences, and liaised to reach an agreement on the final synthesized outcome.

The first and second levels of the coding table were adopted from the *Revised Bloom's Taxonomy* (*RBT*; Krathwohl, 2002). Bloom introduced his taxonomy in 1956 as a tool for measuring learning objectives. Since then, it has been discussed by several researchers (Anderson et al., 2000). The Revised Blooms' Taxonomy (*RBT*; Krathwohl, 2002) has used verbs to replace the nouns defining the learning levels. It includes a process matrix defining the cognitive levels. As there are more examples and indicative keywords, the RBT is shown to be a more appropriate baseline for the coding table. The third-level codes addressed a more specific issue in the taxonomy that was more relevant to the problem-solving process. For each module, third-level codes needed minor changes to match the specific topic of the modules' problems, e.g., Newton's Second Law, friction force, work and energy, etc.

The following steps formed the analysis process. First, all transcribed data were delimited in short, distinct statements. Doing so helped the researcher to decide what codes or interpretations could be attributed to each statement and/or if a delimited statement was independently meaningful. Second, by comparing the coding table and the delimited data, all meaningful statements having one or more thematic interpretations were tagged by an abbreviated code item. In addition, participants' explicit nonverbal actions, e.g., pauses and exclamations were also attributed to a certain category or theme. Third, for each participant, besides a transcribed coded file, one single coded data table was created which showed the number of times every code was observed. By examining individual and integrated coded data tables in different stages, key themes and prevalent codes were identified. An analysis of the codes also served to demonstrate the main features of the CSA modules that affected each student's problem-solving experience.

Appendix C entails an example coding table up to level three with a detailed description of the applied codes.

CHAPTER V

OBSERVATION AND ANALYSIS OF INDIVIDUAL STUDENTS' PROBLEM-SOLVING BEHAVIOR

This chapter addresses the findings of the study. For each module, each participant's problem-solving activity was analyzed and the structural description of the activity was addressed. The chapter is an interpretation of the entire problem-solving process. Highlights of individual transcripts are presented to support the interpretations and offer verbatim comments from several students regarding their attitude, problem-solving process, and style. The structural interpretations revealed common themes and reinforced the initial coding. All of the participants' names are pseudonyms to maintain their confidentiality. In the quoted transcripts, statements inside the brackets represent the observations made by the transcriber about a participant's actions. In multiple instances, the researcher prompted and asked a question to encourage the student restart to think-aloud.

Module-1 CSA Group

Walter:

Walter attempted to solve the problem in the pretest. He spontaneously started with the free body diagram, but missed the friction between the blocks. He did not construct the problem equation or plug in the correct parameter in the correct position. The result was a chain of misconceptions in which he failed to solve the math and eventually declined the pretest. He asked to see the solved problem. In the intervention, he missed the animation, the scrolling slider, and finally, the hints. In the interview, he said that the hints could have helped because it they addresses the same issues he had encountered during the pretest. He believed that the animation did not help much, but the equations did. He also had difficulty reading the solution because he did not scroll down the page to see it in its entirety. In addition, he stated that the module solution confirmed his thoughts about the direction of the friction force. His replies during the interview were consistent with his actions during the problem-solving. He stated:

> *[Makes the system of equations]Okay, mass, force of gravity, and acceleration are unknown, [draws a free body diagram, putting WB on the block],* a_y *is zero and I have no movement in the y-direction). [Calculates the* $N_A = m_A g$*] On block B, the same ΣF, I forgot the frictional force up here. [Writes the equations in x- and y-directions, correcting the sign for friction under the block and weight, going to page 2, writes the equations for F in x-direction. Solves the system of equations with a calculator, having one unknown more than the equation; then, looks at the equations of motion, counting the unknowns.]*Walter's pretest.
>
> *I was not quite sure of which direction the block goes, I knew which direction the friction was, there is one movement of block A, relative to block B, I knew it is going to oppose that movement, by looking at block B. Assuming that is going to go in the opposite direction of motion and because it is an internal force.* Walter's interview.

Bruce

Bruce missed the friction force and spontaneously drew an FBD, but he knew that there was friction. He failed and declined the pretest; he could not figure out the ultimate unknowns and necessary interim parameters to solve the problem. During the intervention, Bruce compared the solution of the module to the unsolved problem step by step. After working with the module, he corrected the cable tension error and recognized the sign convention and direction of the friction force. With the help of the animation, he concluded that the acceleration of the blocks was equal and opposite. By noting the final equations on the last page, Bruce remembered the kinematic equation. He used the CSA module as a pattern to solve the problem and did not miss the friction forces nor the reactions from A and B. He creatively named the unknown force P and constructed and solved the acceleration equation. He was aware of the relative acceleration and calculated it correctly. Bruce commented that the animation helped him in equating the accelerations, but changing the values of the parameters helped very little because he already knew what parameters would be changing. He stated:

> *This is not 300N, this is T. Friction, force µN. [draws the free-body diagram for B, puts the T, the 300N, normal force, mistakes the* N_B *for* W_B *and forgets the fact that* N_B *is* $W_A + W_B$*.] Then we have this pulley [draws the pulley and forces and* x_A *and* x_B*, concludes that* $a_A + a_B = 0$*. Then, goes back to A to calculate the* f_A *– he sets up the equations of motion for A, and then B, but forgets to put* N_A *on B, names he cable force as P, rewrites the equations with numerical values. [Then, he solves the equations by the method of elimination] So, acceleration of A is positive and*

> *is 0.821 $^{m}/_{s}2$, a_B is -0.821 $^{m}/_{s}2$, so this tension P is 191.291N. The relative acceleration is 1.62 $^{m}/_{s}2$ and is the difference between accelerations.* Bruce's posttest.

Charlie

Charlie built up the free body diagram. He did not forget the friction under block B, but eventually could not solve the pretest problem and declined to continue. Although, he accepted to watch the module. During the intervention, from the hint, he found the relationship between the accelerations, and calculated the total acceleration. Although he was aware of the friction and reaction, he initially forgot to put the relevant forces; however, he later remembered and made the appropriate corrections. He forgot the unknown force, and made a numerical error. He commented that the hints were valuable pieces of instruction and helped him to learn. He said that he arrived at all of the conclusions because he felt confident after he studied the solved problem in the CSA module. Charlie commented:

> *Right now, I always forget that we always have the normal and frictional force ... so at this point I guess from there I can solve for B and then determine the time. I have the initial position as zero, probably it is zero, this initial velocity. Another thing to remember is that velocity of A plus the velocity of B and $a_A + a_B$ are zero. Here, they solve the equation similar to the third equation. [Goes to the next slide] Here, they calculated the time that A travels on block B. Oh, a_A relative to block B is $a_A - a_B$ which is 2.6 $^{m}/_{s2}$.Solving for t, [takes note for the $v_0 = s_0 = 0$]s = 0.6, then we have a_{rel}.* Charlie's intervention.

> *So, we have two equations and two unknowns, [Charlie does not realize that T is one unknown that he had missed.] We try to find the time. We have the* $s = 0.5\ a_{rel}\ t^2 + v_0\ t + s_0$*; so first we calculate* a_A*. Solving for* a_B*, we have* $a_B = -3.133$*, so we have* a_B *in the opposite direction, and we have* $a_{rel} = 16.07 - (-3.133) = 19.207$*.* Charlie's posttest.
>
> *The free-body diagram hints in the module did help, just took me a little while to multiply friction by the normal. It was close enough. I reviewed the forces that they were acting on, so they helped quite a bit.* Charlie's interview.

Trevor

Trevor drew two separate free-body diagrams, one diagram for each block. Thence drew all of the necessary forces on the blocks. He could not remember the kinematic equation, nor could he figure out the relative motion or link the motions of the blocks. During the intervention, Trevor read the friction force hints carefully, bypassed the free-body diagram hints, and paid attention to the relative motion and the link between the accelerations. In the posttest he drew the kinetic diagram as what he saw in the module. At first, he forgot the T on the block, but he corrected it and eventually solved the equation. He stated that the animation showing the way the objects moved and especially the direction in which they moved helped conceptually. Trevor said:

> *So looks like I needed to draw both free diagrams and the kinetic diagrams for blocks A and B. The tension should be the same tension on block A. So I already know I can get* N_A *and* N_B *and I got* a_A*,* a_B *and the tension. For the kinetic diagram, [drawing the kinetic diagram] we have [sets up the equations for both*

> *blocks, doesn't put the T on block B, calculates the a_B] I think I forgot the tension here, so I need the third equation and $a_A = -a_B$.* Trevor's posttest.
>
> *I started out not drawing kinetic diagrams, just because I usually draw a free-body diagram; and depending on what kind of problem, it may be needed. In this problem, for example, for block A, it's just mass times acceleration and I could guess from the problem which way it is moving. I'm not sure if the hints really helped, regarding my free-body diagram.* Trevor's interview.

Bill

Bill could not figure out what unknowns were needed to calculate the time. In addition, he wrote the wrong equation, and shortly after that stopped and asked to see the solved problem. During the intervention, he showed no interest in the animation, and simply looked at the solution and the equation. He paid little attention to the concept. After he saw the equations, he could built them up and calculate the answer. He said that he had a feeling that it was wrong, but went on nonetheless and calculated the time. In the interview he stated that the equations in the modules were the most useful. He was not interested in reading text with an abundance of numbers on it. Some of Bill's comments were as follows:

> *[Draws free-body diagram for B and puts W_B, 300N, NB, N_B, friction under the block; doesn't put the N_A, and friction on top of B] So I'm done for free-body diagrams, and need to write down the equations to solve for time. The accelerations are needed? But for velocities, the equation is $v = v0 + at$, and*

> *tension is 300N, so this should be +300, but it will stay. Is it a Newton's Second Law? So,* $v_0 = 0$ *and* $v = at$. *Let's move to the next part.* Bill's posttest.

Module-1 PLE Group

Adam

Adam had a strong background in statics, which helped him build up the free-body diagram. He solved the kinetic part, and indicated that he was of the opinion that the tricky part was the relative velocity issue, but midway through the activity, he declined and asked to see the solved problem. He could not remember how to write equations. In the intervention and posttest, Adam paid more attention to the formulas than the diagrams. In the posttest, he constructed the equations correctly and drew accurate free-body diagrams, but was skeptical about the answer. He evaluated his solution and eventually stopped to work because had more unknowns than the number of equations. He was more interested in the formulas than the concepts. Apparently he obtained the solution from the equations, but did not pay attention to the concepts or tricky points.

> *The* μ_k *between block A and block B is 0.4;* μ_k *between block B and ground is 0.5. To determine the time, I need to think about this. We covered this, but I easily displace these procedures. I have to review the material. I could use the energy principle.*
>
> *As I am thinking of this, I think I can run these [the free-body diagrams]. For some reason, it's easier for me to visualize these bodies [the free-body diagrams].*

> *I am getting used to putting units in my equations; so that I get a better understanding. Now, I cannot decide what the direction of friction is. I need to visualize what is happening between them.* Adam's posttest.

Ted

Ted started his pretest solution by drawing two different free-body diagrams for the blocks. He easily outlined the problem data and constructed diagrams and equations. He made correct assumptions about the direction of vectors, and derived two equations. From that point, he was unable to write the third equation which involved the kinematics part of the problem. He quickly withdrew and asked to see the solved problem. During his intervention, he studied the problem and realized his kinematics error. He also checked the assumptions about the sign of force he had made in the pretest. He was aware of the relative velocity part of the solution, and his awareness enabled him to solve the second part in the posttest. He confirmed this fact in his interview and stated that the diagram of the PLE helped him to solve it.

> *[Works on the equations for block B, calculates W_B = 294 N, calculates N_B, then remembers the N_A from the top block, and puts it on block B]. Because B has a force of weight acting on it, and force from A is pushing on it as well, [Calculates the new N_B, = W_A +W_B] now, it would come into effect, N_B= 441.45 the friction there would be equal to [calculates the friction] which would be going to the right. [Calculates the friction force = 220.7N]Now, calculating the tension, the tension is to the left. So negative -300N -- I know the tension, I know the mass [forgets the cable tension T]. So, for the acceleration, they are connected by the*

> *pulley. So, in this case that's going to move. Assuming if I pull this, that would be pulled back, so I wonder I can use that; my forces, acceleration -- [writes the F=ma for the block B], -300 = 30*a_B*; therefore,* a_B *= -10 m/s*^{2}*. Is that the right way to do it? So, I'm assuming that the tension is constant, that makes the acceleration constant; so I use kinematic equations, I wonder if I can find the velocity of block A [goes back to solve for block A].* V_0 *= 0 the distance to travel is 0.6 m to the right.* Ted's posttest.

Cindy

After drawing one free-body diagram and writing the basic equation, Cindy asked to move forward and see the solved problem. She was not ready for the activity and had totally forgotten how to solve the problem. She identified the problem topic and recalled the solution procedure as soon as she looked at the title of the solved problem. She paid little attention to the details and reviewed the "big picture" solution procedure. Even after replicating the solution procedure, she could not plug in the relevant parameter in the correct slots. Therefore, she found a wrong answer for the acceleration and time. Her overall performance in the activity may not have depicted her real capability because she had forgotten the concept, although details of her actions in the different stages would prove to be helpful in the coding.

> *And from kinematics from chapter 12, I needed that to figure out how to find my acceleration. I know how to do this, so once I can find my acceleration I can find the time, because* $s = s0 + v0t + \frac{1}{2} at^2$ *and I have no initial velocity and displacement. I think I got everything you needed. Can we move to the next stage?*

> *I want to figure out what's going on because I forgot these things. I looked at the pulley; I made a free-body diagram, and a kinetic diagram, and we have the F=ma, so we have forces acting on block B and on block A; we have everything to find the normal forces and then we know that.* Cindy's intervention.

Ray

Unlike the other participants, Ray drew the kinetic diagrams for the blocks. He made a conceptual mistake when he needed to find the last equation. He immediately corrected it, but was unable to find the relationship between accelerations, and because of that, he declined to work on the problem and he continued the process and moved on to see the solved problem. He realized that the accelerations were equal and opposite and how close he was to the conclusion. He focused on this issue, which caused him to make other errors during the posttest. In his interview, he confirmed that he had forgotten to look at the relative acceleration and, therefore, after finding the accelerations correctly, he could not calculate the time.

> *So I need another equation because I have* a_A, a_B *-- I guess it has something to do with the pulley in kinematics. If you pull on A or B, they should move at the same rate. That's a whole lot easier than everything else I did. So, the other equation would be the* $15\times a_A = 30\times a_B$*. So, this is going that way and the other goes this way. Oh, is that velocity? It might be velocity; because forces are different. So, the equation is really* $v_A = v_B$*; that does not help me with acceleration, does it? It could be because if you take derivatives of velocities, it must start moving, they are speeding up, its constant velocity -- come through it -- just says block A*

> *travels over block B. Do they move at constant velocity or not? I don't think so. So if the v_A are changing, then A and B are changing? No, because the derivative of v_A is a_A, so the rate of change of velocity is over. How do I find that? Well, this is the kinetic diagram and is showing it's going to move, so is the equation that relates forces to velocity, F = ma -- then there is ads = vdv.* Ray's pretest.

Matt

Matt followed the standard procedure of drawing free-body diagrams, placing forces, calculating reactions, and building the basic equation. He was unable to find the relationship between the two accelerations and, thus, did not integrate them. Therefore, he used one equation missing one unknown and calculated two different values for accelerations, which were much larger than the correct answer. By looking at the solved problem, he understood where the error was. He also noted that the relative acceleration was the sum of the two accelerations. He used these points in his second attempt. Actually, he did not pay attention to the diagrams of the solved problem. Not looking at the diagram caused him to take a wrong direction for the motion of block A. Consequently, an error occurred in calculating the final answer. During the interview, he confirmed the fact that he was unaware of the normal reaction even after he studied the solved problem.

> *This time I draw the free-body diagram for block A and block B separately. [Draws two separate free-body diagrams. Goes to the problem statement, then puts them on the first free-body diagram.]I was confused how I calculated the normal, so first friction is calculated as $f_B = \mu$ NB. [Puts the normal of B, goes to*

> *the free-body diagram of A; puts the tension "T" on block A, puts W, calculates the value of W, puts friction, puts the normal equal to 147.15 of W].*
> *Now, I draw a kinetic diagram of block B, and B goes this direction, [to the left] and now the kinetic diagram of A, going that direction, [draws the kinetic diagram for A, misses the direction]. Now, I'm checking the free-body diagram, friction that way, tension, so 300N, and ma =-T–147-58, [calculates the value for block A, T is, T - 147 = 15a] So, I have the second equation, so I'm using this equation [solves the system of equations manually by elimination, puts* $a_A = a_B = a$ *and finds a value for A = 0.83m/s2. Solves for the kinematics as=* v^2*]. Then, v= √ a×0.6; then t = 0.6/0.83. [The calculation is incorrect.]* Matt's posttest.

Module-2 CSA Group

Todd

During the pretest, Todd remembered the formula and the principle, but forgot to draw the needed diagrams. He worked on the formula, trying to plug the numbers into the equation. He tried to justify the fact that he missed a conceptual point, drawing the FBD. Todd understood the friction force concept and quickly recalled the formula to calculate it. He said that he was not confident enough to calculate the work done by the force. Based on his prior knowledge, Todd inferred zero initial velocity, and he later realized that the coefficient of friction should be dimensionless.

During the intervention, Todd observed the similarities and differences of the problem to be solved, and attempted to select the information that could help him solve the problem. By playing with the friction factor parameter, he realized the difference in the scenarios and tried to assimilate them with the assessment problem. He realized the conceptual effect of the friction factor in the movement of the block by changing the parameter and making a conceptual conclusion. He predicted that in the assessment problem.

