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INTERACTIVE COMPUTER SIMULATION AND ANIMATION LEARNING
MODULES: A MIXED-METHOD STUDY OF THEIR EFFECTS ON
STUDENTS' PROBLEM SOLVING IN PARTICLE DYNAMICS

by

Yongqing Guo

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

of

DOCTOR OF PHILOSOPHY

in

Engineering Education

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2015

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ABSTRACT

Interactive Computer Simulation and Animation Learning Modules: a Mixed-Method
Study of Their Effects on Students' Problem Solving in Particle Dynamics

by

Yongqing Guo, Doctor of Philosophy

Utah State University, 2015

Major Professor: Ning Fang, Ph.D.
Department: Engineering Education

Computer simulation and animation (CSA) has been receiving growing attention and wide application in the engineering education community. The goal of this dissertation research was to improve students' conceptual understanding and procedural skills for solving particle dynamics problems, by developing, implementing, and assessing 12 interactive computer simulation and animation learning modules. The developed CSA learning modules integrate visualization with mathematical modeling to help students directly connect engineering dynamics with mathematics. These CSA modules provide a constructivist environment where students can study physical laws, demonstrate mental models, make predictions, derive conclusions, and solve problems.

A mixed-method research was conducted in this study: quasi-experimental method (quantitative), and survey questionnaires and interviews (qualitative and quantitative). Quasi-experimental research involving an intervention group and a comparison group was performed to investigate the extent that the developed CSA learning modules improved students' conceptual understanding and procedural skills in solving particle dynamics problems. Surveys and interviews were administered to

examine students' learning attitudes toward and experiences with the developed CSA learning modules.

The results of quasi-experimental research show that the 12 CSA learning modules developed for this study increased students' class-average conceptual and procedural learning gains by 29% and 40%, respectively. Therefore, these developed CSA modules significantly improved students' conceptual understanding and procedural skills for solving particle dynamics problems. The survey and interview results show that students had a positive experience with CSA learning.

(212 pages)

PUBLIC ABSTRACT

Interactive Computer Simulation and Animation Learning Modules: a Mixed-Method
Study of Their Effects on Students' Problem Solving in Particle Dynamics

by

Yongqing Guo, Doctor of Philosophy

Engineering dynamics is a fundamental core course in many undergraduate engineering curricula. This course is widely regarded as one of the most difficult engineering courses for students to succeed in. A variety of instructional strategies, such as hands-on experimentation, multimedia games, and computer simulation and animation (CSA), have been developed to improve student learning. Among these instructional strategies, CSA has been receiving increasing attention and applications in the international engineering education community. CSA provides students with a visualization tool and a constructivist environment to better understand various engineering problems.

The goal of this dissertation research was to improve student learning of engineering dynamics by developing, implementing, and assessing 12 interactive computer simulation and animation learning modules. A mixed-method study was conducted to examine the effect of the CSA modules on students' problem-solving skills. The findings of this study provide evidence that if properly designed, CSA can greatly improve student learning of engineering dynamics.

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Yongqing Guo

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CHAPTER 1

INTRODUCTION

Engineering dynamics is a foundational course that many engineering students are required to take (Fang, 2012a; Fang, 2011). This course introduces the fundamental principles and applications of engineering mechanics. It is the basis of many advanced engineering courses, such as fluid mechanics, advanced dynamics and structural mechanics.

Engineering dynamics is a mechanics branch of physics that studies physical systems (particles and rigid bodies) in motion. It mainly includes two important parts: 1) kinematics, which only deals with the geometric aspects of motion, and 2) kinetics, which analyzes the forces that are associated with motion (Hibbeler, 2012). Dynamics covers a broad spectrum of foundational concepts and important principles (Fang, 2012b; Gray et al., 2009; Hibbeler, 2012). These concepts and principles are applied in a variety of ways to solve various real-world dynamics problems.

Therefore, engineering dynamics is widely regarded as a very challenging course for many students. Many students struggle with learning this course (Magill, 1997; Self and Redfield, 2001; Rubin and Altus, 2000). Poor problem-solving skills in dynamics have become a widespread issue in engineering undergraduate curricula.

Existing research has shown that students have difficulties in learning dynamics due to the abstract nature of the subject (Gray et al., 2005; Streveler, Litzinger, Miller, and Steif, 2008; Hibbeler, 2012). Many engineering educators have realized that, if students are able to see the movement of a mechanical system, students are much more likely to understand and appreciate the abstract and complicated phenomena of

movements (Kozhevnikov, Motes and Hegarty, 2007; Trindade, Fiolhais and Almeida, 2002). Moreover, some research evidence has shown that most engineering students rely heavily upon a visual learning style. Students prefer to take in and process new information by visualizing the learning materials (Felder and Silverman, 1988; Kapadia, 2008; Kolmos and Holgaard, 2010; Kuri and Truzzi, 2002). Specifically, a visual learning approach to dynamics often involves students in watching demonstrations of a variety of movements. However, traditional teaching methods do not pay particular attention to the representations of these movements in dynamic manners (Kozhevnikov, 2007; Manjit and Selvanathan, 2005).

Computer simulation and animation (CSA) has received growing attention and wide application in the engineering education community because it provides a visualization tool to help students learn by capturing the dynamic nature of mechanical systems and structures (Kraige, Akhtar and Bisht, 2007; Nordenholz, 2006). Computer simulation and animation is particularly suited to deal with dynamic topics that involve motions of objects, structures, and components. Nevertheless, relatively few studies have been conducted on computer simulation and animation in engineering dynamics. The literature review shows that existing CSA studies emphasize improving students' conceptual understanding only, rather than improving students' both conceptual understanding and procedural skills.

Purpose Statement

The goal of this dissertation research is to improve both students' conceptual understanding and procedural skills of particle dynamics problems, in order to improve their problem-solving skills, by developing, implementing, and assessing a total of 12

interactive computer simulation and animation learning modules. As stated, dynamics consists of both particle dynamics and rigid-body dynamics, and the former is the essential basis of dynamics. Students must take particle dynamics first before taking rigid-body dynamics.

This dissertation research was conducted in the following three phases:

1. Developed 12 interactive computer simulation and animation learning modules for particle dynamics.
2. Implemented the developed CSA learning modules in ENGR 2030 Engineering Dynamics course taught in the College of Engineering at Utah State University.
3. Assessed the effects of the developed CSA learning modules on student learning outcomes by using a mixed-method research design that involves both quantitative and qualitative research studies.