In the posttest, Todd distinguished the scenarios of the problem by observing the animation changes. Before going to the solution slides, he scrolled through the modules three times, thinking he might have missed some information. At the same time, he realized that the block had three types of free-body diagrams before and after being detached from the spring. Todd confirmed that he observed the navigation features, defining them as individual sections. In the interview, Todd recalled that because he could see the figures clearly, he was able to understand the forces and the work done by them. Todd commented:

> *At the point that is going, nope, that is not going to be it because it is going to have friction on it. [Laughs] At no point because that is accounting for friction. Now that is going to be the force pushing on it. It is going to have a minus mu k times my NO [adds to sum of forces in x equation]. It has to be greater than zero for it to be moving. Because that is static friction, so for it to be greater than that, then it's just ½ times 600.04 equals mu k times 49.5. 600N per meter times meters squared, and this is Newton's divide 5 times. Yeah, that doesn't make sense -- my coefficient of friction is -- shouldn't be meters or anything. It is unit-less, so that's*

> *where my problem is coming in now that I am making a mistake. And I can see that I am making a mistake.*
>
> *How much the maximum coefficient of kinetic [is] and then how far it will go. Or, how far we have to compress if we have .717.*
>
> *For different values of friction, you may check it. For example, for the .5 maximum. What happens there?*
>
> Interviewer*: Well, you may say what you think.*
>
> Todd*: I do not know my coefficient. [Laughs] Okay. Since this is now velocities, so we know that it ends, we are going to have plus my fri-- [about to say friction] my spring force, my, minus my, well, coefficient of friction -- that's going to be equal to 0 – 2.8. No. Mu k is actually not going to be that. I need to write it out. That should be the distance it travels right along here, between A and B, because that's where my frictional force is. I mean, I guess it just showed kind of how it changes, but the thing that helped me more was the free-body diagrams and then working out each equation after that.* Todd's posttest.

Cameron

In the pretest, Cameron remembered the parameters, the procedure, and everything needed to solve the problem. He drew the necessary diagrams, and built up all of the equations, and after making one numerical mistake, he realized that and corrected it. He knew the value of the friction factor and when it did not look right, and he checked out the process. During the intervention, Cameron explored the animation several times, asked multiple questions about the effect of parameter change on the animation, and tried to find the critical coefficient of friction. He focused on the animation and paid little attention to the diagram hints. He used the information he learned about the critical value for the coefficient of friction to find the distance that the block moves. In the interview, he mentioned that the best feature in the module was the parameter change, because he already knew about the formulas, the concept, and the solution process. Cameron stated:

> *“First thing I'm going to determine is the maximum allowable value of the coefficient of kinetic friction between the block and the entire surface 01 A and AB for the block to reach point B, which is at the end of the horizontal surface. Number two, if the coefficient of kinetic friction is .35 determine the block finally stops.*
>
> *Before solving this problem, the block will either make it over the ramp or onto the ramp or not on the ramp.* Cameron’s pretest.
>
> *“I started out thinking that I was going to draw at the tilted angle, but that's always been kind of hard for me to visualize. I like drawing them perpendicular to my vision, so I resolved the gravitational force into its components, perpendicular to the ramp and then drew it as I have shown on the paper. I think the slider helped introduce me to the concept that a higher kinetic, or a higher coefficient of friction would prevent it from clearing the ramp. It would've been nice if the slider had been labeled more clearly.* Cameron’s posttest.

Jacob

In the pretest, Jacob built up the equations, although he missed the point that getting a controversial answer does not mean that he had made a mistake. Rather, the answer might have been due to wrong assumptions. While studying the module, he focused on the parts on which he felt that he made a mistake, and the formula that he felt unsure about. Jacob did not play with the animation parameters and clicked only one hint. In the posttest, he focused on the correctness of the formulas. He did not look at the concept during the intervention, but since he had looked at the solution of the module problem, he followed the same procedure. Jacob checked if the block reached to the top of the ramp, calculated the distance on the ramp, and finally found the correct answer. He stated that he believed that the animation had been helpful and “nice,” but he was just focusing on the formula. He agreed that he used the modules to confirm his assumptions and memory, rather than the concept. Jacob stated:

> *[Draws the angle and sine and cosine for that],*
>
> *Jacob: so the force of gravity is mass times the acceleration, which is 49.05N, so I got the force of gravity and I need to find the normal direction. [Draws the system of coordinates] Then I set the coordinates system like this, and gravity goes straight down like this, and the angle will be 11.31 and y-components of my gravity will be normal force. [Erases the wrong direction]I always draw the wrong coordinate system. I need to find the right direction. So this is hypotenuse, so the force of gravity, that means that the normal force is 48.1, which is reasonable, and now we can calculate the force of gravity in the x-direction. To do that we just use* $F_{g\text{-}x}$ *is equal to* F_g *times sine of 11.31, which is 9.62N. Now we can do the summation of our forces and then set up our equations, and then solve*

> *for the coefficient of kinetic friction. So, determine the allowable friction between the block and surface.* Jacob's pretest.
>
> *[Reading the problem and the solution]*
>
> *Jacob: To reach point B -- so if I had the kinetic friction, if it was little, in the first part of the problem, the block would go over all the way, if it was a little more, it would go between A and B, and if it was a lot more than the max, it will go close to point A, And so, it has less friction, it has to account for the change in the gravity and that is why it accelerates in the animation. [Looks at the velocity of the block, runs the animation, scrolls to the next part, solution] We are now using the energy principle. Okay, that makes sense, [reading the solution and looking at the solution of the second part of the problem in silence] "Jacob's* intervention**.**

Alice

In the pretest stage, Alice calculated the coefficient of friction after making correct diagrams and correct assumptions, and building up equations, but because she made a numerical error, she realized that the value was out of the normal range. She recalculated the correct answer. While working with the module, she studied the free-body hints thoroughly, played with the animation, and tried to link the final position of the block with the friction coefficient value. In the posttest, she wrote down almost everything, repeating the same procedure, even the diagrams. She found a negative value for the answer, which did not make sense to her. She checked the initial assumption, changed it, and found the correct answer. She confirmed that she improved her diagrams after working with the module and stated that the improvement was due likely to studying the hints about the free-body diagram. She believed that the best features of the CSA modules were the step-by-step explanations which she could reference back and forth. Alice remarked:

> *We have the normal force of weight which is 5 kilograms times 9.81 meters per second squared. We will have the force of the spring, which will be equal to one half K delta S squared, and the kinetic friction times the normal force of the acceleration. Here, delta S-one is equal to .713, which is larger than .51.*
>
> *Interviewer: how did you draw the free-body diagrams, can you explain.*
>
> *Alice: I drew them, either out of slope or not depending on where it was at the instance along the ramp, and then I just added forces as they would be, like the normal force is perpendicular to where it rests, and the weight always acts directly downward.* Alice's posttest.
>
> *Interviewer: Okay, good. I noticed that your free-body diagrams are different from these two stages, I mean, before the simulation and after the simulation. How did this happen? Did this help? If yes, how?*
>
> *Alice: I didn't really notice a difference in my free-body diagrams. I already knew what the math was, I plugged it in. The first difference, you have two sets of, two free-body diagrams. So I guess I added the second free-body diagram set to make the math easier, or make the math more visual.* Alice's interview**.**

Barbara

After reading the problem statement, Barbara used Newton's Second Law to solve the problem. Realizing her error, she declined to move further and asked to study the animation module. As she studied the solved problem, she focused only on the equations and the items she needed to solve the problem. She skimmed over the animation page quickly and summarized the entire solution. In the posttest, she tried to remember the formulas. She struggled with the direction of forces. She did not find the correct answer and had no idea how to solve the second part. Her interview showed that she had used the animation to draw the free-body diagrams. Because the problems were similar, she simply copied the solution, explaining the likely reason why she was not interested in the pop-up hints and figures.

> *Barbara: So we can solve for friction totally, in the x-direction, sum of forces equals weight, actually it is negative, plus the force of spring -- I don't know if I need to break in the components. Is this force a vector? Yes, all forces are vectors. Okay, so the force of spring in the direction, and I cannot remember the spring force [Looks in the book and class notes]*. Barbara's pretest.
>
> *Barbara: So, now that friction is 0.17, which is less than 0.19, then the block passes the tip. [Reads the solution in part two].The mathematical form of work and energy is as follows. Because the velocity is zero at the final point, [reads very softly] is this* o_1 *times* o_2*? No, it is just a distance. Okay, so writing the Principle of Work and Energy, from 01 to A to B to C. So the direction of the distance-- Barbara*'s posttest.
>
> Interviewer: *Did you like the scroll bar to change the friction, and did you like the text input?*
>
> Barbara*: Definitely the scroll bar so that I could see the all the way in.*

> Interviewer*: Did the animation help?*
>
> Barbara*: Yeah, for sure, except for the figures that pop over the text, I needed to see the text and figures and some instructions that tell me to change the scrollbar. On the screen where you move the scrollbar, because you told me to do it.*
>
> Barbara's interview.

Allen

In his first attempt, Allen solved the problem, but with a math error. He calculated a large value for the coefficient of friction. The module helped him correct some of his misconceptions about the work done by the forces. In the posttest, Allen corrected his numerical error and by copying the module's solution procedure, he solved the problem completely. In his interview, he confirmed that the animation and figures helped him get what he wanted and, in addition, it confirmed what he already knew about sign of the work done by the spring.

> *Now we have all the forces, zero plus sigma u from 1 to 2, I guess I divide it into two parts, .0 to A and A to B. so I'm going to call it 48.15, times S. I do not think this sign matters because no work is done when block is going up [erases the work done by normal], so I have sine 11 times 48.15 times s + 300 s. Oh, so we know S, it is 0.5, so it has potential energy, so we can't use T_1 – U-T_2, it has friction. So it has to go all the way to there, which is 0.9 in total. So the total length on slope is 0.51. So the total will be 0.81, and I put that as my S and v-final is zero. I just plug in the checks again, this is only one, so it put this one 7.44 +2.43 – 39.002 mu-k = 0. So mu-k is 6.9. It is ridiculously off.* Allen's posttest.

> *Allen: I was assuming that the kinetic energy, if it reached the top would not be a negative value, so it stops before it reached the top. So it starts and ends with zero kinetic energy. I assumed that velocity was zero when it starts. The assumption was that the block was to start from rest and end up at rest and the friction force was what stopped it.* Allen's interview.

Module-2 PLE Group

Jonathan

In the pretest, Jonathan solved both sections of the problem. He identified the problem core concept, remembered the formulas, and constructed the correct equations. In the intervention, he compared both problems and checked to see if anything was missing in the first attempt. He checked to determine if the block would stop on the downward slope. During the posttest, he added only a few more drawings and changed nothing. All of his answers in the interview confirmed that he did not learn anything new from the paper solution.

> Interviewer*: How did you calculate the value of the work done by the weight or the potential energy change of the weight?*
>
> Jonathan*: Energy change is just the work of the displacement. M G is just mass, and gravitational* --
>
> Interviewer: *How about frictional force?*

> Jonathan*: The frictional force is just the -- oh, you want me to say just the frictional force or the -- the work is the frictional force times the length as the block moves.*
>
> *Interviewer: How about normal force?*
>
> Jonathan*: Normal force is just MG times the sine theta, because the normal force is always perpendicular to the velocity -- or perpendicular to the displacement, so it doesn't contribute to the work decrease.*
>
> Interviewer*: How about the kinetic energy of the block at A or B?*
>
> Jonathan*: Always decreases.*
>
> Interviewer*: How did you calculate it?*
>
> Jonathan*: If I want to calculate the kinetic energy -- the kinetic energy is zero."*
>
> Jonathan's interview.

George

During the pretest, George first used Newton's Second Law to solve the problem. Thereafter, he was guided to the correct concept and tried to make assumptions about the work done by the forces, although he had a problem with finding the normal force. Eventually he solved both parts of the problem. During the intervention, he studied the diagrams thoroughly and checked out his previous knowledge. He did not perform a posttest because he believed strongly that he had gotten the correct answer to both parts initially. During the interview, he said that he had not paid much attention to the solved problem because he knew that he had done a good job on the first try. He said that he simply checked out the formulas to make sure they were correct. He believed that the solution was over-explained. George elaborated:

> *George: My assumption was that the work from the spring was going to be positive and that the frictional work and the work from the weight was negative. There is another assumption and it is about the energies. Well, I thought up here, when I read it, I read it a second time and I saw just the .51 meters, I'd assumed that it was this right here, but I didn't understand why it wasn't there, but I just didn't look to see that, so I think that by itself, it was fine. I just needed to pay a little bit more attention.* George's interview.

Joe

Joe solved the first part of the problem incorrectly, calculating a value of 3.5 for the friction coefficient, and realized that it was wrong, but he could not find out where that happened. Then he asked to move to the next part of the interview. In the intervention stage, Joe looked at the diagrams and the explanations given with the figures. He made correct conclusions about the value sign of the work done by the weight. During the posttest, he copied the solution procedure, tried to correct the value of the work done by the normal force, and found the error that was made initially. During the interview, he confirmed that he had copied the solution procedure without actually understanding what would happen. He believed that the solution contained plenty of explanation which he stated might be boring.

> Joe*: So we are going to see,* T_1 *is zero, this is* O_1*, this is A and this is B, can we say,* T_A *and* T_B *is zero?*

Interviewer: *No, it will not stop in A; you use it all the way to B.*

Joe*: So we write the Principle of Work and Energy, in two portions, so the spring is compressed, and work is ½ k times 0.2 squared -- is 12 joules. Then we have another work weight. So the normal force is equal to weight, [in the horizontal portion, in the inclined part] multiplied by the sine theta.*

Interviewer*: Would the spring force change that?*

Joe*: No, because the spring is perpendicular to this one, it does not change Itoh, I see, so all I have is friction, [draws another horizontal free-body diagram, and writes the work done by friction. Finds it] so all I have to do is to add up all this and put it is equal to zero. Making the correct one in negative and positive, and so, this one is negative, this one positive, and this one negative.* Joe's posttest.

Tony

Tony read the problem quickly, and he readily calculated the works done by different forces, but he paid little attention to the sign of the works. He did not consider the large, suspicious value for the friction factor. In the next part, Tony tried to build up the scenario and eventually figured out how to interpret the wrong assumption. After a couple of small errors, he finally found the correct answer to the second part.

In the intervention, he explained the solution procedure and studied the sign of the works. As soon as he compared his solution to the solution of this problem, he passed over the pages quickly. He used the solution to fix the errors he had made during the pretest, and this time he found the mistake in calculating the distance. During the interview, he reviewed the entire process and confirmed that he had used the solved problem to check his work with more focus on the distances and calculations. He stated that he had not read the explanations thoroughly, but instead was looking at the mathematical relations.

> Interviewer*: How did you determine the kinetic energy of the block at each point, before and after you saw the solved problem?*
>
> Tony*: So, in the beginning I missed it, when I started to solve it, it was being measured as when I was solving the problem again, and I knew it was asking about the kinetic energy before it is released and had no motion and no kinetic energy and also at the very end of each equation which is the zero kinetic energy.*
>
> Interviewer*: What assumption did you make?*
>
> Tony*: The first problem? The assumption was that the block was to start from rest and end up at rest and the friction force was what stopped it. In part two, finding the distance, I was assuming that the kinetic energy, if it reached the top, would not be a negative value, so it stops before it reached the top. So it starts and ends with zero kinetic energy.* Tony's interview.

Farrell

Farrell started the solution process by drawing free-body diagrams. He managed to write the energy equation correctly, but failed to plug in the right parameter in the correct position, and he came to a contradiction, 12 = 0. Therefore, he asked to move to the intervention stage. By reading the problem and looking at the solution, Farrell understood how to plug the known and unknowns into the equation. He almost remembered that and asked to return to the problem. When asked if he was sure about the solution, he stated that he felt totally sure. During the posttest, it was apparent that he had recalled how to solve the problem. He confidently wrote the work done by each force and knew that he had made a verifiable assumption. After finding the answer, he verified it. During the interview, he confirmed that he had forgotten the concept, and the solved problem had helped him to recall the solution. In fact, he suggested that the solved problem had not taught him anything new. He believed that the paper solution over explained and could have been shorter. Farrell commented:

> Farrell*: Yes. I can solve [the problem], so they broke it up into two sections, [draws the problem diagram] then right here at A the forces are different, because there is no incline anymore [completes the figure and goes back to the problem to follow the procedure]. So, initially the work done by the spring is ½ k times* s^2 *which is 12, and the work done by the friction is mu-k times normal times the distance, so mu times cosine theta which is 11.3, you said? [Calculates and says it].*
>
> *And the work by the friction from A to B, this time normal is 49.05, and work done by the friction from A to B is, 14.75 times mu, so the basic formula is T1 + work done by the forces is equal to T2, so the U is summation of all the forces.*
>
> Interviewer*: You assume that it goes farther than A?*
>
> Farrell*: Yes, I did, probably I shouldn't have [calculates] I am just adding these two to see if they are more than 12, and they are, so it doesn't go up, so [rewrites the equations] it is more complicated than the other one.* Farrell's posttest.

Patricia

Patricia took more time than the other participants to find the dimensions and mathematical relationships before starting to solve the problem. She tried to find the concept in the book and looked up the equations. Shaded not draw a free-body diagram at this stage. Shortly thereafter, she asked to see the solved problem, and in studying it, she looked for the solution procedure, as if she already knew the concept. She compared the problem with the first one and concluded that they were basically the same. She took notes from the equations and formulas that seemed new to her. Regarding the concept and assumptions of the block passing over the tip, she looked confused.

In the pretest, she followed the same procedure as the solved problem. Apparently she had recalled the solution, but was still uncertain about the concept. She made a notable algebraic mistake in finding the answer to the first part, and after some checks, she found the right answer. During the interview, she commented on the fact that she had forgotten the concept, but she remembered the formulas for kinetic energy and work done by forces. Even after studying the solved problem, she was unable to make assumptions to solve the second part of the assessment problem.

> Patricia*: Okay, so it is pretty much the same [problem]. So just the numbers are changed, we have pictures. So they started with the free-body diagram, so they said what we have, the normal force, the force of the spring which is up here, and friction, and they had the weight. So, same as mine, it is just at the spring -- [writes on the same page] equals -- it is going backwards, so it is negative and it is force times the distance [hesitates]. So, that is going to mean negative mu times*

> *normal times distance. [Writes it] So, now we use the principle of work and energy to find the mu. So, T1 + ΣU = T2. So, .1 and sum of works and the energy -- kinetic energy [reads from the solution] and the* T_1 *is zero because it starts from zero, it is ½* mv^2 *and sum of works and* T_2 *which is zero, and we need to sum all the forces. So,* F_1*, S, W and* F_2 *are to be summed [counts the works that she has calculated – looks confused]. So, we write all the forces.* Patricia's intervention.

Module-3 CSA Group

David

David could not figure out the concept from memory. He tried to model a similar problem regarding angular impulse and momentum. After making sure that it was an impulse and momentum problem, he built up the equations easily and found the solution. David believed that it was his memory that failed him initially, and when he recalled the concept, he was able to solve it. He said that was why he did not study the module thoroughly. He played the animation a couple of times and changed the mass and initial velocity. He commented about the relationship of change of the parameters to the changes in the animation. Then, he checked the reason that weights were not present in the final momentum equation. He was convinced by the explanation given in the module. He briefly checked out the math of the problem to see if he had placed all of the terms in the equation, and then moved on. David remarked:

> *I remember we did a disk, so finding the distance of the sphere in 3 seconds, the distance is 0.35 me [draws the figure again]. You want angular impulse and momentum. It is angular, because it is rotating, r cross mv plus integral of r cross forces, equal the final angular momentum, conservation [mumbles in a fading voice]. Therefore, the momentum is in the initial momentum diagram. It is the top view. This is the arm moving in, 200 times 8 feet, initial momentum diagram, three m, this is the crate, to arms, mass, linear, angular -- It isn't going to be r cross mv [scrolls to the next]. Impulse diagram, in the free-body diagram shows all the moments and forces that act, so it is adding time to the free-body diagram.*

David's intervention.