Research Questions

The dissertation research includes the following two research questions:

Research question 1: To what extent are the developed computer simulation and animation (CSA) modules effective in improving students' conceptual understanding and procedural skills in particle dynamics, therefore improving students' problem-solving skills?

Research question 2: What are students' attitudes toward and experiences with the developed CSA learning modules?

Research question 1 is answered via a quasi-experimental quantitative study that involves a comparison group and an intervention group. Research question 2 is answered

via surveys and interviews. A detailed description of research methods is presented in Chapter 3.

Definition of Terms

In STEM (science, technology, engineering, and mathematics) education, terminologies such as “knowledge,” “understanding,” and “skills” are often used without clear and explicit definitions. Learning engineering dynamics requires more than just taking in conceptual and procedural knowledge. Learners also need to understand concepts thoroughly and apply procedures properly when solving problems. For this reason, this dissertation uses the terms “conceptual understanding” and “procedural skills” to describe the development of problem-solving skills in dynamics. In the following sections, the terminologies of “conceptual understanding,” “procedural skills” and “problem-solving skills” are defined.

Conceptual Understanding (CU): Hiebert and Lefevre (1986) define conceptual knowledge as “knowledge that is rich in relationships.” It can be thought of as a connected web of knowledge, in which linked relationships are as prominent as discrete pieces of information. In this dissertation research, conceptual understanding is defined as “a student’s mastery of the true meaning and implications of dynamics concepts and principles” (Fang and Guo, 2013). It consists of coherent explanations of the materials that fortify learners for problem solving. For example, a student knows that the Principle of Conservation of Energy involves both kinetic energy and potential energy, and that the total amount of energy remains constant over time. However, he/she does not understand that the work done by a conservation force depends upon its position relative to the

datum. In this case, the student does not truly understand the Principle of Conservation of Energy.

Procedural Skills (PS): Hiebert and Lefevre (1986) define “procedural knowledge” as “symbols, algorithms, and rules for solving mathematical problems.” In this dissertation research, procedural skills are defined as “a student’s skills at using his/her conceptual (qualitative) understanding to set up mathematical equations to generate a numerical (quantitative) solution to a dynamics problem” (Fang and Guo, 2013).

In the context of engineering dynamics, procedural skills are more than just procedural knowledge, the latter of which involves knowing the appropriate rules and how and when to apply them. For example, in solving a particle dynamics problem, a student may know that he or she needs to draw a free-body diagram, and then apply Newton’s Second Law to set up mathematical equations, and finally solve the equations to generate a numerical solution. However, this student may not be able to identify the specific situation in which the procedure is used or transform the constraints imposed upon the procedure into useful information. As a result, the student cannot correctly draw a free-body diagram or set up correct mathematical formulas. In this case, the student does not have the necessary procedural skills to solve the problem.

Problem-solving Skills: According to Mayer and Wittrock (2004), problem-solving skill is “cognitive processing directed at achieving a goal when no solution method is obvious to the problem solver.” About.com (2003) defines problem-solving skill as “a mental process that involves discovering, analyzing and solving problems. The ultimate goal of problem-solving skill is to overcome obstacles and find a solution that

best resolves the issue.” Engineering problem-solving skill involves activities which “identify and formulate a problem” (Mourtos, DeJong-Okamoto and Rhee, 2004).

In this dissertation research, problem-solving skills are defined as “a student’s combined conceptual understanding and procedural skills when solving dynamics problems.” For example, when solving a car collision problem involving impulse and momentum, a student needs to have a clear understanding of the relationship between impulse and momentum, and the effect of coefficient of restitution on the relative velocities of the two cars after collision. The student also needs to apply an understanding of concepts to set up appropriate mathematical equations in order to finally solve the equations to general a numerical solution. If unable to combine concepts and procedures in this topic, the student does not have abilities for effective problem solving.

Comparison Group: A comparison group is a group that is exposed to all of the conditions of the study except the variable being tested. The difference between a comparison group and a control group can be seen in the way a comparison group is exposed to all of the same conditions as the intervention group, except for the variable being tested, while a control group is not exposed to any condition. The comparison group is more similar to the intervention group than the control group because the comparison group is exposed to the same conditions, except the experimental condition, while the control group is simply observed (Gall, 1996).

Intervention Group: An intervention group is a group receiving the study agent that is being tested in a study. There is no obvious difference between an intervention group and an experimental group in research design (Gall, 1996).

Normalized Learning Gain: Normalized learning gain is defined as the change in score divided by the maximum possible increase (Hake, 1998).

Limitations of the Study

There are several limitations for this dissertation research. First, the research uses a quasi-experimental study design rather than a truly random experimental design. This is because at our research, the class size for ENGR 2030 Engineering Dynamics is large, with 80-120 students each semester. It is difficult to divide the class size into two segments with limited resources of the instructions and classrooms. The limitation of quasi-experimental study design is its difficulty in controlling all variables. In other words, the quasi-experimental study design does not recognize that the factors outside the experiment may have affected the results.

Second, this research focuses on the investigation of the extent to which the developed CSA learning modules improve students' learning. Students in the comparison group received traditional lecture instructions only, while students in the intervention group learned from traditional lecture instructions and CSA modules as well. It is true that students in the intervention group learned more due to their exposure to extra learning opportunities through CSA modules. In future work, extra learning opportunities through interventions other than CSA modules will be provided to a new comparison group, so as to compare student learning outcomes between the new comparison group and the intervention group.

Dissertation Outline

The rest of this dissertation is organized as follows. Chapter 2 gives a detailed review of the literature for each of the key aspects of this research. Specifically, Chapter

2 covers areas of problem-solving skills (focusing on the relationship between problem-solving skills and conceptual understanding, and the relationship between problem-solving skills and procedural skills), computer simulation and animation (in engineering dynamics), and research methods (applications in CSA in engineering dynamics).

Chapter 3 presents the details of the research design and method used in this study. In particular, the development of CSA modules, mixed-method research design, participants, and analysis procedures are described.