In the posttest, David quickly checked his initial solution and answer with more confidence. He replied to the interview questions saying that he could not figure out the topic of the problem because he had forgotten it. He did not draw free-body or impulse diagrams; instead, he redrew the diagram to understand it better. Regarding the animation, he was more interested in the trajectory of the slider, and he believed that it was the only new issue that he learned from that module. David replied:

> *It kind of helped to illustrate the concept. We talked about that in class, just spent a little time and twice used the example with the disk. Maybe twice just kind of to illustrate it. Other than that, we didn't go over the conservation of angular momentum as much, so having that as a two-part system really helped me to learn that everything is contributing to the motion of the particle as a rigid body as it is changing and the moments in the middle is what is actually slowing it down it*

> *becomes –I was just kind of copying this to figure out how it is moving, so I did not draw specific diagrams, but I drew this to tell me what is moving down because the rope is moving down. And the disk is spinning. That is how I was thinking that I got velocity as 0.05 and how I got weight.* David's interview.

Kayla

In the pretest, Kayla was unable to identify the concept and asked to move to the next stage and study the module. She did not exhibit an activity signifying a notable cognitive code during the pretest. While she studied the module in the intervention, she quickly scrolled to the animation, almost bypassing the problem statement. She played the animation with multiple parameters, some of which were low and caused the animation to run slowly. By going to the solution slides, she read the text with little attention to the figures, hints, or 3D diagrams. In her interview, Kayla stated:

> *Just reading, backtracking to make sure that I can understand where they are getting certain variables. I don't understand where they are getting this negative 50t from, now with the moment equation here.*

Shewa's able to solve the problem in the posttest, used her notes, and replicated the solution procedure of the module. Obviously she did not concentrate enough and, therefore, made multiple calculation errors. In the interview feedback, she mentioned that she had forgotten the topic and was thinking about the energy topic. Kayla continued:

> *I can remember that was the Principle of Conservation of Energy, but not Conservation of Linear Momentum and Angular Momentum, I could not*

> *remember exactly what formulas were, but I knew it was concepts. I just needed to refresh my memory to have a second look.*

Andy

Similar to Kayla, Andy was unable to figure out the concept. He asked for help on solving it, and after a short time, he declined and asked to study the module. During the intervention, he was more interested in the equations than the concepts. He looked briefly at the animation. He did not click the second 3D figure after clicking a first diagram. He read the text carefully to prevent errors in the solution. His answers during the interview confirmed this:

> Interviewer*: Do you want to say, if you had to remember the concept itself, automatically you could find out how to write the equations?*
>
> Andy*: Not really, I could remember the concept, but remembering the equations takes more effort.*
>
> Interviewer*: What assumptions did you make?*
>
> Andy*: It gave me a couple of assumptions to make. It told me that don't need to worry about the friction. The mass of pole and the cord is really a factor. I guess there are no other external forces acting on it. And starting from rest, and you did not calculate to time.*
>
> Interviewer*: What was the most difficult part?*
>
> Andy*: The direction of r-m-v. Because I know the moment is acting clockwise, so the mass is definitely -- the ball is going this way. It was more intuitive in this case because it knew that that the moment is causing it this way. I could make it*

> *very complicated by giving an initial velocity and moment in the opposite direction.* Andy's interview**.**

John

John could not remember the concept, the equations, nor the definitions. He asked to move to the intervention and study the module. By looking at the title page, he recalled that topic and read the problem. He was not interested in the animation nor the parameter change feature. His concern was merely noting relevant equations, plugging in the parameters, and finding the answer. The approach worked successfully during the posttest. His interview replies showed that the most attractive feature in the module to him was the systematic navigation through the solution. He had not seen a telescopic crane. The 3D figure of the problem and the 3D diagrams showing impulses helped him more than the other features. John remarked:

> Interviewer*: How did the module help you?*
>
> John*: It definitely helped refresh it and put it back in my mind. So, I have been more confident if I could see a problem like this in my mind again. One thing back of this specific problem, I could find out anything by seeing the video movie, animation*
>
> Interviewer*: If I had told you that this problem is about angular momentum, would you have read it?*
>
> John*: I would have, but still it would have helped.*
>
> Interviewer*: How about the hints? Were they useful?*

> John*: Yeah, the 3D diagrams were. You come up with what it was like more real life.* John's interview.

Sam

Sam was unable to solve the problem in the pretest. After he moved to the module, he was interested in the animation and changed the parameters several times, running the animation after each change. He analyzed the changes and asked himself multiple questions and tried to imagine why it happened and how masses changed the speed. His concentration decreased when he looked at the solution, and he paid little attention to the hints. During the posttest, he used the textbook to write the equations. He copied the solution without drawing the impulse and momentum diagrams.

In his interview, Sam stated that he almost found the concept and if he was given more time, he would have solved the problem. He believed that the textbook would have helped him through similar examples. He also said that the module refreshed his memory. His reasoning about why he did not draw an impulse diagram was interesting, as he explained in the following conversation:

> Interviewer*: You did not draw an impulse and momentum diagram like we did in the module. Why is that?*
>
> Sam*: The way my mind works is a lot plug and chug. I am used to having an equation to be handed to me and I figure out the different components to go from there, sometimes I lack the fundamental conclusions to draw it myself.* Sam's interview.

Greg

Greg read the problem statement thoroughly and slowly. He was able to identify the problem concept after some help. He systematically classified the knowns and unknowns of the problem and drew the necessary drawings. He found pertinent equations in the textbook. Apparently he had forgotten the equations, but after recalling the concept, he plugged in the parameters and calculated the answer. During the intervention, he realized that the problem was about how students solve problems on the impulse and momentum topic. His frequent mentioning of a similarity between the module and assessment problem showed that he was comparing the two problems. He paid little attention to the animation and solution texts, but instead was more interested in the 3D figures. In the posttest, he once again confirmed his initial solution. Even after friction and normal forces were added to the problem, he figured out how the new forces acted, and he solved the problem correctly. In his interview, he stated that he had learned the most from the module figures, reminding him about how each force generated the angular momentum vector. Greg elaborated:

> *So, changing the linear momentum diagram, you can change it to an angular momentum diagram, with a radius -- mass times velocity. So, the impulse diagram is just the moment with the weight and the crate, whereas before -- And all of these are clickable. So, that's the angular momentum because of the right-hand rule, this is the radius, this is velocity, same deal. Yeah, so this is the angular one.*
>
> Greg's posttest.

Module-3 PLE Group

Mary

Similar to several other participants, Mary was unable to identify the concept of the problem. In fact, she stated that she did not have enough known parameters to start. She tried Newton's Second Law, but stopped at calculating the acceleration caused by the base moment. She could not go further and asked to study the module. She compared the solved problem with the assessment problem and repeated the procedure. Mary commented:

> *Okay, because it has that* t^2 *there. So angular impulse [draws diagram] -- we have some angular impulse is the integral of the moment. It is just* $0.02t^2$ *for 0 to t and the weight here, so the momentum here [where the ball is] is the mass times the final velocity, which is what we are trying to find. So, now we will do the equations. Initial angular momentum plus angular impulse, which is M x dt equals final angular momentum. Therefore, initial angular momentum is zero for this one because we start from rest. Then, the integral from 0 to 3 of* $.02t^2dt$ *is our angular impulse and it equals the final, which is the radius.* Mary's posttest.

Jennifer

Jennifer easily found the concept. She had forgotten the equation. So, she searched through the textbook, found the formula, and wrote it down. She was unsure about how to plug in the correct parameters in the correct position. Jennifer was busy finding out if the angular momentum was a vector and scalar. When she studied the PLE-solved problem, she searched for the final equation, although she read the solution explanation. During her interview she stated that she had found the topic because it was rotating and there were mass and velocities. It could not be the work principle because there was no angle for the moment. She also believed that the solution was too wordy, although it was not misleading. She preferred the 2D figures and believed that they were enough. Jennifer commented:

> *Initial length of the arm is 8 feet. As it rotates, its length is shortened at .05m/s. Initial momentum diagram and impulse diagram and final momentum diagram [reading aloud word for word]. Calculate the time of motion based on the shortening of the arm [continues reading, turns to last page, and looks at the solution].* Jennifer's posttest.

Mike

Mike could not find what topic the problem was about, and he decided to study the solved problem. As soon as he started with the solution, he wanted to write the information he needed. He did not pay attention to the tricky point about the two weights and the relationship between their motions. During the posttest, he confidently drew free-body and impulse diagrams, and constructed the equations using his notes. In his interview, he mentioned that he had forgotten the entire topic and that the solved problem helped him recall. Mike stated:

> Interviewer*: How did this solved problem help you understand the concept?*
>
> Mike*: It really helped me understand where to start. I think that's the hardest part in problem-solving. It was a while ago. I remembered it was the Principle of*

> *Impulse and Momentum. Generally said, it helped me remember what I had learned before, refresh rather than teach additional stuff.* Mike's interview.

Katie

Katie, after not being able to find the concept, quickly moved to the intervention, that is, the solved problem. She read the problem and developed the idea of the solution. After returning to solve the assessment problem, she replicated the procedure, starting from the free-body diagrams, then to the impulse diagram, much like the solved problem. During the interview, she stated that she had learned the concept but had forgotten the solution procedure. She liked the 2D figures because they were simple and included the needed information only. Katie stated:

> Katie: *It's similar to the other one because it's rotating and shortening [reading]. We use the Principle of Angular Impulse and Momentum but not the conservation because angular momentum is not conserved. That is because M is applied to the arm and changes as the angular momentum of the arm rotates. Okay, then they start with step 1: Draw the initial momentum diagram, which is shown below the explanation. In general, a momentum diagram shows linear momentum mv, where m is mass and v is speed. So that's how we relate linear momentum. Angular momentum, which is the moment of linear momentum, can later be calculated using r times mv, where r is the distance between the origin of the coordinate system and the point where the linear momentum mv acts.* Katie's intervention.
>
> Interviewer*: How did these figures help you? (The figures in the module)*

> Katie*: They helped because it showed a simplified version of what was going on in the 3-dimensional figure. Since it was a top-view we could just see the velocity and its direction on this one, especially. Then we could relate the origin to the different masses and to each of the components.* Katie's interview.

Keith

Keith strategized the solution by looking through the textbook to find a similar problem. He made solid conclusions from the problem statement, but after not finding the relevant topic, he asked to move on and see the solved example. He read the problem and solution thoroughly. He did not note any equations from the solved problem, and made another attempt to solve the assessment problem. He solved it easily -- even the posttest problem contained more parameters and was more difficult. During the interview, his interest in similar problems was confirmed. He believed that he was close to solving the problem the first time, and the solved problem only helped him organize his solution, which explained why he liked the short explanations that followed each equation. In his pretest, Keith elaborated:

> Keith*: Yes, the free-body diagram m=1.5kg. The weight of the ball is 1.5 times 9.81 [using calculator]. It is 14.7 Newtons. The distance from the ball to the center of rotation is 0.35 meters. This moment is* $0.02t^2$*. Okay. This is moving inwards at a rate of 0.05m/s. Therefore, I look in the textbook to see if there is anything similar to this. Rotation about a fixed axis is what I am looking for.*
>
> Interviewer*: Did you remember the topic?*

> Keith*: Well, I could remember doing homework problems similar to this from the class, and they used angular momentum. I did not remember about the conservation of momentum, but I knew that there were forces involved, and it gave me a time of rotation, so I knew that usually when there's forces and time involved, it is best to use the Principle of Angular Impulse and Momentum, So, I thought of that.*
>
> Interviewer*: Which part of the problem did you like best?*
>
> Keith*: I think what I liked best about it was having them diagram the equations and a short explanation about why they were used. So, I liked the little notes, like the sizes of the arm or the weight of the crate, or that they don't generate moments, or that this is twice as fast because of the radius. So, I like having the equations there and a little note, or explanation, about why those equations were used.*

Richard

Richard quickly realized that the problem dealt with particle dynamics, and he had a solid understanding of the concept. From the existing rotating moment, velocities, and force, he concluded that the problem was one of impulse and momentum. Initially he searched for the angle of rotation to apply the Principle of Work and Energy, but he quickly identified the topic. The solved problem helped him confirm the equations and check out what happens if two masses were present. During the posttest, even though friction and normal reaction forces were added, he applied the effects of those forces and solved the problem. He stated that the solved problem helped him more in organizing the procedure, but did not include any information that he did not know. Richard commented:

> Richard*: Okay, what we change, is now we have -- [adds to the free-body diagram] cable force is 12N, and we have a friction force of 4.5N. That would be same throughout. Momentum-1 is still zero, and momentum-2, is not going to change either, and we are still solving for velocity, right? H-2 is 0.36, for out impulses, are angular is going to be the same. So, it is 0.18, and we added a linear aspect to it, we have added these two forces. Let's see, my mind is little bit confused in the sense that we are not able to use linear momentum.* Richard's posttest.

CHAPTER VI

OVERALL ANALYSIS OF MODULE-1 RESULTS

Chapter VI discusses the findings of the problem-solving activity for the participants who worked with Module-1. The analysis entails two sections: first, the effects of the module on the students' cognitive process are investigated; and second, the similarities and differences between application of the CSA module and the PLE-solved problem are described and deliberated. In the first section, the students' actions during each of the four stages of the problem-solving experience were coded according to the main coding table. Specifically, each student's actions were interpreted to codes that belong to the main coding scheme. Each participant's frequency of a code denoted the total number of times that the code was noted in all of the participant's activities. The number of students whose transcripts contained that code was also noted. Another quantity was defined as code index which is the product of the code frequency and the number of students; the code index helped to distinguish the significance of that code among the participants. If two codes with equal frequencies emerged among a larger number of students, the code index showed the prevalence of the code with a larger number of students. For each category, the frequency, number of students, and prevalence index were calculated and compared in tabular and graphical formats in this chapter.

In order to compare the effects of the CSA and PLE representations, transcripts of conversations with the students who worked on the PLE-solved problem were coded. The corresponding code frequencies, number of students, and code indices were tabulated.

Comparing the corresponding codes yielded valuable insight about the item insofar as differences and similarities. There were situations in which a participant repeated an activity which represented a code multiple times in different stages. In that case, the code was recorded only once, and upcoming identical codes were ignored. Thus, the recorded codes depicted new activities only, and the comparison of numbers between stages was meaningful. After preparing comparison tables, the differences between results of the CSA and PLE groups were investigated. A review of the coded data described student's general problem-solving behavior. Several themes were observed regarding students' common strategies and similar mistakes.

Effects of the Module on Cognitive Process

The first level of the coding helped identify the themes associated with the categories of *Revised Bloom's Taxonomy*. This section addresses the five categories of cognitive process which form the structure of the coding table and discusses the themes classified in each category. Coding tables of all three modules were identical up to the first and second levels. There were slight differences in level three because of the content of the topic. In module-1, simple concepts included velocity, and acceleration and force and complex concepts included Newton's Laws of Motion, relative motion, and pulley system. For each category, the relevant table included the total code frequency of that category or subcategories. The next figure denoted the number of students who indicated that and the next figure was the code index. As mentioned before, this index was the product of frequency and the number of students. For example, if one code is observed in five students' activity, one time each, its code index will be 5 × 5 = 25. If the code were seen in one student's activity five times, the code index would be 5 × 1 = 5. This comparison shows the significance of code index in the analysis.

Remembering

The CSA-group students performed a few remembering activities during their pretest. This was due to the simple form of the Newton's Second Law equation and objective definitions of the parameters involved. Among the group, almost every student recalled the main concepts; however, only Bruce recalled the frictional force formula after working with the module. It was observed that all participants remembered the trivial facts which were needed to solve this problem. The coding table does not include activities with small importance. The table reveals that students tend to forget the relationship between the frictional force and the normal force. It was expected that the text information in the module would help students remember the equation forms and help to refresh students' memories. Charlie remembered the velocity after he worked with the module, and Bill used the module to remember the kinematic formula. The most frequent codes were remembering the relative acceleration and force concepts. Because most participants recalled the concepts in the pretest, it may be concluded that the CSA did not cause much "remembering". Bill commented in his posttest:

> Bill*: Okay, step 5, acceleration of A is negative* a_B*, I was really stuck there, so I find that, that's* $s = \frac{1}{2} at^2$ *I realize it was relative acceleration.*
>
> Interviewer*: Okay, if you need to take notes?*

> Bill: *Which "a"? [Noting the issues, equations, and formulas, and* $s = \frac{1}{2} a t^2 + v_0 t + s_0$*. . .* a_{rel} *which is* $a_A - a_B$*.] So for the last equation you get* a_{rel} *which is* $a_A - a_B$*.*

Understanding

Among all seven subcategories of "understanding," the CSA modules caused highest effects on "making inferences" in which all of the participants made at least one inference about the solution. One significant inference entailed "equivalence of the blocks" accelerations made by Ryan, Walter, Bruce, Ray, and Matt. Another observed inference was the presence of the normal reaction and frictional force according to Newton's Third Law, as stated by Walter, Bruce, and Ray during their intervention. Each participant applied that understanding in their posttest and commented on it during the interview. "Summarizing" was the only code that students did not exhibit many activities, most likely due to the fact that the students had not large amount of information to note from the problem which would need to be summarized. The CSA module caused the students to make inferences when they were playing with the animation. They made specific conclusions about the motion of the blocks (which is identical in opposite directions). For example, in his posttest Walter stated:

> *Then, I'm going to have my next free-body diagram, [puts the W and N on the block A free-body diagram, draws the free-body diagram for B and all of the forces] and my [300 N] force is going that way, and my fiction force is going this way, [the opposite direction]. Here I', going to have* f_1*,* f_2*,* N_1*, T, 300N. [Draws the pulley system, drawing the* x_A*,* x_B*] and we have:* $a_A = a_B$*. [He writes the*

equations of motion in x-direction, plugging in the parameters]. Then, I'm going to have the y-direction.

Another student, Cindy, commented in her intervention:

So, that block has the tension, has the friction, the weight, the normal, the weight A+B, which is equal to normal force going up. [Reads more from the free-body diagram hint; telling the forces and putting the reaction on the interface]. This friction force is applied by A, because A goes this way, and friction goes that way.