The pretest-posttest results and analysis of the present study are presented in Chapters 4, 5, and 6. Chapter 4 discusses student's overall conceptual understanding and procedural skills across all 12 CSA modules. Chapter 5 presents student's conceptual understanding and procedural skills by individual CSA module. Chapter 6 presents students' overall problem-solving skills across all 12 CSA modules. The results and analysis of surveys and interviews of the present study are described in Chapter 7. Finally, conclusions and implications are summarized in Chapter 8, along with recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

The literature review begins with a synopsis of both historical and recent research in dynamics and mechanics physics problem solving. The discussions focus on the relationship between students' problem-solving skills and conceptual understanding, and also on the relationship between students' problem-solving skills and procedural skills. The existing CSA learning modules developed for dynamics are classified and described based on the multimedia design features used in the modules and discussions then move to their limitations in improving students' problem-solving skills. The literature review also discusses whether the multimedia design features used in existing CSA modules improve students' problem-solving skills. Finally, a brief overview of research methods used in existing CSA studies in engineering dynamics is presented.

Problem-Solving Skills

The development of problem-solving skills is a key goal of introductory engineering curricula (Jonassen, Strobel and Lee, 2006; Gok, 2010; Coletta and Phillips, 2010). In recent studies of problem solving, much of the work has focused on expert-novice differences and effective problem-solving strategies; one reason is to discover how students can become more expert-like in their problem solving. A variety of problem-solving strategies have also been recommended in order to help students solve problems more effectively.

Experts vs. novices in problem-solving skills: The differences between experts and novices in problem-solving skills are mainly their problem-solving behaviors and the manners in which knowledge is organized in their memories.

Experts possess a large, organized, and well-connected structure of knowledge that leads to the perception of hierarchies and meaningful patterns (Ross, 2007). Expert knowledge is more thoroughly integrated into a coherent mental model that includes specifications of when, where, and how to use their knowledge (Bransford, Brown and Cocking, 2000). In physics, experts organize their knowledge and represent problems according to underlying physical laws and principles (Singh, 2009). Experts make connections across multiple representations to carry out goals and strategies (Jonassen and Strobel, 2006). When experts work on a problem, they first engage in qualitative analysis, and then tend to employ a forward-reasoning strategy to generate a solution (Gerace, 2001; Singh, 2008). Experts concentrate on deep features and start with planning steps before resorting to the implementation issues. As a result, experts have a deep understanding of problem situations, increasing speed and accuracy during solving problems. Even if they get stuck during the process of solving a problem, they can generally find alternative approaches to get out.

In contrast, novices only have a sparse knowledge set with gaps. Novices access only individual principles or pieces of knowledge and use them with little understanding. Even though novices may have stored knowledge of concepts and procedures, they are not able to sufficiently integrate sets of mental models. Novices tend to work from a single representation, and depend on fixed knowledge structures rather than adapting them based on information in the problem (Spiro et al., 1989). When novices solve problems, they tend to rely on surface features of problems to categorize problems, and employ a backward-reasoning strategy to solve problems. They often fail to recognize what conditions knowledge can be applied. Novices focus on surface features and jump

into the implementation phase of solving problems immediately without thinking if a concept is applicable. In the process of solving problems, if novices are stuck, they often fail to figure a way out (Singh, 2009; Ross, 2007).

Problem-solving strategies: An effective problem-solving strategy begins with a conceptual analysis of the problem situation; moves forward with a plan of the problem's solution; implements and evaluates the plan, and, last but not least, reflects upon the problem-solving process (Singh, 2009). Kapa (2001) also recommends a strategy for solving physics problems. Problem solvers should first identify and understand important elements of the problem situation, then examine both qualitative and quantitative aspects of the problem, and then use qualitative understanding of the problem to prepare a quantitative solution. Finally, an evaluating process encourages students to reflect on their problem-solving skills and to find other approaches to specific problems. Other problem-solving strategies for physics also have similar ideas and processes (Fink and Mankey, 2010; Gok 2010; Teodorescu, Bennhold and Feldman, 2008; Yerushalmi, Singh and Eylon, 2007).

Most students in introductory engineering courses start as novices. The gap between expert and novice problem solvers has been studied to help students develop expert or expert-like problem-solving skills. It is clear that experts have a deep understanding of underlying concepts and principles before constructing a rich and well-connected knowledge framework. Experts apply flexible and logical procedures to transform their knowledge into solutions. Meanwhile, problem-solving strategies have also been studied in order to help students enhance their problem-solving skills. It is clear that an effective problem-solving strategy in physics usually requires students to perform

qualitative analysis and planning and also requires students to conduct quantitative manipulation and procedures (Kapa, 2001; Fink and Mankey, 2010; Yerushalmi, Singh and Eylon, 2007). Therefore, conceptual understanding and procedural skills are both indispensable cognitive components that comprise students' competence in solving physical problems. In order to successfully solve a problem, an individual first needs to understand the relevant concepts and procedures of the problem (Mioković, Varvodić and Radolić, 2012; Wynder and Luckett, 1999). If the development of any of the above-mentioned knowledge is inadequate, students will not be fully competent in solving problems (Hiebert and Lefevre, 1986). Thus, it is generally agreed that the development of problem-solving skill is the development of both conceptual understanding and procedural skills (Taraban et al., 2007). Understanding how the two types of abilities are interrelated and analyzing these relations is highly significant for the development of meaningful problem-solving strategy (Scheider and Stern, 2010).

Conceptual Understanding and Problem Solving

Many educators have already stressed that the mastery of conceptual understanding of phenomena and processes is the foundation for problem-solving skills (Savander-Ranne and Kolari, 2003; Engelbrecht, Bergsten and Kagesten, 2012; Chittasirinuwat, Kruatong and Paosawatyanong, 2010). Conceptual understanding helps students organize their knowledge and store their knowledge as a network. Such a knowledge structure increases the chance that the knowledge will be retrieved when needed (Hiebert and Lefever, 1986). Conceptual understanding can help students identify key features of a problem, and lead them to properly decode the problem and construct a useful problem representation. It can help students assess the causal relations between

quantities in problem situations, and predict how the quantities respond to changes (Kolloffel and De Jong, 2013). It can increase a student's ability to monitor whether an appropriate procedure is used and whether an answer makes sense (Hiebert and Lefever, 1986; Rittle-Johnson and Star, 2007; Gerace, 2001, Streveler, Litzinger, Miller and Steif, 2008). When students get stuck in a problem-solving process, conceptual understanding can also help them seek a variety of different tactics for getting unstuck.