Applying

The participating students conducted small number of activities that had to do with "applying" during the pretest, although they observed how the solution outlined the problem, grouped the input data, drew free-body and kinetic diagrams, and applied dynamics principles. The CSA module obviously changed their method of applying dynamics principles in the solution. Students' solutions clearly were more structured after working with the module. They grouped the knowns and unknowns more precisely and drew more organized free-body diagrams, and in their interviews, almost everybody mentioned that was because of working with the CSA module. The subcategory codes "executing" and "implementing" involved more engagement. It was expected that the students would conduct a few activities to signify "executing" and "implementing" during the intervention, but it was obvious that the module caused more structuring of the problem. During the pretest, the students did not need to start over nor strategize, although they were able to reach to the final parts of the solution which involved performing the mathematical operations and solving the equations. Bill and Bruce solved the equations easily after they wrote them and plugged in the correct parameters. In his posttest, Bill stated:

> *[Rewrites the equations, plugging the a_A as -a_B] I want to use the calculator, but I don't know how to use the matrices [solves the equations manually and finds the answer for T = 32.435 N and for a_B = 0.4006]. It is really small, but it makes the a_A = -0.4; therefore, the a_{rel} is 0.808 and finally $s = ½ a t^2 + v_0 t + s_0$ in which s_0 = 0 and v_0 = 0; so we have the t^2 = 1.45 and t = 1.224sec. [Sets up the equations of motion for A, and then B, forgets to put N_A on B. Plugs in the numbers to solve the system of equations, names the cable force as P. Then, rewrites the equations with numerical values and solves the equations by elimination].*

Analyzing

During their pretest, the students exhibited three types of analyzing activities. The first was to distinguish the knowns and unknowns of the problem. Because of the close association of the terms "distinguishing" and "understanding," distinguishing could be mistakenly grouped in the understanding category. However, distinguishing was more of an analyzing activity than understanding because the students needed to analyze the problem statement to distinguish the knowns and unknowns after they understood the problem and concept. The second analyzing activity was to organize the solution and establish the relationship between the interim variables. Identification of the relationship between the accelerations was an example of this activity. It was shown that "organizing" codes emerged during the different stages of problem-solving at the times that the students determined such relationships. Attributing the appropriate parameter to the variable was the last subcategory that was observed in analyzing. The latter code appeared significantly during the posttest after working with the module. After watching the overall solution process, the students constructed the equation by which the unknown was calculated. Bruce corrected the tension force, which was different from the cable force, and he had wrongly assumed they were identical. Bruce commented in his posttest:

> *Oh, this is not 300N, this is T, okay, friction, force µN, [draws the free-body diagram for B, puts the T, the 300N, normal force, mistakes the N_B for W_B and forgets the fact that N_B is $W_A + W_B$ -- but puts the friction on top and bottom]*
>
> *Then we have this pulley [draws the pulley and forces x_A and x_B, and concludes that $a_A + a_B = 0$. Then, goes back to A to calculate the f_A and sets up the equations of motion for A, and then B, but forgets to put N_A on B. He then plugs in the numbers to solve the system of equations and names the cable force as P and then rewrites the equations with numerical values and solves the equations by method of elimination].*
>
> *So, acceleration of A is positive and is 0.821 ${}^{m}/_{s}2$and a_B is -0.821 ${}^{m}/_{s}2$, so the tension P is 191.291N. Relative acceleration is 1.62 ${}^{m}/_{s^2}$ and is the difference between accelerations [calculates the time by kinematic equation] t = 0.742 sec.*

Evaluating

In the category of evaluating, a small number of observed codes indicated that the observed effects on evaluating were not significant during the pretest. In the intervention and posttest phases, the students showed several evaluating-related behaviors, including critiquing, monitoring, and checking. Trevor conducted a few checks before watching the module and detected a probable error in his solution. He made an overall parameter check to verify the entire process. It may be concluded that the step-by-step solution only helped the students to review their solution and parameter check. The fact that it was only Trevor who exhibited most of the coded activities, indicated that evaluation mostly depended on the student rather than the module. In his posttest, Trevor spoke with the interviewer:

> Trevor*: [Draws the kinetic diagram, sets up the equations for both blocks, but doesn't put the T on block B. Calculates the* a_B*]*
>
> *So, I think I forgot the tension here, so I need the third equation and* $a_A = - a_B$
>
> Interviewer*: So, now you have 3 unknowns and 3 equations?*
>
> Trevor*: No, I still need to setup the kinematic equation* $s_A + s_B = constant$*;* $v_A + v_B = 0$*,* $a_A + a_B = 0$*. So, three equations, three unknowns.*
>
> Interviewer*: So by solving* a_A *will it be 0.2?*
>
> Trevor*: 0.2? Ah, if* $a_A =0.2$ *then* $a_B = -0.2$*, the relative acceleration will be* $a_A- a_B = 0.4$*. And now we are going to find the time, which is our s=0.6; I'm not sure if it is* t^2*.*

Similarities and Differences between CSA and PLE Groups

Similarities between CSA and PLE Effects

There was a moderate similarity between CSA and PLE representations concerning the students' reaction. First, the students exhibited similar behavior in acquiring information. Text information, including descriptions and equations as well as static diagrams were the obvious commonalities of computer-based and paper representations of the problem. At the times that the student wanted to take a note of an equation, both groups acted the same way. They were seeking the key equation which they believed could solve the problem and checked if they remembered it correctly. Comparing the coding tables showed that in remembering during the intervention phase, both groups behaved similarly. In both groups, the majority of participants looked for the key equation regardless of its representation.

In addition, a similar trend was observed among students in both groups. They all needed the formula for distance or the kinematic equation. Seeking information in a reference is associated with remembering, and the most frequent entity recalled by the students during intervention was the friction force relationship with normal force. Similar trends were observed for CSA and PLE representations.

Another observed similarity was students' reasoning. Students in both groups strategized the problem in a similar manner. In the pretest, it was expected that they would implement the procedure they had learned insofar as drawing a free-body diagram, placing forces on the bodies, figuring out the direction of motion, and writing the equation. The strategy did not change with the intervention. In fact, students' procedural knowledge did not change with the representation. As for the conceptual part, significant differences were observed and those will be discussed in the following sections. Students' behavior in the situations in which they could find the concept was similar; they sought a keyword to find the topic and subsequently the main formula. They solved the problem by plugging the parameter values in the correct place and solving the mathematical equation. Such activities included multiple categories i.e. remembering, applying and analyzing. The overall outcome indicated a similar pattern regardless of the type of representation.

Differences between CSA and PLE Effects on Learning

Coding the data revealed that the main differences between PLE and CSA learning pertain to the understanding and analyzing categories of cognitive process. This section addresses the differences from two aspects: first, by comparing students ‘reactions tithe CSA module and PLE representation when they were exposed to them, i.e., the intervention phase; and second, by comparing the changes in students' performance from pretest to posttest between the PLE problem and CSA modules.

Most of the differences appeared during the intervention. The behavior change difference between the PLE and CSA in the pretest to posttest stages confirmed the differences in the intervention phase. Figure 6-1 summarizes the differences between the two groups in each category during the intervention phase. The table demonstrates that both groups showed similar remembering trends during intervention. The remembering category involved recalling both simple concepts such as direction of frictional force as well as more complex knowledge such as form of an equation or statement of Newton's Third Law. Both groups used their tools to confirm what they remembered. There was no significant difference between a PLE solution and a CSA module in the remembering category. Students in both groups remembered the almost identical concepts through similar means, which was reading the text.

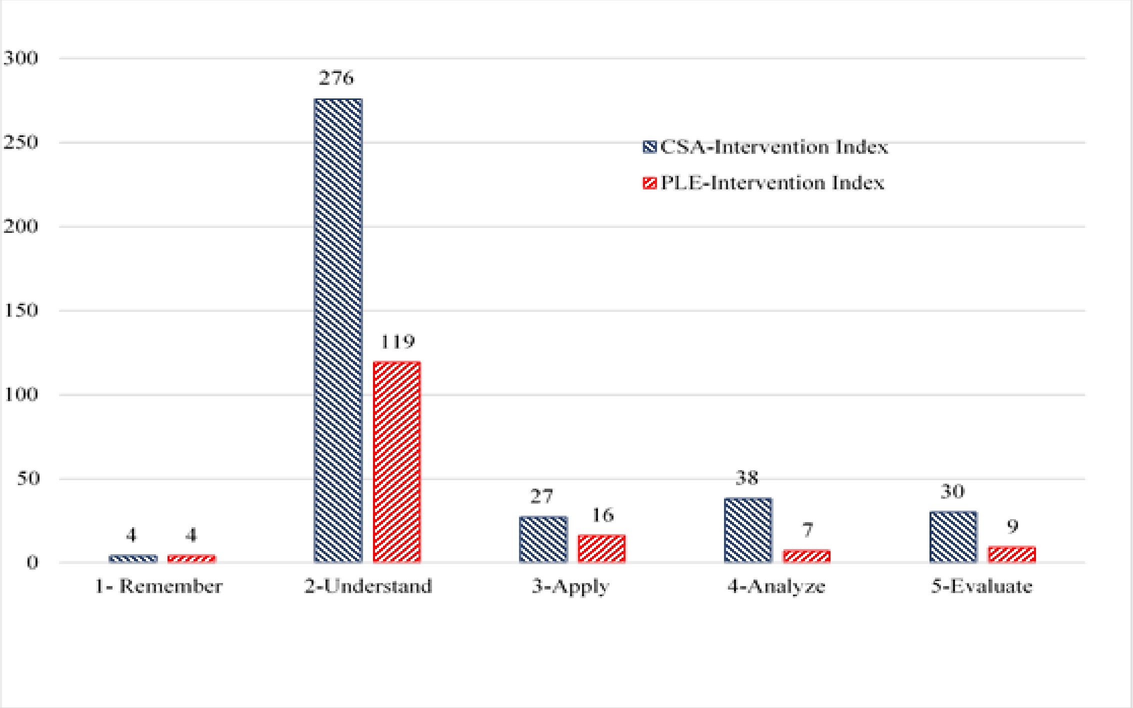


Figure 6-1. Module-1 code indices in intervention phase.

On the other hand, the CSA module and the PLE problem had different effects on students' understanding. During the intervention, especially when a particular student tried to play the animation, she started asking herself questions about how the blocks moved and why they moved consistently. This action was coded as making a comment and/or inference. In case the participant was able to answer her question, it was an indication of explaining. All of these items belong to the understanding category. The PLE group participants rarely exhibited activities of this type. The frequency of understanding codes among the CSA group was 57 vs. the 37 understanding codes among the PLE group. Another component of this difference was that the CSA group students talked about the solution and commented more while playing the animation and navigating between slides.

In the applying category, the differences between the two groups were not as significant as in the understanding category. It was expected that because applying involves active engagement, CSA intervention would result in bolder differences compared to the PLE. Nevertheless, the subcategories of applying entailed components of solution process, e.g., outlining the problem data, structuring numerical input, drawing free-body diagrams, adopting the solution strategy, or solving mathematical equations. Most of the CSA group participants exhibited such activities in the posttest after working with the module. This explains the low number of applying codes compared to understanding codes.

Evaluating was the last code considered in this analysis. Evaluation codes revealed that CSA group exhibited fewer codes than the PLE group during the intervention phase. Among the PLE group, only two participants, Matt and Cindy, looked through the solved problem. Matt reviewed it to detect his error during the pretest. It can be attributed to personal study style not caused by the PLE solved problem. In conclusion, it can be inferred that CSA module and PLE solved problems had similar effects on students' evaluation during the intervention, although CSA students' differences from pretest to posttest were more significant than the PLE group.

Differences between CSA and PLE Effects on Problem-solving

This section describes the differences between the effects of CSA and PLE on students' problem-solving. For this purpose, for each code, the differences between students' performance between pretest and posttest are analyzed. The same order of categories is reflected for this part. It starts with remembering. In the first cognitive category, remembering, changes between pretest and posttest depicted similar trends from both CSA and PLE groups. These changes from pretest to posttest that could have revealed the possible significant effects due to either of the tools. Figure 6-2 illustrates the difference between CSA and PLE effects in the problem-solving stages i.e. when the students were solving the problem for a second time. Interview feedback information was used to triangulate the findings, and validate if the interpretations and codes derived from participants' actions were consistent and trustworthy.

The understanding category revealed different change trends comparing PLE and CSA groups. CSA group students' inferences changed after working with the module even though they exhibited fewer inference codes. The conclusions were mostly about the possible scenarios of the solution rather than interpretations of the problem input

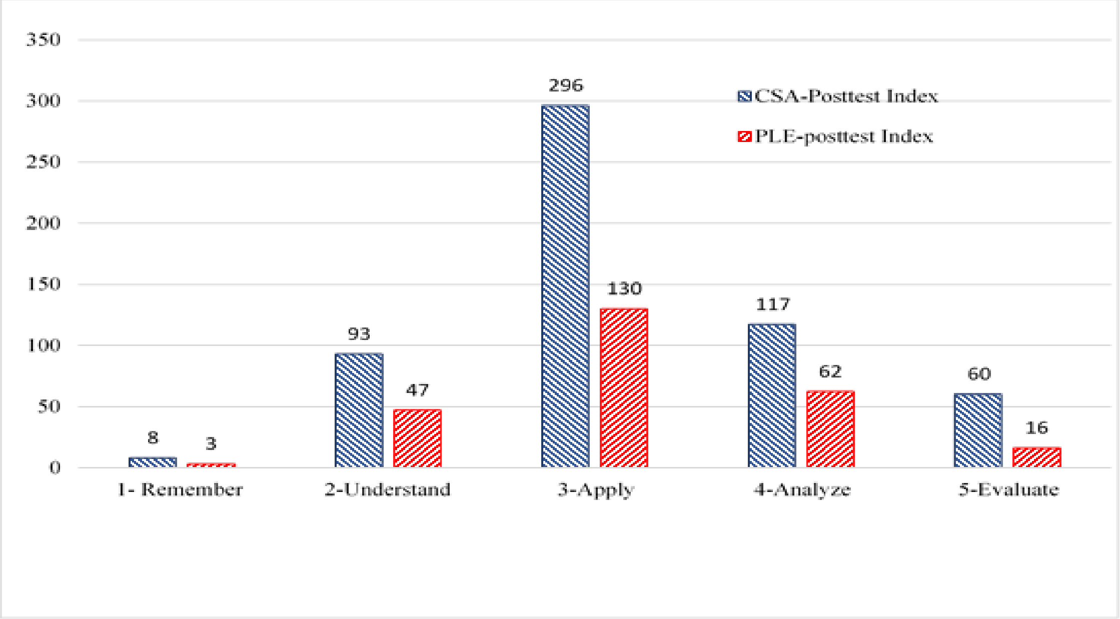


Figure 6-2. Module-1 code indices in posttest phase.

parameters. Within the applying category, the CSA group structured the problem better after working with the module. During the pretest, both groups had a similar type and number of structuring activities, but the number increased significantly for the CSA group in the posttest. An interesting finding about the applying category is that neither the PLE nor CSA students drew a “kinetic diagram” for the problem in the pretest or the posttest stages. Only one PLE group student, Cindy, drew it in her posttest. When asked in the interview about the reason for not drawing a kinetic diagram, almost everybody, regardless of the group, stated that they just used it when they do not know which direction the body moved.

The ability of the CSA group to structure the problem assisted them in establishing the relation between interim unknowns as well as constructing equations. The codes are associated with analyzing category. The PLE group exhibited the codes significantly less in their posttest, although the figures for pretest were similar. The CSA and PLE groups indicated no significant difference in evaluating during their problem-solving, which implies that regarding evaluation, the CSA module did not affect the students’ problem-solving differently from the PLE-solved problem.

Students’ Problem-solving Behavior

Outlining the Problem

Students from both CSA and PLE groups followed a similar pattern in solving the problem in the pretest. They started by drawing and building free-body diagrams. They identified the weight force, normal reaction, and friction on one block, but they failed to associate the reaction forces between the two blocks. Almost everybody constructed the kinetic equations, but only one person identified the relationship between the acceleration of two blocks.

Visualizing the Equality of Acceleration

When the CSA group participants saw the animation, they realized that the blocks were moving with equal accelerations. Although text explanations existed in the PLE solution, the PLE group missed the point. A similar situation occurred with regards to relative acceleration. It was not visually illustrated on the CSA module, and the CSA group participants failed to observe the relative acceleration even though it was a kinematics concept and was not directly related to Newton's Laws of Motion. The relative acceleration issue was also clearly explained in the PLE solution; however, all of PLE group participants missed it.

Parameter Change Feature

Module-1contained a parameter change feature by which the user could change the value of the coefficient of friction, and the solution and answer values would be affected accordingly. Most of the CSA group participants did not notice the feature, and when asked about it in the interview, only Charlie stated that it was "clear." Because the parameter change did not interest the students, the feature was deleted in the next modules.

Direction of the Friction Force

In the pretest stage, when the participants drew the free-body diagram for the larger block which was underneath, almost all of them forgot to place the reaction frictional force generated by the top block. The only participant who did so, Ray, made a mistake in the direction of that force. After watching the module, the CSA group students corrected that error and included all of the forces applied to the block. The procedure for drawing free-body diagrams was shown through a separate set of slides in the module while it was embedded in the paper solution. It caused the CSA group to follow the procedure more effectively. The same situation occurred with the normal reaction between the blocks.

Errors in Outlining the Problem Information

In both groups, Walter, Trevor, and Ray mistook the cable force for the pulling force. The misinterpretation may have been due to the notation; the cable tension force is usually denoted by T, and using this notation for the pulling force caused the misconception. All three individuals corrected the error after studying the solved problem independent of its representation.

CHAPTER VII

OVERALL ANALYSIS OF MODULE-2 RESULTS

Chapter VII describes the changes in participants' problem-solving behavior for Module-2. The coding table used for the module was similar to Module-1, except for level-3 differences, adding work and energy codes to the content. An analysis of the data involved reading the transcripts carefully, deriving statements that signified a cognitive category, and labeling them with the relevant code(s). It was repeated by another coder, and the results were compared and discussed. Finally, prevalent themes were noted and structured. Chapter VII includes a discussion of the effects of CSA through coding results, comparison of CSA and PLE effects, and dominant themes in students' behavior during their problem-solving activities.

Effects of the Module on Cognitive Process

This section investigates the coding results by analyzing three quantities: frequency of the codes observed, number of students who performed an action denoting the codes, and the code index, which is again the product of frequency and student number. Similar to Module-1, the quantities highlight what actions were observed most often and how working with the CSA caused the actions.