Moreover, students come to dynamics classrooms with quite rich and persistent misconceptions, and these misconceptions exhibit a certain degree of coherence. In this aspect, conceptual understanding can help students identify and eliminate misconceptions by constructing or reconstructing their knowledge structures (Rittle-Johnson, Siegler and Alibali, 2001; Galbraith and Haines, 2000).

Existing research (such as by Fang, 2012b; Gray et al., 2005; Streveler, Litzinger, Miller, and Steif, 2008) has shown that many students lack conceptual understanding of dynamics. Even if students strive to develop their conceptual understanding, they usually do so at low cognitive levels (Taraban et al., 2007). For example, some students do not understand that different points on a rigid body have different velocities and accelerations that vary continuously (Gray et al., 2005). Other students do not understand that a rigid body has both mass and a mass moment of inertia. When calculating the kinetic energy of a rigid body undergoing a general plane motion, students consider only the translational component and miss the rotational component of the kinetic energy (Fang, 2012b). Some students, who have learned that the work done by a frictional force to an object equals the frictional force multiplied the force's path distance, have difficulty figuring out why the

work done by the weight of an object equals the object's weight multiplied by its vertical displacement, rather than by the force's path distance.

Procedural Skills and Problem Solving

It is argued that the acquisition of procedural knowledge is a critical determinant of problem-solving skills in engineering. Procedural skills are usually considered more challenging to learn than conceptual understanding. These skills include not only surface structures, such as a sequential series of steps, but also the reasoning that is used to transform goals and constraints into actual surface structures. Conceptual understanding does not solve problems directly, but procedural skills can execute sequences to solve problems (Maciejewski, Mgombelo and Savard, 2011). Specifically, procedures take into account the order of steps, the goals and sub-goals of steps, the environment in which the procedure is used, and the constraints imposed upon the procedure by the environment.

Existing research (such as by Rubin and Altus, 2005; Shryock, Srinivasa, and Froyd, 2011) has also identified a common student's weakness of lacking necessary procedural skills to solve dynamics problems. For example, many students cannot generate graphical representations of a dynamics problem, such as a free-body-diagram or a kinetic diagram. Some students cannot set up correct mathematical equations to quantify the relationships between relevant variables or perform mathematical operations correctly.

Interconnections Between Conceptual Understanding and Procedural Skills

For conceptual and procedural knowledge in STEM learning, the debate over which knowledge develops first has long continued. The "concepts-first" view posits that conceptual knowledge is a prerequisite for the development of appropriate procedures.

Students initially develop conceptual knowledge in a domain and then use this conceptual knowledge to generate and select procedures for solving problems in that domain. The “procedures-first” view posits that conceptual understanding is developed through the repeated application of their procedural skills in problem solving. Students first learn procedures for solving problems in a domain and later extract domain concepts for repeated experience solving the problems (Karmiloff-Smith, 1992; Rittle-Johnson, Siegler, and Alibali, 2001). Recent research has moved beyond the “procedures-first” or “concepts-first” debate and has suggested that concepts and procedures develop together and influence one another (Rittle-Johnson and Alibali, 1999).

Rittle-Johnson et al. (2001) developed the “iterative model” to describe the development of conceptual and procedural knowledge and proposed that bidirectional relations exist between the two types of knowledge. The “iterative model” suggests that procedural and conceptual knowledge develop iteratively, with an increase in one type of knowledge leading to an increase in the other type of knowledge, which triggers new increase in the first (Hiebert and Lefevre, 1986; Rittle-Johnson, Siegler and Alibali, 2001; Schneider, Rittle-Johnson and Star, 2011). They appear to develop in a gradual, hand-over-hand process. They are intertwined in nature (Haapasalo, 2003). Moreover, the findings support the idea that the two types of knowledge lie on a continuum and influence one another. In different domains, either type of knowledge may begin to develop first and both types of knowledge may be constructed at different levels. For example, initial conceptual knowledge leads to the use of appropriate and effective procedures, and then improved use of procedures leads to improved conceptual knowledge (Baroody and Tiilikainen, 2003; Rittle- Johnson and Siegler, 1998).

Conceptual understanding and procedural skill are two mutually supportive factors in the development of problem-solving skills (Rittle-Johnson, Siegler and Alibali, 2001; Baroody, Feil and Johnson, 2007). Conceptual knowledge supports the selection and execution of the most appropriate procedures to solve different problems and guide the way that already developed procedures are adapted to new problem situations. Meanwhile, procedural knowledge helps students recognize and address previous misconceptions and lead to improved understanding of the underlying concepts (Voutsina, 2012). Solving problems involves the creation of links and interplay between concepts and procedures that are generated as important parts of the solution.

Computer Simulation and Animation

Introduction

It is important to define the two confusing terms of “animation” and “simulation.” Although often used interchangeably in both conversation and legal context, there are distinctions between animation and simulation in dynamics. Animation is a method of creating an illusion of movement by using rapid display images of 3-D or 2-D artwork (Solomon, 1989). Simulation is an imitation of a dynamic system that incorporates dynamical illustration, physical properties and laws, mathematical algorithms, and solution techniques to define a model (Banks et al., 2001).

Many studies have shown that traditional instructional approaches are insufficient to improve engineering student learning (e.g., Barron and Darling-Hammond, 2008), especially in presenting the characteristics of the motion of a mechanical system. Existing research findings urge educators and researchers to develop new and innovative instructional approaches to provide quality education to engineering students (Sitzman,

2011; Tambade and Wagh, 2011). In recent years, computer simulation and animation, as an interactive tool to help students learn problem solving, has received growing attention and wide application in the engineering education community (Nordenholz, 2006; Christopher, Pawan, Richard and Adam, 2011; Lin and Dwyer, 2010).

Previous research has indicated that computer simulation and animation can be effective in developing content knowledge, process skills, conceptual change, inquiry thinking, and so on (Jimoyiannis and Komis, 2001; Jiang and Potter, 1994). Students' learning gains have been reported in general science skills and across specific subject areas, including physics, chemistry, biology and mathematics (Kulik, 1994; Bell and Smetana, 2012). Many studies have proven that computer simulation and animation is a powerful instructional tool to help students produce high outcomes of achievement in short periods of time, and help students cultivate their positive attitudes towards learning (Li, Law and Lui, 2006; Demirbilek, 2004).

Computer simulation and animation has many advantages in engineering education, especially in: 1) presenting physical phenomenon or motions, and 2) improving students' cognitive performance. The two aspects are discussed in the following section.

Advantages of Presenting Physical Phenomenon

Computer simulation and animation provides students with the opportunities to observe how the simulated physical system or phenomenon behaves. More important, it provides students with the opportunities to observe physical phenomena that cannot be easily represented in real settings. Students are allowed to experience, explore, and manipulate a physical system and to observe immediately the consequences of their

actions (Hennessy et al. 1995; Weller, 1995). In a simulation-based environment, the structure can be given and changes to the variables can be made quickly, allowing students to stay focused on their inquiry processes without delay or disruption. By systematically changing variables and observing the consequences of those changes, the students can explore the properties of the underlying principles (Löhnerm, Joolingen and Savelsbergh, 2003; De Jong and Joolingen, 2003).

Computer simulation and animation can present phenomena through multiple representational formats, such as pictures, animation, graphs, vectors and numerical data displays, which are combined to describe more effectively a physical phenomenon (Van der Meij and De Jong, 2006). In particular, conveying complex phenomena can be greatly enhanced when multiple representation formats are combined. Displaying problems to learners in different ways helps them build mental models and engage appropriate problem-solving process. Mayer (1976) concluded that the more integrated the representations are, the better the learners' performance on problem-solving activities.

Cognitive Effects of Learning with CSA

Computer simulation and animation can provide a constructivist learning environment by encouraging students to actively engage in the process of learning (Mayer, 1999; Papadouris and Constantinou, 2009). Not only does it help students visualize abstract concepts and functions of complex mechanisms; it also provides an interactive learning environment in which students conduct integrated and complicated activities, such as solving problems (Sahin, 2006; Papadouris and Constantinou, 2009). When students can actively engage in learning, they have opportunities to construct their own understanding and improve their problem-solving skills (Singh, 2009).

Computer simulation and animation can help students reduce their cognitive load, thus leading to more effective information processing. Human cognitive architecture includes limited working memory capacity. During complex learning activities, the amount of information and interactions must be processed simultaneously, thus the processing demands may exceed the processing capacity of the cognitive system. This is a significant challenge for novice students. Usually, students do not automatically develop useful skills by spending lots of time solving problems. Appropriately, computer-based simulation and animation integrating with effective pedagogical strategies, such as segmenting the learning contents and applying the contiguity principle, can effectively reduce cognitive load so students can work on higher-order tasks and develop effective problem-solving skills (Liu, 2010; Lee, Plass and Homer, 2006).

Computer simulation and animation is able to help students construct a mental model. Knowledge is achieved by constructing mental models of physical phenomena (Jimoyiannis and Komis, 2001). Well-developed mental models have many benefits for solving problems, especially complex problems. Computer simulation and animation is capable of illustrating complex structural, functional and procedural relationships among moving objects. Therefore, it allows students to develop accurate and adequate mental models of physical phenomena (Sokolowski, Yalvac and Loving, 2011; Trindade, etc., 2002; Singh, 2009). Through exposing abstract and complex concepts in meaningful and concrete ways, students can test their models against real phenomena, evaluate their hypothesis, and identify aspects that need to be refined. In turn, students gradually modify their existing mental models towards the correct scientific models (Nowak, Rychwalska and Borkowski, 2013; White and Frederiksen 1998).

Computer simulation and animation has demonstrated the potential to facilitate students' conceptual change (Windschitl and Andre, 1998; Jimoyiannis and Komis, 2001; Trundle and Bell, 2010). Conceptual change is a learning process in which students' alternative conceptions transform or reconstruct into the intended scientific conceptions. As mentioned earlier, students usually have quite rich alternative conceptions for mechanics dynamics, and these conceptions exhibit a certain degree of connection. The alternative conceptions are prevalent and tenacious. The process of conceptual change is an arduous challenge in STEM education. It is commonly accepted that conceptual change is a gradually evolutionary process (conceptual perturbation strategy), rather than a sudden shift (conceptual conflict strategy). Computer simulation and animation can assist students to refine their alternative conceptions up to a significant point in a gradual process (Li, Law and Lui, 2006; Lee, Jonassen, and Teo, 2009). Computer simulation and animation provides discrepant events and steps in conceptual learning to help students identify their existing preconceptions and move towards their intermediate scientific concepts, eventually leading to the development of the intended scientific concepts. Especially for those inexperienced students, computer simulation and animation motivates and actively engages them towards construction and reconstruction of conceptual knowledge (Jimoyiannis and Komis, 2001).

Existing CSA in Engineering Dynamics

The following description is a general introduction to different types of simulation and animation used in dynamics. An extensive literature review has been performed using a variety of popular databases, such as EBSCOhost, ERIC, Web of Science, annual American Society for Engineering Education conference proceedings (1995-2014), and

annual Frontiers in Education conference proceedings (1995-2014). The search was conducted to identify all studies that use simulation and animation modules to improve students' problem-solving skills in engineering dynamics. A variety of search terms and search term combinations were used including: "*Mechanics Dynamics + Simulation*," "*Mechanics Dynamics + Animation*," and "*Mechanics Dynamics + Multimedia*." The published articles that address the topics of engineering dynamics, related fields, animations and simulations were collected. Finally, a total of eleven articles that met the inclusion criteria were identified. Note that there are two modules that are not for use in dynamics in this literature. However, since they also simulate the relation between forces and movements and therefore are essentially similar to computer simulation and animation of dynamics, they are included.

The eleven modules are categorized as A, B and C, according to the multimedia design features that they use (shown in Table 2.1).

Category A: This category includes simulations (Sokolowski et al., 2011; Kraige et al., 2007; Gu et al., 2009; Dori and Belher, 2005; Coller, 2011) that share certain common characteristics. In this category, a simulation is just one page with animations containing multiple representations of physical objects and a control panel for adjusting various parameters while working in animation. A simulation module represents and explains a general dynamics phenomenon, rather than a specific problem. It may provide some necessary numerical values describing the phenomenon but does not offer any related mathematical formulas. The category emphasizes the design of its animation and uses high-quality visual representations, which provides students with a fun and attractive learning environment. One point to mention here is that Coller's (2011) simulation is an

actual video game. It is included in this category because to some degree, certain video games can be considered computer simulations.