Remembering

The CSA modules helped students to recall their factual knowledge. Basically, all of the participants believed that they remembered the simple concept definitions, and their behavior confirmed their impression. Nevertheless, in recalling the statement of the pertinent mechanics law or equations, none of the participants was able to write the equation completely. It was observed that the “friction force” concept, which is a simple concept to remember, was the most frequent one recalled by the participants. While working with the CSA module, they showed no evidence of remembering the entire friction concept, but they mentioned that CSA solidified their previous knowledge. A similar condition occurred regarding complex concepts; for example, the Principle of Work and Energy is a level-2 concept, and the module helped participants who failed to recall the principle. In their interview, they mentioned the issue, commenting that the module helped them to recall the formula or the exact principle. There was a close relationship between the participants’ understanding and remembering performance. Those who understood the Principle of Work and Energy as a conservation equation equated the two sides of the equation by denoting the left side as “position 1” and the right side as “position 2.” Then, they constructed the equation by putting an initial energy term in “position1,” then a final energy term in “position 2,” and then putting a work done by forces term in “position 1,” thus remembering the equation by understanding its meaning.

The module also assisted the students’ remembering by reminding them of the sequential procedure of solving the problem that they had learned in the class. It started with drawing a free-body diagram, putting in all of the forces, distinguishing the forces generating work, and then writing the equations. All of the participants followed the module's routine after they watched it. They simply remembered the routine and implemented it in the posttest. Several of the students commented:

> Cameron: *Actually, I was thinking of my free-body diagram that I drew already in my mind, but I will redraw it.*
>
> Jacob: *Okay, so I write my normal force and free-body diagram. I have normal, force of gravity and friction, two free-body diagrams.*
>
> Allen: *This is the free-body diagram from the first, [draws another one without the spring force] so for this part, mu times normal, I have solved it, [writes the normal force value from before] then break the friction from A to B, it is 0.3 times 8.98 times mu -- these are all negative.*

Understanding

Most of the participants' understanding changed by using the module. Although they exhibited several understanding activities in the pretest stage, the CSA module helped them to make more inferences and comparisons, and they were able to explain more during the intervention stage. When they re-solved the assessment problem in the posttest stage, they showed significant "inferring" and more "comparing" activities multiple times. During the interview, almost all of the participants mentioned the issue. The CSA module created the most effects in "making inferences" in the understanding category. On average, each participant made three inferences during the pretest, three inferences during the intervention, and more than one new inference in the posttest, implying that the modules stimulated their cognitive ability. Most inferences were denoted by successfully identifying a relationship between verbal information in the problem and important parameters in the equation. Todd combined his memory with the verbal information to arrive at conclusions about the expected value of the coefficient of friction.

It is noteworthy that “understanding” was observed as the most significant effect among all of the categories of the cognitive process. In the posttest, “inference” codes referred to making new inferences, because it is reasonable to assume that the participant remembered the conclusion made earlier and only new inferences were coded.

Applying

The first subcategory in applying was “executing” which was denoted by one of the following activities: outlining the textual and graphical input data, structuring textual and graphical information, or establishing relationships between relevant variables. The participants performed the activities at least once during the pretest and one time during the posttest. Similar to “understanding,” “applying” activities observed in posttest were not identical to those of the pretest. Because the participants did not write nor solve anything during the intervention stage, little evidence exists regarding executing activities at this stage. However, each participant did outline and rewrite the problem input in both the pretest and posttest stages. Redrawing the problem figure and outlining the input seemed to be a helpful problem-solving technique. Almost all of the participants began their problem-solving with a free-body diagram. The diagram was not always correct nor complete, but it helped them to strategize the solution. For that reason, most of the students observed the solved problem free-body diagram carefully. In the posttest, they all matched their initial free-body diagram with the new one, checking to verify if some forces were missing. The module helped the participants construct their solution by linking the givens and unknowns.

"Implementing" was another subcategory of "applying" which was signified by three code activities: adopting a solution strategy, plugging in the parameter into the equations, and solving the mathematical equations. The participants performed better in plugging in the correct parameters and solving equations after working with the module.

Selecting the correct energy principle was the most frequent code in the intervention stage which was associated with the "applying" category of cognitive process according to RBT. By studying the CSA module, all of the CSA participants selected the correct principle in the pretest stage and could identify the relevant principles. A close analysis of the students' transcripts revealed that they figured out different principles in the module and applied them in their second solution attempt in the posttest. The following observations by Barbara in her posttest confirmed the "distinguishing activity":

> *[Draws the FBD for the slope part, for the horizontal part, writes the T0+U=T1 equation; calculates the friction force and weight force, then writes the equation and solves the algebraic equation]. I guess I got wrong signs, friction is opposite, weight is negative, spring is positive.*

In her interview, Barbara commented:

> *I was definitely struggling with that part, [before seeing the module], I was kind of guessing based on my knowledge of friction doing negative work, spring does positive [work] because it is pushing.*

Barbara tried to solve the problem using Newton's Second Law, then changed to Conservation of Work and Energy. After looking at the module, she realized that it was a Principle of Work and Energy problem, and remembered the principle that friction always does negative work.

Analyzing

The analyzing category was comprised of three subcategories: differentiating, organizing, and attributing. Each participant completed more than one activity associated with differentiating in the pretest. Through working with the modules, the students found more relationships between the parameters. They linked the initial energy of the block to the distance it moved on the ramp, and determined whether or not it passed the top of the ramp.

Organizing was identified by establishing the relationship between the interim unknowns and their relationship with the input and the final unknown. Organization occurred frequently in the pretest and posttest. It showed that the CSA module helped the students to organize their mental solution process and ultimately construct the mathematical equations. Attributing a quantity to the congruent parameter in the equation and constructing the mathematical equation was coded in the "attributing" category.

Evaluating

While working with the CSA module, the participants appeared to be more self-critical. They became aware of their assumptions and their thoughts before they attempted to solve the problem for the second time in posttest. After working with the module, they detected errors or miscalculations more frequently. For example, Alice reviewed her solution and checked for errors to make sure that every parameter was correctly written and in the correct position. Then, she realized that she had used the wrong weight after the problem-solving activity.

> Alice: *So, this the force -- is working and I missed it? Oh, the spring force. So, the only difference I can get was that the work done by weight -- I neglected that the first time through.*
>
> *The work done by the spring will be positive, the work done by the friction in both cases will be negative, and the work done by the weight will be negative. So, it goes that side, it will. . . Oh, this needs to be a negative. The positive value for that was the answer. I did not actually calculate it out, I just realized 12 was -- it would end up negative, which is weird.*
>
> Interviewer: *Well, did you make a mistake?*
>
> Alice: *Oh, the weight. I calculated the wrong weight. Thank you.*

Another evaluating item detected was in the “critiquing” subcategory that involved looking at the process again and deliberating on the final answer to check if it made sense. After working with the module, the participants showed a higher level of awareness about the answer, and they commented about the answer several times, for example, checking the kinetic energy to be positive and double checking the friction factor they had calculated to be “making sense.” Again, Alice checked the values of the answer to be reasonable. George came to the same conclusion in analyzing the calculated value of height. In her posttest, Alice commented:

> *Seventy-five hundred over this value, which is .158 times .51, plus 5 x 9.80 x .3, which is 39.245 = . . . mu sub K . . ., which is . . ., 2500 . . . [pauses in unhappy surprise]. . . That does not make sense. [Writes answer as 191.109]. That doesn't make sense because mu sub K is almost always between zero and one, and that number is much larger than one, which will result in a negative answer which doesn't -- this will end up in a negative answer which doesn't look quite right. Well, maybe a negative response, negative mathematical mistake somewhere.* In his posttest, George stated:
>
> *Oh, I forgot my gravity (corrects it); so d is 0.63. Did I miss something wrong? [Starts the energy equation again, cannot find the mistake, stops talking]. So, we know that d = 0.63, I set up something wrong [observes that 0.63 is greater than 0.5, repeats the calculations]. Oh, so the answer I got from the calculator.*

Similarities and Differences between CSA and PLE Groups

The differences between CSA and PLE problem-solving were examined from two perspectives: first, by comparing student feedback about CSA modules and PLE representation when they were exposed to them, i.e., the intervention phase; and second, by comparing the changes in students' performance from pretest to posttest between the PLE problems and CSA modules.

Similarities between CSA and PLE Effects

In Module-2, students demonstrated similar behavior in remembering knowledge used their own work. Nevertheless, CSA students recalled the complex concepts more when they worked with the module. The difference was observed in recalling concepts such as the Principle of Work and Energy. Figure 7-1 illustrates the cumulative frequencies and indices of cognitive process categories for both groups in the intervention and posttest phases. It should be noted that those activities coded as “remembering” were closely associated to understanding the concept. Although they were grouped in remembering, they could easily be interpreted as “understanding”. In order to handle this issue, all activities were segmented into more distinct parts which would directly link to an understanding code, e.g., explaining or interpreting. Those segments were coded in the relevant understanding code. The main similarity between the two groups was the method they acquired basic knowledge from the information given to them which is associated to remembering.

As for other categories, during intervention, applying category shows similar results because learning during intervention required a low level of activity and both groups performed more or less the same. It explains the similar trend observed in intervention phase for applying category. Comparing with Module-1, as the assessment problem involved assuming a value and checking an answer, both groups showed more “evaluating” activities more inModule-1. After studying the solved problem, regardless of the representation, the students solved the problem by first making an assumption and verifying it. The process required at least one trial and one evaluation. It caused the frequency of parameter check coded to increase compared to Module-1.

Differences between CSA and PLE Effects on Learning

As was the case with Module-1, similar code trends appeared when CSA and PLE intervention phase were compared. Coding the data revealed that the main differences between PLE and CSA learning pertained to the understanding and analyzing categories of RBT. It was also observed that students tend to forget drawing the free-body diagram, and by looking at the graphical elements of CSA modules, they recalled the procedure. The PLE solved problem did not include a detailed graphical factor. Therefore, PLE participants did not exhibit significant remembering activity through the graphical components during intervention. Nevertheless, they acquired the needed information like equations through the text. As shown in Figure 7-1, the CSA group declared similar remembering behavior while they worked with the module. It can be because of the fact that the students had forgotten the equations or procedural methods rather than the

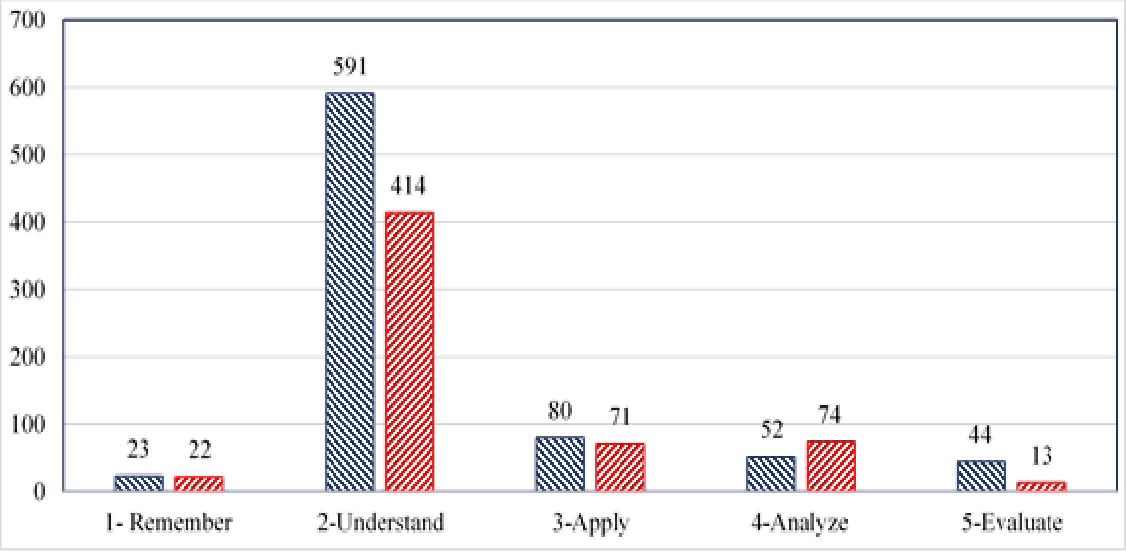


Figure 7-1. Module-2 code indices in intervention phase.

concept and they simply needed to be reminded regardless of the type of representation, animated or static.

The CSA module and the PLE problem changed the students’ understanding differently. During the intervention, the CSA module could show the scenario change visually, which attracted the students. When the participants could see the change of the motion regime, they made more interpretations, more inferences, and asked more questions. They also tried to explain what they could see. The only code in which the PLE group had a higher frequency was comparing. In that, the PLE participants made more comments pertaining “comparison.” The total number of understanding codes among the CSA group was 107 vs. the 92 understanding codes among the PLE group. Both groups’ comments during their interviews also confirmed this observation. During their intervention, the CSA group students made more comments about the problem and the module.

In the applying category, the total number of applying codes of the CSA and PLE groups were 25 (CSA) vs. 22 (PLE), which means that differences between the two groups were not as significant as with the understanding category. The relevant indices do not show a significant difference either (80 vs. 71). As with Module-1, it was expected, and both groups were not as active in applying activities at intervention stage. “Applying dynamics principle “was the subcategory four which four CSA students and none of the PLE students showed an activity.

Although Figure 7-2 shows that both groups indicated similar behavior in analyzing during intervention, the CSA participants in their posttest, constructed more equations. That was because of their ability to solve the problem after they saw the solved problem with more attention.

For Module-2, evaluation codes reveal that the CSA group exhibited significantly more codes than did the PLE group students during their intervention phase. It was because CSA group members started to be more criticizing the solution, the animation, their own solution and reviewed the solution more. One participant, Todd, reviewed the module which was coded as monitoring the solution categorized within evaluation. Among the PLE group, Jonathan, George, and Patricia went through the solved problem, just to collect information which they assumed would help them. George reviewed it to find what he needed for the posttest. It may be inferred that for Module-2, CSA module and PLE-solved problems had similar effects on students' evaluation during the intervention but significantly different effects during posttest. However, a comparison of students' behavior in both the pretest and posttest showed that working with interactive module affected students' attitude towards the problem and their own solution strategy. CSA group became more critiquing during posttest.

Differences between CSA and PLE Effects on Problem-solving

In analyzing the coded data, when the observed effects due to application of CSA module were significant, interview codes were studied to verify those codes. Because of the parameter change capability, Module-2 entailed stronger interaction characteristics by enabling the user to change the parameter and observe the results. The feature caused more frequent "inference" actions and assisted the CSA group students in building solution scenarios which was characterized by finding the relationships between interim parameters. It was expected that PLE and CSA would create similar effects on students ‘remembering during their problem-solving. Comparing the code indices in Figure 7-2 confirmed this fact. Furthermore, all of the PLE and CSA students said that they used the intervention to refresh their memory through the text, which showed no significant difference between the CSA module and PLE problem.

Understanding codes revealed that both groups were able to identify the concept of the problem. Actually, all of the PLE group students and five CSA group students identified the problem concept (Work and Energy) in the pretest stage. Both groups made a similar number of inferences in the pretest, and the PLE group participants exhibited more comparing codes in the pretest. Considering the posttest frequency of codes, it can be seen that CSA participants compared the module and the assessment problem mostly after studying the module. The inferences made by the CSA participants also were not only more frequent but they made new conclusions about the solution. One example of such inferences was realizing that a seemingly wrong answer does not necessarily mean an incorrect solution; it may be due to a wrong assumption which needs to be corrected in order to solve the problem. The total frequency of understanding codes in posttest for CSA group are approximately twice more that PLE group (58 vs. 30). The index also shows a meaningful difference for CSA group (252 vs. 133) which means that the more students were engaged with understanding.

In the applying category, the effects of the CSA modules on problem-solving were more significant in all of the subcategories. Although the CSA participants performed weaker in their pretest, they were able to outline the problem input, structure the graphical information, and draw diagrams. The CSA group students also exhibited more activities concerning solution codes, i.e., plugging the correct parameter and executing mathematical operations. Since there is less significant applying activity in learning phase, the frequency and indices do not indicated large difference. However, in posttest, which more activeness is expected from the student's side, the CSA group students exhibit more applying which is attributed to application of CSA.

In the category of analyzing, the CSA group exhibited more improvement in problem-solving. After working with the module, all six students in the CSA group constructed the problem equation and were able to distinguish the needed parameter and establish the relationship between parameters. The frequency of applying codes was significantly higher than those of the PLE group participants. The prevalence index for establishing the relationship between interim parameters for the CSA group was 45 (nine

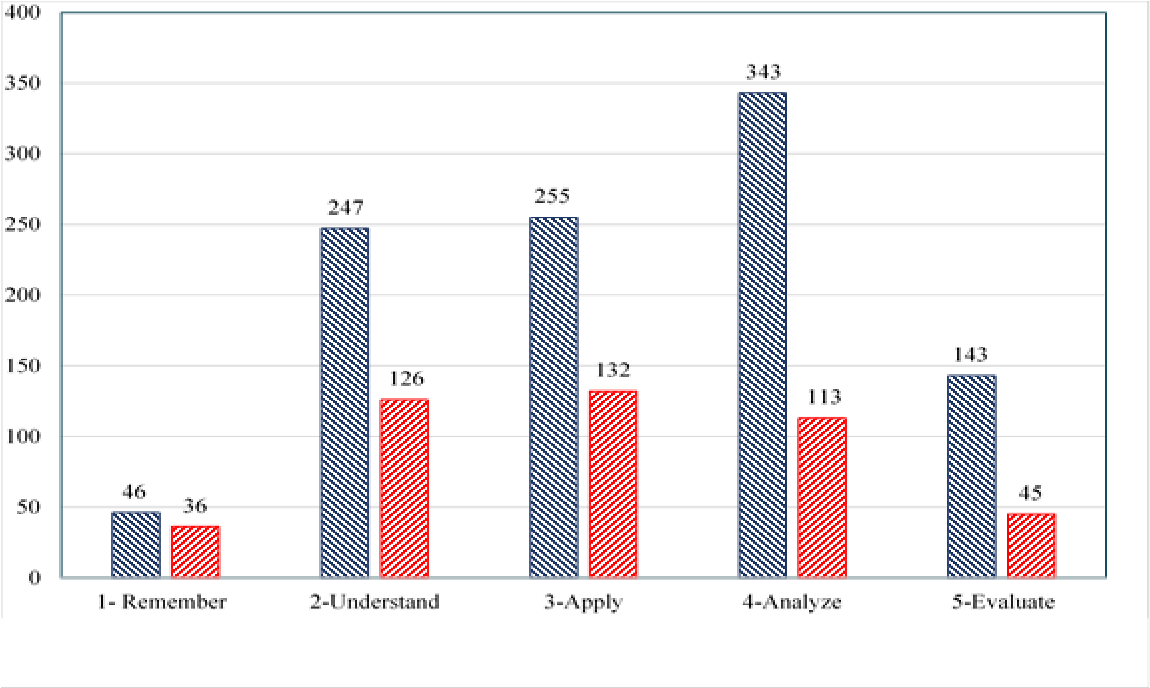


Figure 7-2. Module-2 code indices in posttest phase

times for five participants) compared to 15 for the PLE group (five times for three participants).