Table 2.1

The Classification of Existing CSA in Dynamics

Category	A					B			C		
Author(s) (Data)	Sokolowski et al., 2011	Kraige et al., 2007	Gu & Tan, 2009	Dori & Belher, 2005	Coller, 2011	Stanley, 2008	Nordenholz, 2006	Kumar et al., 1997	Scott et al., 1994	Budhu, 2001	Manjit et al., 2005
Subject	P/D	D	D	EM	D	D	D	D	D	SM	D
Animation	√	√	√	√	√	√	√	√	√	√	√
Parameter Variation	√	√	√	√	√	√	√	√	√	√	×
Multiple Representation	√	√	√	√	√	√	√	√	√	√	√
Interactivity	√	√	√	√	√	√	√	√	√	√	√
Stand-alone Online Module	√	√	√	√	√	√	×	√	√	√	√
Example Technical Problem	×	×	×	×	×	√	√	√	√	√	√
Step-by-step Process	×	×	×	×	×	×	×	×	√	√	√
Math Modeling	×	×	×	×	×	×	×	×	×	×	√
Conceptual Understanding	√	√	√	√	√	√	√	√	√	√	√
Procedural Skill	×	×	×	×	×	×	×	×	×	×	×

Note: D-Dynamic; P/D-Physics/ Dynamics; EM-Electromagnetism; SM-Soil Mechanics.

Category B: This category (Stanley, 2008; Kumar et al., 1997; Nordenholz, 2006)

has some similarities with Category A, but a simulation in this category is also an

interactive web-based learning tool that combines animations with parameter variation, multiple representations, and interactive features. However, a noticeable difference between Category A and B is that Category B is based on example technical problems, but Category A is not. Category B is linked to a specific problem in homework, textbook, or lecture. The design of example technical problem provides students with the application of concepts in a problem situation. However, the category of simulation does not offer a problem-solving process, because it does not represent any mathematical modeling or solution procedures.

Category C: This type of simulation (Scot et al., 1994; Budhu, 2001; Manjit et al., 2005) also provides students with an example technical problem, which integrates animations with variables, rich representations, and interactive features. Its main difference from Category B in design of example technical problems is that it offers a series of procedural steps, which guide students towards the solution of a problem. However, those procedures are text-only without mathematical formula support. Although Manjit's module represents a few related equations, it does not offer all required formulas for a complete solution. Moreover, its mathematical formulas have no connections to the solution procedures.

Based on the above classification of existing computer simulation and animation in dynamics literature, the researcher of this dissertation identified that their differences are mainly due to the fact that they use different multimedia design features. However, in a CSA module, these features are not independent of each other. Rather, they interconnect to constitute a holistic framework. The differences between CSA modules also derive from different types of connections among features. Different CSA modules

ultimately have different effects and bring different possibilities to students' learning. Therefore, when designing and developing a CSA, researchers not only need to consider the influence of its individual elements but also the influence of its structure and framework.

Limitations of Existing CSA in Engineering Dynamics

The above eleven articles have similar conclusions in general: their simulation and animation modules can all improve students' conceptual understanding in dynamics. However, none of the articles mention whether students' procedural skills can also be improved. As discussed in previous sections, conceptual understanding and procedural skills are two indispensable factors of problem solving, and neither can exist effectively without the other. Therefore, focusing only on the improvement of conceptual understanding will undoubtedly result in an inadequate development of students' problem-solving skills. For this reason, engineering educators are starting to recognize the increasing demand for new CSA in dynamics that can help students improve on both sides, and realize that developing such new CSA is a necessary task for engineering education.

It is also noted that the following features — animation, parameter variation, interactive features, multiple representation, example technical problem, and stand-alone online module — have been widely used in dynamics CSA. However, the approach of mathematical modeling and the approach of step-by-step process are rarely used. This may partly explain why those existing simulations and animations can emphasize the improvement of students' conceptual understanding, but neglect the improvement of their procedural skills. In the following section, efforts are made to find out through previous

research findings how the eight above-mentioned features improve students' problem-solving skills, so that theoretical support can be provided for the design of our CSA learning modules.

Multimedia Design Features of Computer Simulation and Animation

1. Animations

Many studies have proved that animations can help learners understand the underlying mechanics principles by visualizing the motion in a dynamic manner (Manjit and Selvanathan, 2005; Hoffler, 2010; Koch, 2011). Visualization allows students to “see” dynamics at small length scales, and then process the motion at each step. This process can transfer concepts from an abstract level to a concrete level, alleviating difficulties in students' conceptual understanding of phenomena (Dori and Belcher, 2005; Adams et al., 2008; Koning and Tabbers, 2011). To solve dynamics problems, students need to use external representations to construct their own internal representations. Animation can provide an accurate, complete and direct representation of dynamical phenomena to help students create a correct mental representation. In addition to facilitating the understanding of principles and rules, spatial elements in animations play an important role in learning procedures (ChanLin, 2000).

2. Parameter variation

Previous studies have shown that it is effective and necessary to combine animations with parameter variation modes (Adams et al., 2008). Simulations including the two modes can be used to support exploratory learning activities in which students can explore what may actually happen in the given motion system under a range of conditions, by manipulating the variables provided (Li et al., 2006; Scott, Devenish,

Entwistle and Stone, 1994). When more than one variable is allowed, students can explore not only the effect of one individual parameter on the motion system but also the coordinated effects of multiple parameters on the system as well (Kraige, 2007). Students therefore can develop an understanding of the causal relationships among variables, concepts, and phenomena. Moreover, by drawing students' attention to the variables, a simulation scaffolds and guides student thinking on learning objectives (Tambade and Wagh, 2011).

3. Multiple representations

Many educators recommend the use of multiple representations to help students master physics concepts and solve problems (Rosengrant, Etkina and Van Heuvelen, 2006; Wong, Sng, Ng and Wee, 2011). Multiple representations can help students build correct problem representations and construct a deep conceptual understanding, by integrating information from various representations (Rittle-Johnson, Siegler and Alibali, 2001). By combining different representations with different properties, learners are not limited by the strengths or weaknesses of one particular representation. When a learner is provided with various representations for a problem, he/she is able to build references across these representations. A learner who thinks in multiple representations is able to reason more flexibly when solving a problem. Multiple representations not only help learners to solve problems but also to evaluate their results (Rosengrant, Etkina and Van Heuvelen, 2006).

4. Interactivity

Interactivity in dynamics CSA generally includes two types: low interactivity (i.e., clicking of buttons to control the delivery of information) and high interactivity (i.e.,

changing parameter variations to explore the effects and interactions among variables) (Park, Lee and Kim, 2009). The low-interactive buttons allow users to divide a simulation/animation into digestible chunks of information and move information from one segment to the next at their own paces. Human working memory is limited with respect to the amount of information it can take in all at once, so in each segment, students devote their full mental capacity to processing the given learning material. When students learn using a high-interactive feature, they change parameters and observe the way in which the CSA responds to the changing parameters, discussed above. Both interactive features enable learners to manipulate CSA, so each learner can get a more direct feeling of the phenomenon being demonstrated and actively engage in the learning process (Koning and Tabbers, 2011). Only when students can actively engage in a learning process, do they have the opportunity to organize their knowledge, and then construct their own understanding (Singh, 2009).

5. Stand-alone online module

A stand-alone online module allows learning to occur outside of traditional classrooms and allows students to learn with their own time, in their own places, and at their own paces. In the adaptive learning environment, learners can concentrate on specific areas with which they have difficulties, and skip sections of which they have sufficient knowledge (Sitzman, 2011). Therefore, learners are able to develop their cognitive strategies to organize and manage their own thinking and learning. This relaxed environment can also help students reduce their anxiety towards learning and increase their motivation to learn (Sahin, 2010). Furthermore, another advantage it offers is the

indefinite repeatability of learning material demonstrations. Repeated practice is crucial for increasing procedural proficiency (Wynder and Luckett, 1999).

6. Example technical problem

Because of the highly mathematical nature of the dynamics subject, the most effective way of learning dynamics is to solve problems. Example technical problems help students to achieve required knowledge, promote conceptual understanding, and develop problem-solving skills (Hmelo-Silver, Duncan and Chinn, 2007; Jolly and Jacob, 2012; Perrenet, Bouhuijs and Smits, 2000). Such design presents students with opportunities to actively engage in a task and demonstrations of an orderly and complete procedure to solve the task. The feature allows students to construct cohesive or structured procedures rather than isolated parts (Tan, 2011). When a principle is intertwined with several examples, the main features of those examples are embedded with aspects of the principle and thus can reduce the degree of abstractness of the principle. Example technical problems are therefore identified as an aid in developing both conceptual understanding and procedural skills by means of subjecting students to solving the problems offered to them (Sahin, 2010).

7. Step-by-step process

A problem in dynamics can lead to a series of steps, from the problem statement to the solution. The step-by-step process helps students understand which step should be applied first and which subsequent steps should follow, leading toward the development of an overall strategy for solving problems (Ross and Bolton, 2002). This is a natural way of information processing with which students are already familiar. Moreover, the mode breaks a complete and complicated process down into separate phases, which decrease

students' cognitive load (Tan, 2011). The step-by-step process with mathematical modeling can augment students' problem-solving skills with the development of procedural skills (Rittle-Johnson, Seigler and Alibali, 2001).

8. Mathematical modeling

Mathematical modeling offers an effective instructional tool to connect mathematical formulas and dynamics/physics concepts and help students to construct their quantitative reasoning in a dynamics context (Sokolowski, Yalvac and Loving, 2011; Redish, 2005; Tumaniro and Redish, 2003). Quantitative reasoning is fundamental to successful problem-solving skills (Cui, Rebello and Bennett, 2005; Undreiu, Schster and Undreiu, 2008). As mathematical modeling sets up procedures to achieve solutions, it helps students develop procedural skills in solving dynamics problems (Basson, 2002). Mathematical modeling design also offers students relief from the cognitive complexity of mathematical formulations, thus increasing the likelihood that students focus on qualitative analysis and understanding.

Summary

Based on the above analysis, it is noted that, among the eight multimedia design features mentioned above, some focus on improving conceptual understanding, others focus on improving procedural skills, and some do both while stressing different points. Among them, mathematical modeling and step-by-step procedure are mainly used to improve students' procedural skills.

The computer simulation and animation modules developed in this dissertation research aim to improve students' conceptual understanding and procedural skills in particle dynamics in order to improve students' problem-solving abilities. The computer

simulation and animation modules developed in this research integrate all of the above-mentioned features to achieve this goal.

A Brief Overview of Research Methods

Quantitative research designs are generally used to examine whether there are differences between groups on various indicators and to test hypotheses that concern relationships between and among various indicators, with statistical analyses. All the data collected would be quantified or counted, to generalize findings from the sample to the population and make inferences using statistical analysis. However, this method generally does not include an explanation of “why” and “how,” and participants are constrained to a pre-determined set of possible responses. On the other hand, qualitative approach is often employed to collect non-numerical information to answer the why and how of opinion, experience, and attitude information. Also, participants can respond freely (Creswell, 2002; Thorme and Giesen, 2002; Brrego, Douglas and Amelink, 2009).

A mixed method can maximum the strengths and minimize the weaknesses of both approaches described above. Mixed-method research can combine both quantitative and qualitative data in a single study to better understand research questions, to complement one set of results with another, and to discover something that would have been missing if only one single method had been used. The combination of the different perspectives provided by qualitative and quantitative methods may produce a more complete picture of the study (Teddlie and Tashakkori, 1998, 2003). In addition, the concurrent research approach can increase the validity of the study.

Research Methods Used in Existing CSA Studies in Engineering Dynamics

In the existing CSA research in dynamics, quantitative methods are used to measure improved students' achievement from CSA, and qualitative methods are used to examine students' experiences with and attitudes toward CSA. While, a mixed method answers the both aspects above and thus provides a big picture of the study of developing and applying CSA.