As for the category of evaluating, the CSA group indicated more activities on reviewing the solution and detecting small errors during their pretest. A difference was observed when they tried to justify the final answer, for example, by comparing with real values. The CSA group was more cognizant about the issue after they worked with the modules. They criticized their own behavior and paid more attention to the issued raised through the module although all of them were addressed within the PLE solution.

Students' Problem-solving Behavior

Principles of Work and Energy vs. Conservation of Energy

In their pretest stage, 10 participants (out of 12) mentioned the Conservation of Energy as the main concept that they planned to use to solve the problem. However, because friction force was taken into account, Conservation of Energy could not be used. The CSA group students grasped clear explanations about the subject within the CSA module with the help of an interactive hint box. While for PLE group, in the textbook-style problem solution, detailed explanations were merely static text information supported by small, static diagrams. The CSA group participants stated in their interviews that they identified the difference between Conservation of Energy and Principle of Work and Energy because of the hint. Nevertheless, only two PLE students had noticed that in the paper solution text.

Potential Energy vs. Work Done by a Force

Another common error was the misuse of potential energy which was mostly generated by the weight and the spring force with the value of the work done by the forces. Because the relationship to calculate the quantities were identical in format, they were basically different in nature. It caused a misconception especially for non-conservative forces, e.g., frictional force. Although it was explained in the solution both on CSA and PLE, it could not be graphically explained.

Initial and final conditions to calculate work and energy

Almost all of the students assumed only one initial and one final condition to apply the Principle of Work and Energy. It was apparent that they did not differentiate the conditions that the forces applied on the block changed in geometry and magnitude. After studying the solved problem, they realized that the principle should be written when configuration of applied forces does not change. For new configurations, the equation parameters would change. It happened when the block was detached from the spring. The students failed to draw a new, to revise the free-body diagram for different phase of motion and also failed to distinguish the free-body diagrams before and after the slope of the path changed.

Scenario-Building and Wrong Assumptions

The assessment problem contained two parts. In the first part, the student was asked to find a threshold value for friction. It could be achieved by writing and solving energy equation. On the other hand, in part two, the students needed to make an assumption and find the height based on that assumption. If the calculated value was negative or larger than the ramp height, they would conclude that the assumption was incorrect and they should shift to the other scenario. Only two participants, Todd and Allen, were confident enough to make such conclusion. Allot the other participants stopped at that point during their pretest, not trusting their calculations after they calculated an abnormal value due to a wrong assumption.

CHAPTER VIII

OVERALL ANALYSIS OF MODULE-3 RESULTS

Module-3 covered the topic of “Impulse and Momentum.” The participants in the Module-3 study group showed similar behaviors and actions as those from the modules 1 and 2. The original coding table had to be changed to include the “impulse and momentum” concepts, and the “work and energy” concepts were removed from the coding table. The changes were applied to the third level of coding in the remembering, understanding, and applying categories. Chapter VIII addresses the changes in the cognitive process, the differences in the effects of the CSA module and PLE problem, and the students’ common problem-solving behavior which pertained to the application of the CSA module.

Effects of the Module on the Cognitive Process

Remembering

Similar to the previous modules, the students did use the module to refresh their memory. The only difference was that the impulse and momentum equation was more difficult to remember. Because the participants were allowed to note what they needed from the module, they all noted the form of the equation from the module and used it in the posttest, which explains why they did not exhibit any remembering activity during the posttest. Four participants stated in their interview that they would have been able to derive the impulse and momentum equation if were given more time in the pretest even though they did not immediately recall it.

Understanding

The coding in Module-3 revealed the same behavior trends in understanding as the first and second modules. Students made more inferences during the intervention and posttest. Review of the recorded codes showed that all of the students exhibited the inference code-making. A total of 14 conclusions showed a large increase, from 6 inferences made by 3 participants. The inferences involved conclusions about: (1) the initial velocity of the ball and crane;(2) the direction of linear momentum and angular momentum; (3) the effects of the change of load mass and initial velocity on the animation; (4) the relationship between velocities of the load and the crane arm; and (5) how the weight force did not participate in the angular momentum equation. It was shown that interactive animation, pop-up hints, and 3D diagrams enabled the students to make the inferences. For example, Andy concluded that he did not need to include weight forces in the angular momentum because he saw the 3D figures which showed how angular impulse was calculated. In his posttest, Andy explained;

> Andy: *Right, I can figure out the angle if I wanted to. I am going to need that? H equals r-m-v so the initial velocity is zero so it would be equal to zero. M·dt is--we’ve got 0.02 t -2 from zero to 3 seconds, that 0.02 / 3 t cubed, from 0 to 3, [calculates] and it is 0.18, the left-hand side, h-2 = the r = m-v, r is 0.24, mass is 1.5 kg. And velocity is what I am solving for. Is that all I need?*

That looks really too easy. [Solves the equation.] And the velocity is 0.49 m/s. That is so much easier than what I expected. I remember the stuff we already learned.

In his interview, Andy continued:

Interviewer: *First, what was more helpful?*

Andy: *Probably the combination between the figures and plugging the data from the figures in the equations, because it was easy to see why these figures go into these equations. That was most helpful, as far as the design, since there were pop-ups , like from this figure, we get that equation about the weights, because we kind of refer to this figure without three clicks, which I do a lot times in the class.*

From the text of the module, John observed that he did not need to include the momentum of the weights, but he checked it with the diagrams. He generalized it to both arm and crate when he became sure about that. Another theme that emerged from the coding results was explaining theme. The modules encouraged the student to talk more about their understanding of the problem when they changed the parameters and played the animation. Every single participant did make remarks about the module, problem, or solution at least twice.

Applying

Regarding the “applying” category, “structuring the problem” and “outlining the problem input” showed significant changes from pretest to posttest. All of the participants performed such an activity at least twice. The result was expected because once they saw a similar problem, they drew the needed impulse diagrams, and organized the problem data in a meaningful order to achieve a correct solution. John, after running the module, organized the equations for finding a time parameter, which was already given in the problem. Nevertheless, he lined up the equations and plugged in the parameter soon after. In John's posttest, he stated:

> John: *So we have the ball again and it shortens at the rate that it shortens, so it is down the pole, with the given moment that it is going to rotate as it shortens . . . and giving the starting position and it starts at rest . . . it's after looking at that one it fixed for start with the time that it is going to go, [calculates the time which is already given in the problem]*
>
> Interviewer: *How do they find it?*
>
> John: *OH, it has given us the time . . . And so, to line up with this equation . . . I am just going to rewrite it, to start with it, it is going to go to zero, we plug in the moment that is going to rotate . . . because it is going about the pole, so we have the integral from zero to 3 of moment which is 0.02* t^2 *equals to the radius which is 0.244 times by 1.5 kg, and that is our* v^2*. That's just what we are looking for. So we integrate this, it is going to be like . . . 0.02* t^3 */3 . . . from 0 to 3.*

Kayla drew the impulse diagram and wrote the equations together in a step-by-step method after looking at the module. In her posttest, Kayla commented:

> Kayla: *Angular is right here, [points to her own notes]. This problem seems similar to the one given here. That angular momentum isn't conserved -- because there is an impulse. I don't think it applies to this kind of problem. I'm thinking that conservation of linear momentum is what they're trying to --*

> Interviewer: *Conservation of linear momentum is also not going to happen here. Because you have the weight forces, they have impulses, they are not working in the same plain, and you have the momentum. So, you are using the Principle of Angular Impulse and Momentum. Does it make sense?*
>
> Kayla: *So, I am trying to remember the force, how did they go without that?*
>
> Interviewer: *Which force?*
>
> Kayla: *They say the summation of force, that's the impulse part of the equation and I'm trying to remember --*
>
> Interviewer: *Okay, R cross force is moment.*
>
> Kayla: *OH, so that would be this here. Okay, let's see, it is in the given time, looking for velocity, initially we assume velocity is zero and now--*

Analyzing

The analyzing category involved differentiating, organizing, and attributing. During the intervention, all of the participants who had failed to identify the dynamics principle of the problem were able to select explicitly which principle to utilize. It helped them establish the relationship between the linear and angular momentum of the load. Subsequently, they constructed the equations which solved the problem. It was observed in the posttest performance of Andy, John, and Greg. In the following quotation from his posttest, Andy realized the velocity as the quantity he was solving for.

> *Right, I can figure out the angle if I wanted to. I am going to need that? H = r-m-v, so the initial velocity is zero. So, it would be equal to zero. M·dt is -- we've got 0.02 t -2 from zero to 3 seconds, [calculates] and it is 0.18, the left-hand side, h-2*

> *equals the r = m-v, r is 0.24, mass is 1,5kg -- and velocity is what I am solving for.*

Greg exhibited a similar behavior after he worked with the module. He determined the direction and sign for the initial and final angular momentums easily, and he believed that was because of the 3D diagrams. In his posttest, Greg explained:

> *So then, .81. . . 0.5. Then . . . So that's the same deal as we did before, 0, we're using this equation, the summation of these guys [writes equation]. [Plugs in numbers] I guess this is M·dt = h2. So, zero. So, this is an integral from 0 to 6 of* $0.02t^2dt$*. This is for the applied moment. Then plus 0 to 6 of 12 times t·dt. This is for the tension, goes to zero. Equals radius times mass times velocity. The radius we're using is the second radius. So equals 0.24. So it uses the same basic idea. [Uses calculator.] So, solving for the final velocity is 4m/s.*

Then, in his interview, Greg stated:

> *The 3D figures helped me see it a little more conceptually. Because sometimes if you're looking at it just the 2D you can't tell if it's the side of the beam or the top of the beam, but the 3D helped me see which direction the radius was going, which direction the velocity was going, and the angular moment of velocity. Those were good to see in 3D. It made it easier.*

Evaluating

As with previous modules, the students exhibited most of their evaluation activities in their posttest. All participants checked their final answers (value of velocity) to be consistent with the physical conditions. Other evaluation codes as well were associated with the critiquing students’ solution and reviewing the solution steps. It was apparent that in posttest participants made such comments more frequently. In the coding table, the last code is associated with evaluating the final answer, the content of module, student’s assessment about his or her performance, and the problem difficulty level. Students’ comments about problem difficulty level was asked about in the interview and everybody confirmed his or her remark about the problem. Checking the final answer to be reasonable was another major theme. For example, Sam checked only the answer to “make sense” after he calculated the final velocity. In his posttest, Sam commented:

> *The value is . . . 0.18. So putting in the calculator I have . . . V is equal to 0.572197. Is that correct? It makes sense to me. I think so. Going back to the book, I see . . . [looks through the book]. Okay. Let’s see. So we had to work the same way here -- r is your distance. I had d here and your mass and everything. Okay. And that is my final answer. Is this correct?*

Similarities and Differences between CSA and PLE Learning Groups

Similarities between CSA and PLE Effects

As in the previous modules, Module-3 representations produced similar effects on students’ remembering. Because a majority of the participants, in the pretest stage, were not able to identify the basic concept with the problem addressed, they needed a quick look at the title of the solved problem in order to recall the concept. Thus, during the intervention, they displayed remembering activities more frequently – in fact, both groups showed almost equal frequency. In this regard, representation of text information such as the format of the equation was similar in both representations, therefore, both PLE and CSA group students acted similarly in intervention stage. Figure 8-1 compares the frequency codes of both groups during the intervention and posttest phases. It highlights that in remembering, both groups behaved similarly. Another observed similarity occurred with students' plugging in the parameters into the equation which is categorized in applying. Students in both groups solved the equation in a similar manner. In should be noted that other sub-codes of the applying category did not show a similar behavior.

Differences of Effects in Learning

Akin to the two previous modules, Module-3 caused similar effects on the students' learning. Figure 8-1 illustrates the code indices of different categories for CSA and PLE groups. It is shown that major differences between PLE and CSA learning were associated with understanding, analyzing, and evaluating. Most intervention differences referred to inferring, explaining (understanding category), and evaluating the problem and solution (evaluating category).

Both groups indicated similar remembering trends during intervention. The remembering category involved recalling both simple concepts, such as the definition of linear and impulse, and more complex notions, such as the difference between angular and linear momentum and the mathematical form of the Principle of Impulse and Momentum.

It was expected that the CSA module and the PLE problem have different effects on each student's understanding. The capability of parameter change, which changes the speed of the arm and the crane in the module, elicited interesting behavior. By watching the velocity change, the CSA participants took their pencil and started to think why this happened. One major objective of the CSA module, i.e., stimulating students' curiosity, was accomplished. Their solution process changed specifically when they constructed the equations. The PLE group participants went through the solved problem, noted the basic equation, and applied it to solve the assessment problem. The CSA students exhibited 55 understanding activities in total compared to 39 activities by PLE group. The code index of the CSA group was 285 vs. 186 in the PLE group. The result was consistent with the relevant numbers in Module-2. The CSA group made more explanations which emerged from the parameter change feature.

In the applying category, the differences between the two groups were not as pronounced. The PLE students exhibited applying activities slightly more than did the CSA group students. Nevertheless, only four PLE students performed such activities, whereas all of the CSA students performed an applying activity at least once. The subcategories of applying involved outlining the problem data, structuring numerical input, drawing free-body diagrams, adopting the solution strategy, or solving mathematical equations. The low number of applying codes during intervention was because of the fact that the CSA students spent more time on understanding activities than on applying activities. A similar result was observed in the analyzing category. Both groups' analysis indicated a similar number of analyzing codes, which was sparse compared to other categories.

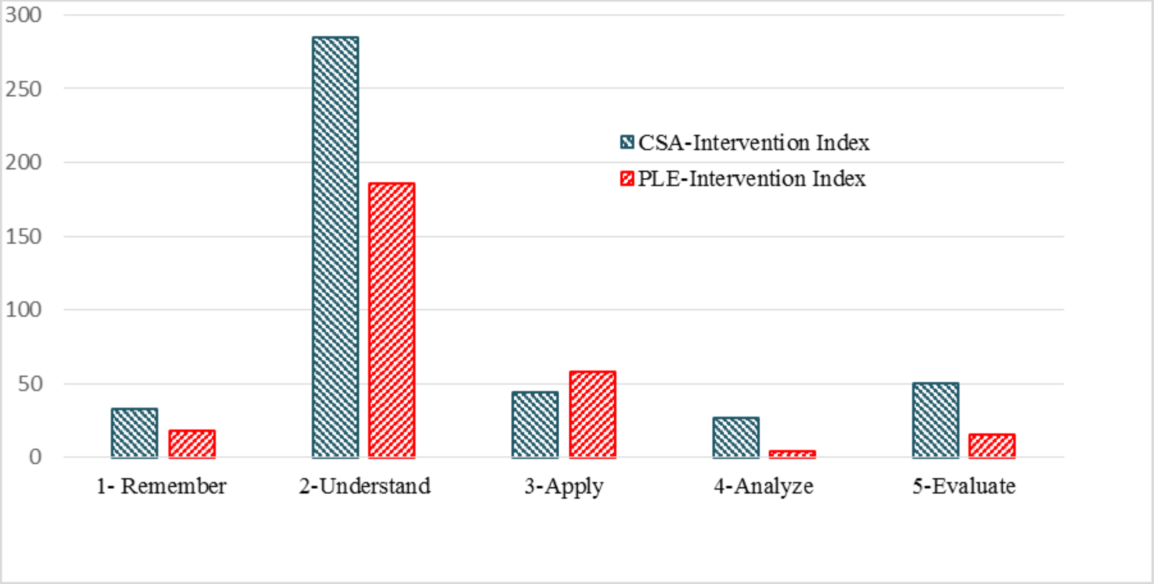


Figure 8-1. Module-3 code indices in intervention phase.

During intervention, both groups exhibited a few activities pertaining to evaluation. These activities were mostly comments about the difficulty of the problem and the errors they had during the pretest. There was one exception, Andy while working with the animation, tried to detect an error within the module. Although he was wrong about that, it was a notable attempt which involved evaluation during learning.

Difference of Effects of CSA and PLE in Problem-solving

As with previous modules, similar code trends appeared when comparing the CSA and PLE groups in the intervention phase. The major property of module-3 was the interaction characteristics by enabling the user to change the rotation parameters and observe the results. As with odule-2, the feature caused more frequent “inference” and explanation actions and assisted the CSA group students in building solution scenarios which was characterized by finding the relationships between interim parameters. It was expected that PLE and CSA would create similar effects on students' remembering during their problem-solving. Figure 8-2 clearly shows this similarity. Furthermore, all of the PLE and CSA students stated that they used the intervention to refresh their memory through the text, which showed no significant difference between the CSA module and PLE problem. One significant theme that was observed was the students' failure to identify the concept of the problem. However, after some assistance, most participants were able to construct equations.

The total frequency of understanding code indices in posttest for CSA group are approximately 60% more that PLE group (154 vs. 53) which means that the more students were engaged with understanding. For example, during the posttest, the CSA group students were able to compare their observations of the solved problem with the assessment problem. Working with the animation, changing the parameters and observing the change in motion enabled them to establish the relationship between parameters in the posttest, construct the equations, plug the correct variables into them, and ultimately solve the problem. Because these activities are closely related, they may not distinctly appear in the student's think-aloud but they are reflected in the coding. Both groups' comments during their interviews also confirmed that they went through this process.

In the applying category, the changes of the CSA groups from pretest to posttest was 60% (from 21 to 33). A similar increase occurred with the PLE group. However, the number of students who exhibited applying activities was different. All of the CSA group students indicated the “applying” code during their posttest compared to only four PLE group participants.

In the evaluating category, the effects of the CSA modules on problem-solving were more significant among all of the subcategories. Five CSA group students tried to justify the final solution they calculated, compared to only one PLE group student who did such an assessment. The CSA group students also exhibited more activities concerning solution critiquing codes, i.e., monitoring the correct parameter and checking mathematical operations. Since there was less significant evaluation activity in learning phase, the frequency and indices do not indicated large difference in intervention. However, in posttest, which more activeness is expected from the student’s side, the CSA group students exhibit more evaluating which is attributed to application of CSA. Comparing code indices (189 vs. 71) also indicates that CSA group students tend to

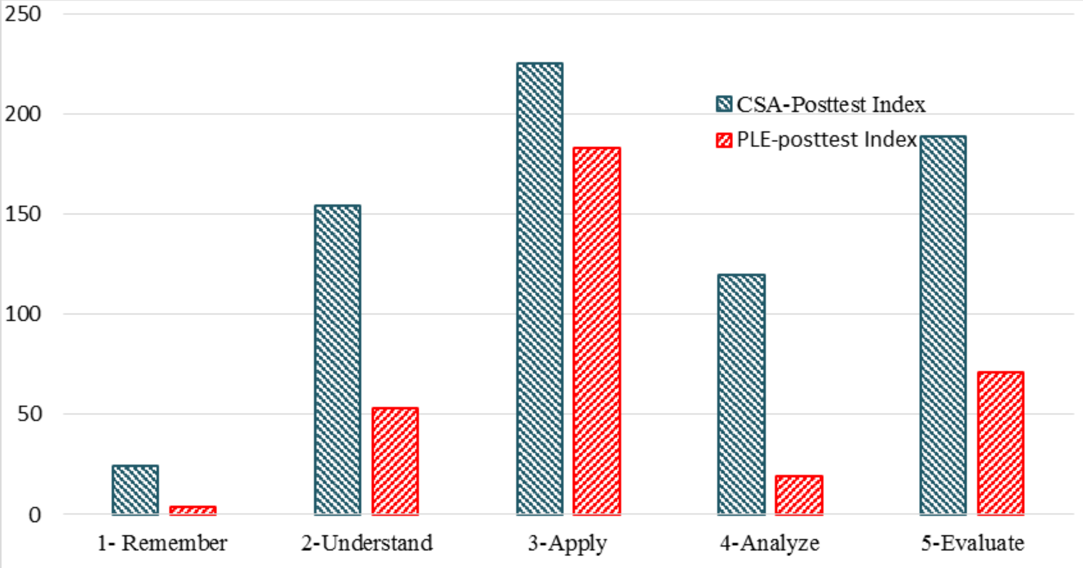


Figure 8-2. Module-3 code indices in posttest phase.

evaluate their own solution method. It might be attributed to the engagement which CSA module caused among students.

Students' Problem-solving Behavior

Identification of the Dynamics Concept

Only one participant identified the exact dynamics concepts targeted by the assessment problem. This issue may be described as a failure to strategize the solution. Nevertheless, neither the CSA module nor the PLE-solved problem were able to affect the failure. As soon as a student read the module's title or the first equation in the PLE-solved problem, she would realize that the problem concerned impulse and momentum. Looking at the rotating bar or rotating arm caused every participant to differentiate between linear and angular impulse and momentum. Real-life problem-solving entails identification of the possible concepts which are a part of the problem, although such identification cannot be taught in a single problem-solving activity in a course. Neither CSA modules nor PLE representations can directly enhance the skill in students because it requires more in-depth insight that is achieved through a longer, more extensive educational pursuit.

Misapplication of the Problem Input Parameters

One common mistake among students of both groups was misinterpretation of an input parameter. Nine participants took the cable's shortening rate identical to the velocity of the ball. As they stated in their interviews, it was partly because of a quick judgment due to the unit of that quantity which was meters per second. The miscalculation could have been avoided had it been highlighted on the diagram of the assessment problem -- which proves the significance of visual representation.

Misconception of the Angular and Linear Momentum Quantities

Most of the students could not distinguish the forces that contributed to the angular momentum of the object. Failure to omit the forces that were not present in the equation was because of a misconception regarding the direction of the angular momentum vector. One frequent mistake by the participants was using the linear momentum vector instead of the angular momentum vector. The error was attributed to confusion on the part of most of the participants. Two participants, Sam and Greg, stated that the 3D diagrams in the CSA module helped them to visualize how it was calculated. Another factor that caused confusion was the failure to draw the impulse and momentum diagram for each body. Drawing that diagram would have helped distinguish the two vector quantities. Almost all of the participants failed to pay attention to the fact that both the CSA module and PLE-solved problem highlighted the essential procedure of drawing impulse/momentum diagrams.

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to scrutinize the effects of the application of CSA on students' cognitive processes in the engineering dynamics course. For this purpose, three modules in particle dynamics were developed. For each module, two groups of participants conducted the problem-solving activity, and their think-aloud monologues were recorded, transcribed, and coded. The *Revised Bloom's Taxonomy* of learning objectives (Krathwohl, 2002) shaped the foundation of the coding table and data analysis process. The study addressed the following research questions:

1- How do CSA modules affect students' problem-solving in engineering dynamics from the perspective of cognitive process?

2- What similarities and differences exist between the effects of CSA modules on students' problem-solving and the effects of textbook-style instruction in Engineering Dynamics?

This chapter summarizes the research findings from the analysis of coded data along with an interpretation of the students' behavior. The discussion is followed by presenting implications for engineering education and future research on the topic.

Effects of CSA on Students' Problem-solving Process

Insofar as the first research question, collected data from the CSA group's problem solving were analyzed. The results confirmed the previous research, which suggested that CSA modules help students in conducting problem solving and support conceptualization of the material as compared to the textbook-style representation in Engineering Dynamics (Deliktas, 2011; Sidhu, 2010; Sidhu, Ramesh, & Selvanathan, 2010). While previous studies addressed one category of the cognitive process, i.e., understanding category, or students' development of a concept, this study covered five categories of the cognitive process as a basis for data analysis including understanding (Krathwohl, 2002). Furthermore, this study explored how student learning was affected by CSA in each of categories mentioned in the *RBT*.

The results of this study revealed that the application of CSA modules affects students' comparing, summarizing, inferring, and explaining, which were classified in the "understanding" category of the cognitive process. The most frequently observed activity associated with understanding was "inferring." The interactive capability of CSA modules offered the user a chance to change the input parameters that subsequently altered the visual output of the animation, such as motion velocity. The feature helped the students make inferences in addition to thinking critically, and how the find an answer to 'how that happened' questions about the dynamics concept. The efforts of the students to answer those questions and make conclusions about the concept deepened their understanding, and an improvement in their understanding was reflected in their problem-solving behavior during the posttest.

CSA modules also affected the students' organization and self-monitoring. After working with the CSA module, participants outlined the problem information more clearly, drew more clear drawings, and identified more dynamics principles. The CSA module stopped them from simply copying the solution equation; rather, they made well-thought comments about the derived solution. CSA modules changed students' understanding, analyzing, and evaluating more than the other categories. In this regard, working with interactive animations caused the students to start monitoring their solution process, the problem input and analyzing the problem statement.

Fostering problem solving as a subject-specific competence is an essential educational objective in various subject areas including engineering mechanics (Buchwald, Fleischer, & Leutner, 2015; Byun & Lee, 2014; Carbonell & Romero, 2013; Deliktas, 2011; Sidhu, 2010; Sidhu, Ramesh, & Selvanathan, 2010) because it is the cognitive process that guides students' learning (Smetana & Bell, 2012). Effects of CSA on problem solving may be described through associating problem-solving process steps with the categories of the *RBT*. Problem-solving involves three major stages: formulation, ramification, and evaluation. After understanding and describing the problem, the next step is formulating the solution. It refers to adopting a strategy to solve the problem, and linking the relationship between the problem parameters and problem unknowns. CSA modules helped the students visualize the physical phenomenon so that they could make more solid inferences about the problem. In this regard, the animation feature was the major visualization component that affected the formulation stage.

In the second stage of problem-solving, ramification, CSA representation enabled the students to identify the relationship between parameters more quickly and construct the problem equations more easily. Analyzing the data suggested that all CSA group participants constructed the problem equation more easily and plugged the correct parameters into the equation during the posttest phase. Working with the module helped them figure out why and how to apply the relevant equations. Most often during the pretest, the PLE students wrote the equation (formulation) and differentiated between the initial and final conditions (description). Nevertheless, they did not realize that for different situations, multiple equations should be written and forces for each geometrical or physical situation should be considered (ramification). The CSA modules enabled the participants to better strategize the solution and implement it more effectively.

Similarly, CSA helped the students monitor the solution procedure and the problem parameters. It also encouraged them to be critical the problem input and their own behavior and to check for wrong parameters and mathematical errors, and attempt to justify the final answer. The step-by-step solution reinforced students' judgment about the problem their own solution strategy. It helped them in reviewing of the steps and looking for possible errors. By working with the module, the students made more comments about their actions and mistakes. A strong influence was observed between the degree of engagement in a module's interactive feature and students' evaluation behavior while solving the problem.

Similarities and Differences of effects of CSA and PLE Representations

The second research question referred to comparing the effects of the CSA module with paper, textbook-style instruction during problem solving. To accomplish the comparison, a textbook-style, paper representation was developed for each module that included the problem statement and a detailed solution. Another group of participants, the

PLE group, used the paper representation as their intervention instrument. The PLE group utilized the identical procedure, and their problem-solving activity results were coded and analyzed through the same method. Their results were compared with the CSA group. The changes between the pretest and posttest between both groups denoted the instrument's effects on problem solving.

Similarities between CSA and PLE Effects

Both CSA and PLE groups showed similar behavior in acquiring information. Text information including descriptions and equations as well as static diagrams were the obvious commonalities of computer-based and paper representations of the problem. At the instants that the user wanted to rewrite or note a formula or an equation, both groups acted the same way. They all noted the formulas they could not recall in a similar fashion, regardless of the type of representation. From the cognitive process viewpoint, recalling information is associated with remembering, the first cognitive level. Comparing the total number of codes for each category showed that during the intervention phase, both CSA and PLE groups displayed similar remembering behavior in the three modules. Remembering occurs immediately after a lecture, and entails minimum cognitive load. For all three topics, participants could partly remember the simple and combined concepts of the topic during their pretest. They used the solved problem in either representation to refresh their memory. The text of the CSA module or PLE-solved problem caused the refreshing. The implication was that representation was not the main factor in students' remembering. Students' comments in their interviews confirmed this assumption.

Another observed similarity was students’ solution strategy. A similar trend was observed among students in both groups -- they all needed the exact equation of the problem. Thus, students in both groups strategized the problem in a similar manner. In the pretest, it was expected that students would try to implement the procedure they had learned previously in the class. The procedure involved trying to outline mathematical information to a graphical depiction, i.e., drawing a free-body or an impulse diagram, placing forces on the bodies, identifying the direction of the motion, and writing key equations. The procedure did not change with the intervention. In fact, students’ knowledge about the solution procedure was unaffected by the representation. Students’ solution strategy in situations in which they could find the concept was similar. During the intervention, they sought out a keyword to find the topic and subsequently the main formula, regardless of the type of representation.

Differences between CSA and PLE Effects

Comparing the performance of the PLE and CSA groups during pretest, intervention, and posttest stages revealed several differences. The differences may be grouped into two components, the learning aspect, which involves the intervention phase, and the problem-solving aspect, which is associated with the posttest phase. The differences between PLE and CSA effects on both learning and problem-solving pertained to understanding, analyzing, and evaluating categories of the cognitive process.

The understanding category included interpreting, explaining, inferring, and summarizing activities. While the CSA group participants, during the intervention and posttest stages, made several inferences about the problem information, main parameters, and dynamics principles, twelve students out of total seventeen students in the PLE group skipped parts of the solution with long explanations, searching instead for the main equation and the final solution. Most inferences made by the PLE group were mathematical interpretations of the verbal information. Also, unlike the CSA group students, the PLE group rarely addressed conceptual explanations while they studied the solved problem or thereafter.

The analyzing category was the other code that revealed different outcomes between PLE and CSA groups. Analyzing involves differentiating, organizing, and attributing. After working with the modules, the CSA group participants could better distinguish the relationship between interim parameters and problem unknowns. Such distinguishing activity was characterized as organizing. During their interviews, the CSA students confirmed the role of the module and voiced significant attention to strategizing the solution. Conversely, such behavior was rarely observed among the PLE participants. In addition, during the posttest phase, the CSA participants selected and arranged the needed equations, which further confirmed their attention to organizing. Comparing the codes and searching for posttest activities of the transcripts of the PLE participants showed no significant changes between their pretest and posttest stages.

The last category in which CSA and PLE groups demonstrated different behavior was evaluating. Students in the CSA groups exhibited evaluation activities more frequently. They checked their own solution with the solution they saw in the module. Also, after working with the module, they were more criticizing about the parameters. Although there were students in both the PLE and CSA groups who reviewed their solution process by searching for numerical errors, in the CSA group, there was a notable tendency to assess the final answer and checking if the final answer was “making sense”. In Module-1, most of the CSA group participants (four individuals) tried to justify the value of their final solution in order for it to “make sense,” while only one of the PLE group students showed such behavior. A similar trend was observed in modules 2 and 3 in which the solution required an assumption to be verified. Five CSA group students in Module-2 checked their assumptions that led them to the correct answer of the problem. For Module-3, most of the participants in both groups failed to review their solution, including monitoring the calculations, detecting mathematical errors, and attempting to justify the final answer. However, they made more comments about the topic and their own ability to solve the problem. Changes in students’ evaluation activities were clearly shown to be associated with the type of the representation. CSA modules caused more changes.

Characteristics of CSA Modules

The CSA modules used in this study involved four different learning characteristics which produced different effects on students’ cognition process (Fang, 2012). The major features included visualization (animation), interactivity (capability of changing parameters with visible effects), immediate help (pop-up hints), and self-paced learning (navigation feature). In Module-2 which involved the Principle of Work and Energy, participants could perceive the effect of the change of friction parameter on the regime and speed of motion and tried to find the critical parameter value that altered the direction of the block’s motion. According to their replies in the interviews, they indicated that the parameter visualization helped them to see the relationship between the mathematical equations and the physical quality of the phenomenon, i.e., the motion. All of the participants, after playing with the animation, were able to explain the relationship between the coefficient of friction and the maximum kinetic energy of the block. Participants who worked with Module-3 exhibited similar behavior. In Module-3, the participants commented that they could see the effects of the change of mass on the velocity of the crane arm, which prompted them to question the relationship of parameters. Their efforts to find an explanation helped them reinforce their insight about the dynamics concept, an insight which was evident in their consequent problem-solving behavior. Their actions in the posttest showed that it changed their approach by giving them the confidence to try different possibilities in the solution. The students reported enjoying the autonomy of self-paced learning that the scrolling feature enabled. While two participants used the pop-up hints, four others skipped them because they felt that they already understood the concept.

Implications for Engineering Education

Developing CSA modules for educational purposes requires both content knowledge and pedagogical skills (Sidhu, 2010). Additionally, analyzing students’ behavior in this study showed that effective CSA modules should target specific categories in the cognitive process. Understanding is the most important cognitive category that should be addressed in the development of CSA modules. Table 9-1 illustrates the main features of the CSA modules which affected students' learning. It summarizes the detailed effects of each feature and the targeted category of the cognitive process.

Table 9-1 is also an effective guideline for the educators who use CSA modules as a tool in their instruction of dynamics. It helps users evaluate the capabilities of the modules in each of the features that the modules entail. For example, if a module focuses on interactive animations without parametric quantitative changes, it is helpful in understanding concepts. If a module includes multiple hint features, it can be used to improve remembering. Thus, an educator can have a reasonable judgment about the expectations of different available modules.

Table 9-1 *Characteristics of CSA Modules*

Characteristics	Rationale	Targeted cognitive category
Sequential slides, navigation in the module	The students are able to adjust their learning pace.	Understanding, analyzing, evaluating
Interactive animation	The students feel engaged, they apply their knowledge.	Understanding, applying, analyzing
Immediate pop-up hints	The students are able to get immediate optional help.	Remembering, understanding, evaluating
Different scenarios	Students can compare different cases with different parameters.	Applying, analyzing
Mathematical pop-up hints	The user has the autonomy to read or bypass the hint.	Remembering, understanding

Outlook for Future Research

The focus of this study was on problem-solving in particle dynamics. Insofar as future research, it would be beneficial to design a research with multiple modules covering rigid body dynamics in which problem-solving behavior is studied for a longer period. In such a study, learning and problem-solving phases can be integrated into one module. The presented solution can include quiz-type, conceptual questions to evaluate learning and elicit immediate feedback based on the user's response to a given question. Thus, insight may be gained into the students' thinking at specific moments or phases instead of analyzing the entire solution process.

This qualitative study is an effective approach to studying the effects of CSA. The qualitative approach introduced here can be extended to other engineering courses, especially those courses with high conceptual complexity, e.g. thermodynamics or advanced dynamics. Appropriate relevant modules should be developed and tested, although the research design can be similar. In addition, the qualitative coding table should be altered accordingly to account for different concepts to analyze relevant codes.

Final Comments

An analysis of the collected data revealed that CSA modules affect almost all categories of the cognitive process. The most significant effects were observed in the understanding, analyzing and evaluating categories of the *Revised Bloom's Taxonomy* of learning objectives. According to Krathwohl (2002), the understanding category refers to seven subcategories: interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining. In the analysis, the inference code had the highest frequency considering that every participant's inferences increased in the posttest, i.e., after working with the module. Most of these inferences were about the effects of input parameters on the solution.

Comparing problem-solving behavior of the PLE and CSA groups demonstrated that although both representations had similar effects on student's remembering, the CSA students exhibited more analytical behavior during and after working with the CSA module. The interactive characteristics of the animated module caused them to ask more questions and attempt to find an explanation for the visual effects they observed in the animation. An analysis of the coded data and scrutiny of students' interviews confirmed the different effects caused by CSA modules and the textbook-style paper representations.

Although distinct effects in each category were observed, it was noted that interactive characteristic of the CSA modules built a bridge between understanding, analyzing, and evaluating. This study revealed that the interactive feature of CSA was the major element which impacted students' cognitive processes by augmenting their analytical thinking. Furthermore, the study showed that students become more concerned about analyzing an answer after working with the interactive module, by making more inferences, and exploring more deeply how changing one parameter qualitatively affects their solution. This study also exposed the need for more investigation about the interaction between conventional instruction and the application of CSA in postsecondary education.

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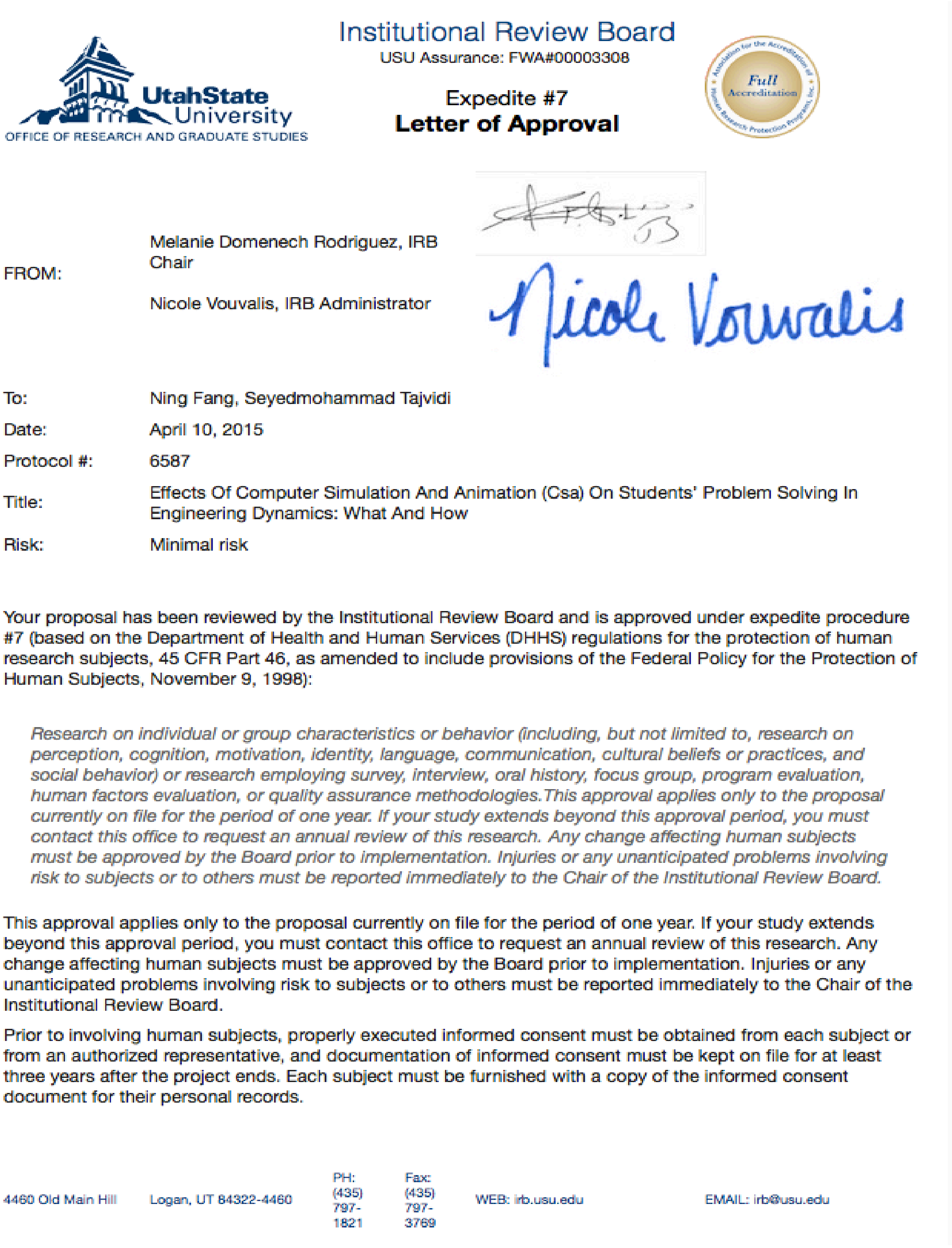
APPENDICES

Appendix A- IRB Approval



UtahState University
OFFICE OF RESEARCH AND GRADUATE STUDIES

Institutional Review Board
USU Assurance: FWA#00003308

Full Accreditation

Expedite #7
Letter of Approval

FROM:	Melanie Domenech Rodriguez, IRB Chair Nicole Vouvalis, IRB Administrator
To:	Ning Fang, Seyedmohammad Tajvidi
Date:	April 10, 2015
Protocol #:	6587
Title:	Effects Of Computer Simulation And Animation (Csa) On Students' Problem Solving In Engineering Dynamics: What And How
Risk:	Minimal risk

Nicole Vouvalis

Your proposal has been reviewed by the Institutional Review Board and is approved under expedite procedure #7 (based on the Department of Health and Human Services (DHHS) regulations for the protection of human research subjects, 45 CFR Part 46, as amended to include provisions of the Federal Policy for the Protection of Human Subjects, November 9, 1998):

> *Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.This approval applies only to the proposal currently on file for the period of one year. If your study extends beyond this approval period, you must contact this office to request an annual review of this research. Any change affecting human subjects must be approved by the Board prior to implementation. Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Institutional Review Board.*

This approval applies only to the proposal currently on file for the period of one year. If your study extends beyond this approval period, you must contact this office to request an annual review of this research. Any change affecting human subjects must be approved by the Board prior to implementation. Injuries or any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Institutional Review Board.

Prior to involving human subjects, properly executed informed consent must be obtained from each subject or from an authorized representative, and documentation of informed consent must be kept on file for at least three years after the project ends. Each subject must be furnished with a copy of the informed consent document for their personal records.

4460 Old Main Hill Logan, UT 84322-4460 PH: (435) 797-1821 Fax: (435) 797-3769 WEB: irb.usu.edu EMAIL: irb@usu.edu

Appendix B- PLE and CSA groups' interview questions

Module 1- Interview questions: CSA group

Drawing free body diagrams

- How did you draw the free body diagram for block A and block B? Please explain.
- How did the hint help you draw the FBD?
- For block B, how did you conclude the force N_1 on block B is the reaction of N_1, which is acting on block 'A'?

Drawing the kinetic diagram

- Please explain how you drew the kinetic diagram.
- How did the kinetic diagram page help you learn how to draw a kinetic diagram?

Friction forces

- How did you find out the direction of friction between the two blocks?
- How did the hints help you in finding the direction of friction?
- How did you link the friction force F1 on block 'A' and the reaction of F1 (opposite in direction, the same magnitude) on block B?
- How did you link the friction force F2 on block B and direction of motion of block B?

Relative motion

- How did you find out what the direction of motion is?
- How did the hint help you in finding the direction of motion?
- How did you find out the relative motion of blocks?

- How did the hint for the relative motion help you in calculating the acceleration and time?

Module content and design

- Please explain how the friction scroll bar helped you learn something in the module?
- In which parts of the solution did you need more explanation? Please explain.
- Which item did you especially like in the module, it is OK if more than one you mention. Briefly explain your reason(s).
- If given a choice, how would you change the difficulty level of the problem?
- How do you explain your experience with “think aloud technique”?
- If you were given a chance to modify the module, how would you change it? Please explain.
- Please explain your opinion regarding the color and arrangement design of the module.
- Please tell us about your experience with the animation illustrations.

Module 1- Interview questions: PLE group

Drawing free body diagrams

- How did you draw the free body diagram for block A and block B? Please explain.
- For block B, how did you conclude the force N1 on block B is the reaction of N1 which is acting on block A?

Drawing the kinetic diagram

- Please explain how you drew the kinetic diagram.
- How did the kinetic diagram help you learn how to draw a kinetic diagram?

Friction forces

- How did you find the direction of friction between the two blocks?
- How did you link the friction force F1 on block ‘A’ and the reaction of F1 (opposite in direction, the same magnitude) on block B?
- How did you link the friction force F2 on block B and direction of motion of block B?

Relative motion

- How did you find out about the direction of motion?
- How did you find out about the relative motion of blocks and the relation between accelerations of A and B?

Solution content and design

- In which parts of the solution did you need more explanation? Please explain.
- If given a choice, how would you change the difficulty level of the problem?
- How do you explain your experience with “think aloud technique”?
- Please tell us about your experience with the illustrations.

Module 2- Interview questions: CSA group

- When you started to solve this problem, how did you find out what dynamics concepts or principles are involved? (Such as Conservation of Angular Momentum, Principle of Angular Impulse and Momentum)
- Which formulas or equations did you remember before solving the problem? How did the solved problem help you?

- How did the solved problem help you understand anything new about the Principle of Angular Impulse and Momentum?
- Explain if the solved problem helped you to remember or understand any dynamics concepts or principles.

Drawing free body diagrams / impulse diagrams

- Could you describe how did you draw the free-body diagram? Before learning from the solved problem and after learning from it.
- Could you please describe how did you draw the impulse and momentum diagrams?
- How did the figures help you draw the FBD?
- How did the figures help you draw the momentum diagram and the impulse diagram?

Acting forces and moments

- How did you find out if a force or a moment generates an impulse to affect the momentum of the crate and the arm?

Impulse and momentum principle

- How did you find out the value and direction of linear and angular momentums of the crate and the arm?
- How did you find out the value and direction of linear and angular impulse of the weights of the crate and the arm, and those of the base moment?
- What were the assumptions you made to determine the final velocity in the assessment problem?
- How did you find the relationship between the velocities of the arm and the crate in the solved problem?

Solved problem content and design

- About the design of this technical dynamics problem
- Which parts of the problem statement and/or solution did you need more explanation?
- Was the first problem difficult? Why?
- Was the solved problem difficult? Why?
- How did the solved problem help in solving the assessment problem?
- Which particular design did you especially like for the solved problem? And why? Explain about the: Length of explanations; Diagrams, equations; Pictures' color and layout
- If you could change the design of the solved problem, what changes would you make?
- Could you please describe your experience with this "think-aloud" technique?
- How did you feel about the interview setting, the room, the computer, the camera and recorder?
- What interventions during the problem-solving process did/didn't you like to have?

Module 2- Interview questions: PLE group

Drawing free body diagrams

- Could you please describe how did you draw the free body diagram for the block?

Friction forces

- How did you determine the direction of friction between the block and the surface in different positions?

Work and energy principle equation

- How did you find out the value of work done by each force acting on the block (weight, friction force, normal force and spring force)?
- How did you determine the sign for work done by each force acting on the block (weight, friction force, normal force and spring force)?
- How did you determine the kinetic energy of the block at each point?
- What were the assumptions you made to determine the maximum friction factor?

Solution content and design

- Which parts of the problem statement and/or solution did you need more/less explanation?
- Please describe your experience with those illustrations contained in the solution.
- Could you please describe your experience with this “think-aloud” technique?
- How did you feel about the interview setting, the room, the camera and recorder?
- What interventions during the problem solving process do you like/dislike to have?

Module 3- Interview questions: CSA group

Drawing free body diagrams

- Could you please describe how did you draw the free body diagram for the block?
- How did the figures in the hints help you draw the FBD?

Frictional forces

- How did you determine the direction of friction between the block and the surface in different positions?
- Looking at the slider changing the value of the friction factor, how did you determine if the block passes over the tip (point B)?

Work and energy principle equation

- How did you find out the value of work done by each force acting on the block (weight, friction force, normal force and spring force)?
- How did you determine the sign for work done by each force acting on the block (weight, friction force, normal force and spring force)?
- How did you determine the kinetic energy of the block at each point?
- What were the assumptions you made to determine the maximum friction factor?

Module content and design

- About the design of this technical dynamics problem
- Which parts of the problem statement and/or solution did you need more explanation?
- If you can change the difficulty level of the assessment problem, what changes will you make?
- How did the computer module help in solving the assessment problem?
- About the design of graphical user interface
- Which particular design did you especially like for this computer simulation module? And why?
- For this computer simulation, you can move the scroll bar to change friction coefficients, could you please describe how did this functionality help you learn?
- Please explain your opinion regarding the color and layout design of this computer simulation module.
- In this module you can run animations. Please describe your experience with animations.

- If you can change the design of graphical user interface of this computer simulation module, what changes will you make?
- Could you please describe your experience with this “think-aloud” technique?
- How did you feel about the interview setting, the room, the computer, the camera and recorder?
- What interventions during the problem-solving process do you / don’t you like to have?

Module 3- Interview questions: PLE group

General problem-solving

- When you started to solve this problem, how did you find out what dynamics concepts or principles are involved? (such as Conservation of Angular Momentum, Principle of Angular Impulse and Momentum)
- Which formulas or equations did you remember before solving the problem? How did the CSA module help you?
- How did the CSA module help you understand anything new about the Principle of Angular Impulse and Momentum?
- Explain if the module helped you to remember or understand any dynamics concepts or principles.

Drawing free-body diagrams and impulse diagrams

- Could you describe how did you draw the free-body diagram? Before watching the module and after watching the module.
- Could you please describe how did you draw the impulse and momentum diagrams?

- How did the figures / animations in the hints help you draw the FBD?
- How did the figures in the hints help you draw the momentum diagram and the impulse diagram?

Acting forces and moments

- How did you find out if a force or a moment generates an impulse to affect the momentum of the crate and the arm?
- By changing the mass and velocity parameters, did you think if the arm is going to move faster or slower? Why?

Impulse and momentum principle

- How did you find out the value and direction of linear and angular momentums of the crate and the arm?
- How did you find out the value and direction of linear and angular impulse of the weights of the crate and the arm, and those of the base moment?
- What were the assumptions you made to determine the final velocity in the assessment problem?
- How did you find the relationship between the velocities of the arm and the crate in the module?

Module content and design

- About the design of this technical dynamics problem
- Which parts of the problem statement and/or solution did you need more explanation?
- Was the first problem difficult? Why?
- Was the CSA solved problem difficult? Why?

- How did the CSA module help in solving the assessment problem?
- About the design of graphical user interface
- Which particular design did you especially like for this CSA module? Why? Explain about the Navigation function; 2D animation; Parameter change function; Hints; General color and layout.
- If you could change the design of computer graphical user interface of this CSA module, what changes would you make?
- Could you please describe your experience with this “think-aloud” technique?
- How did you feel about the interview setting, the room, the computer, the camera and recorder?
- What interventions during the problem-solving process did/didn’t you like to have?

Appendix C- Coding Table Example

Category	Description
1-Remember	
1-1-Remembering simple concepts	
1Re-lev1-Math	1-1-1. Recognizing mathematical concepts
1Re-lev1-S	1-1-2. Recognizing displacement
1Re-lev1-Acc	1-1-3. Recognizing acceleration
1Re-lev1-F	1-1-4. Recognizing force concepts (weight, frictional or reaction)
1-2-Remembering advanced concepts	
1Re-lev2-Rel-Acc	1-2-1. Recognizing relative acceleration
1Re-lev2-N2	1-2-2. Recognizing Newton’s Second Law of Motion
1Re-lev2-N3	1-2-3. Recognizing Newton’s Third Law of Motion

2-Understand	
2-1-Interperting	
2-1-1-Int-Int	2-1-1. Interpreting numerical or verbal data given in the problem statement and/or problem solution
2-2-Exemplifying	
2-2-1-Exe-Exe	2-2-1 Providing a specific example or illustration of a concept in engineering dynamics
2-3-Classifying	
2-3-1-Un-Cls-Id	2-3-1. Categorizing a group of concepts and identifying core concepts in engineering dynamics based on their common characteristics
2-4-Summarizing	
2-4-1-Un-Sum-Sum	2-4-1. Providing a brief statement of main points embedded in textual or graphic information
2-5-Inferring	
2-5-1-Un-Cnc-Inf	2-5-1. Making inferences or drawing conclusions from the given information
2-6-Comparing	
2-6-1-Un-cmp-Pri	2-6-1. Comparing prior knowledge with present knowledge
2-6-2-Un-cmp-con	2-6-2. Comparing two relevant concepts involved in the problem
2-7-Explaining	
2-7-1-Un-Exp-Re	2-7-1. Explaining reasons of a phenomenon or an activity during thinking, learning, or problem solving
2-7-2-Un-Exp-Ta	2-7-2. Reading and reviewing the learning materials and making relevant comments

3-Apply	
3-1-Executing	
3-1-1-App-Exe-Outl	3-1-1. Listing given inputs of the problem
3-1-2-App-Exe-Stru	3-1-2. Structuring textual and graphical information
3-1-3-App-Exe-FBD	3-1-3. Drawing free-body diagrams of the objects
3-1-4-App-Exe-Princ	3-1-4.Selecting appropriate dynamics principles for problem solving
3-2-Implementing	
3-2-1-App-Imp-Srg	3-2-1. Developing textual and/or graphical representations of the problem and adopting a problem-solving strategy
3-2-2-App-Imp-Plug	3-2-2. Plugging correct numbers into mathematical equations
3-2-3-App-Imp-Math	3-2-3. Executing mathematical calculations

4-Analyze	
4-1-Differentiating	
4-1-1-An-Dif-Distin	4-1-1. Distinguishing interim unknown variables from known variables
4-2-Organizing	
4-2-1-An-Org-Estb	4-2-1. Establishing relationships among relevant variables
4-3-Attributing	
4-3-1-An-Att-Const	4-3-1. Constructing mathematical equations to generate results
5- Evaluate	
5-1-Checking	
5-1-1-Ev-proc-Det	5-1-1. Detecting small errors made during learning or problem solving
5-1-2-Ev-proc-Mon	5-1-2. Monitoring mathematical equations for syntax correctness
5-2-Critiquing	
5-2-1-Ev-proc-Par	5-2-1. Correcting wrong variables used
5-2-2-Ev-fin-Sol	5-2-2. Judging the reasonableness of the final solution to the problem

CURRICULUM VITAE

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Education

- PhD, Engineering Education, Utah State University, 2013-2016

  Dissertation Title: “Effects of Computer Simulation and Animation (CSA) on Students’ Problem-solving in Engineering Dynamics: What and How.” Advisor: Dr. Ning Fang.
- MS, Structural Engineering, University of Tehran, Iran, 1995-1997

  Thesis Title: “Fluid-Soil-Structure Interaction in Dynamic Analysis of Ground Storage Tanks.” Supervisor: Dr. A. Noorzad.
- BS, Civil Engineering, Isfahan University of Technology, Iran, 1990-1995

Peer-reviewed Publications

- Tajvidi, M., Fang, N., “Application of Computer Simulation and Animation (CSA) in Teaching and Learning Engineering Mechanics.” Proceedings of the ASEE Annual Conference, Seattle, WA. 2015.
- Tajvidi, M. “Application of the Project-Based Learning (PBL) Method in a Senior-Year Engineering Design Course.” Proceedings of the ASEE Zone IV Conference, Long Beach, CA. April 24-27, 2014.

- Tajvidi, S. M., Noorzad, A., Moinfar, A.A., “Fluid, Soil-Structure Interaction in the Dynamic Analysis of Ground and Underground Storage Tanks.” Proceedings of the 12th European Conference on Earthquake Engineering, London, 2002.

Research Experience

Research Assistant, Engineering Education Department, Utah State University, 2013-2015

Graduate Mentor, Research Experience for Undergraduates (REU) Project, Department of Engineering Education, Utah State University, 2015 and 2014

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