Table 2.2

Research Methods Used in Existing CSA in Dynamics

Author(s) (Data)	Research Method			
	Quantitative	Qualitative	Mixed	Mentioned
Sokolowski et al., 2011				Not Mentioned
Kraige et al., 2007		Survey		
Gu & Tan, 2009			Survey; Exams	
Dori & Belher, 2005			Survey; Pre-post tests	
Coller, 2011	Pre-post tests			
Stanley, 2008		Survey		
Nordenholz, 2006		Survey		
Kumar et al., 1997				Not Mentioned
Scott et al., 1994				Not Mentioned
Budhu, 2001		Survey		
Manjit et al., 2005				Not Mentioned

The research methods used in existing CSA in dynamics are summarized in Table 2.2. In a total of 11 studies, 4 studies did not mention any research method used; only 2

studies used a quantitative approach; and 6 studies used a qualitative approach. Generally, most studies focused on introducing and explaining key features and functions of their developed CSA modules. They only provided a brief description on research design and short assessment results. Some important information related to research design was not mentioned in the papers, such as selection of subjects, procedures of experiment, or triangulation of different data. Therefore, the validities of the conclusions drawn from these studies were relatively weak.

In the CSA studies, the aspects of “students’ improvement” and “students’ opinions” are extremely important. Mixed methods used in the study should be more appropriate, because they produce a more complete picture of the study than only one method used. This dissertation research uses a mixed-research method not only to compare student learning outcomes, but also to understand students’ experiences with and attitudes toward computer simulation and animation.

CHAPTER 3

METHODOLOGY

This dissertation research is built upon a pilot study that was carried out to test the validity and reliability of CSA learning modules and to refine the intervention (Fang, 2012a). In the pilot study, a different set of CSA learning modules were developed, implemented, and assessed in an Engineering Dynamics course in multiple semesters. The assessment results of the pilot study by Fang (2012a) show that “students made an average learning gain of 48 to 84 percent, and that a total of 60 to 86 percent of the students who responded to a questionnaire survey indicates positive experiences with the CSA learning modules.” Built upon the encouraging results of the pilot study, this dissertation study conducts a comprehensive development and assessment of CSA learning modules.

The Development of CSA Modules

A total of 12 CSA learning modules were developed for particle dynamics. The development involved team efforts including:

- 1) Determining learning objectives of each CSA learning module;
- 2) Designing corresponding dynamics problems that each CSA learning module addresses;
- 3) Designing the layout of interactive graphical user interfaces (GUIs) for each CSA learning module on paper;
- 4) Designing the interactive GUIs of each CSA learning module using Adobe Flash;

- 5) Writing computer code using Adobe Flash and testing the CSA learning modules through an interactive debugging process.

The details of the steps above are provided through an example in the following paragraphs.

Step 1: Determining learning objectives of the CSA modules. The example module addresses the Principle of Linear Impulse and Momentum, shown in Figure 3.1.

Its learning objectives are:

- Apply the Principle of Conservation of Linear Momentum to determine velocity for a system of particles
- Apply the Principle of Linear Impulse and Momentum to determine impulsive forces
- Understand how the coefficient of restitution plays a role in velocity changes

Learning Objectives

- Apply the Principle of Conservation of Linear Momentum to determine velocity for a system of particles
- Apply the Principle of Linear Impulse and Momentum to determine impulsive forces
- Understand how the coefficient of restitution plays a role in velocity changes

Figure 3.1 Learning Objective Page in an Example CSA Learning Module

Step 2: Designing corresponding dynamics problems that the CSA modules addressed. A new dynamics problem was designed to address all learning objectives

described in step 1. The new dynamics problem is shown in Figure 3.2. The problem is about the two bumper cars that collide head-on. Students were asked to determine the velocity of the two cars after the collision and the average force between the two cars if the collision takes place in a split second. To solve this problem, student must learn how to set up mathematical equations using the Principle of Conservation of Linear Momentum and using coefficient of restitution to calculate the velocities of the two cars after collision. Students must also learn how to set up a mathematical equation using the Principle of Linear Impulse and Momentum to finally compute the average force between the two cars.

Problem

Given: **Mass** of bumper car A $m_A = 160$ kg
Mass of bumper car B $m_B = 180$ kg
Initial velocity of bumper car A $(V_A)_1$ (**variable**)
Initial velocity of bumper car B $(V_B)_1$ (**variable**)
Coefficient of restitution between the two bumper cars e (**variable**)

Find: **Velocity** of bumper car A after the collision $(V_A)_2$
Velocity of bumper car B after the collision $(V_B)_2$
Average force between the two cars if the collision takes place in 0.05 seconds



Figure 3.2 Problem Statement Page in an Example CSA Learning Module

Steps 3 & 4: Designing the layout of GUIs of each CSA learning module on paper and in Adobe Flash. Two primary factors were considered in designing the GUI layout. First, it must provide students with a variety of interactions, such as adding

commands directly to the module space and changing variables to see how different values of a parameter affect the final solution to the problem. Second, students' cognitive load for learning with each GUI must be controlled at an appropriate level. Research (Mayer, 1998; Sweller, 1988) has revealed that student learning outcomes are not optimum if cognitive load is too high or too low. Moreover, it should be constructed with sound design principles; that is, although multiple representations are used, it is necessary to keep the display simple, clear and distinctive, with emphasis on critical information. Figure 3.3 provides the layouts of GUIs of the example module.

Step 5: Writing computer codes using Adobe Flash and testing the CSA learning modules through interactive debugging process. Because the purpose of this dissertation is not to describe the process of writing and debugging computer codes, only a short segment of code for running the animation is shown in Figure 3.4.

Solution

$(V_A)_1 =$ m/s

$(V_B)_1 =$ m/s

$e =$

Step 1: Apply the Principle of Conservation of Linear Momentum

Vector form: $m_A(\vec{v}_A)_1 + m_B(\vec{v}_B)_1 = m_A(\vec{v}_A)_2 + m_B(\vec{v}_B)_2$

Scalar form: $\rightarrow 160 \cdot 2.0 - 180 \cdot 2.0 = 160(v_A)_2 + 180(v_B)_2$ (Eq. 1)

Step 2: Apply the equation of coefficient of restitution

Coefficient of restitution is calculated as

$$e = \frac{(v_B)_2 - (v_A)_2}{(v_A)_1 - (v_B)_1}$$

← Previous
Animation
Reset
Return to 1st page →

Figure 3.3 Problem Solution Page in an Example CSA Learning Module

```

function timerIngl(e: TimerEvent):void
{
    if ((Math.round(Variable56*100)/100<-0.009 )&&(Math.round(Variable55*100)/100<-0.009))
    {
        c00.x = c00.x -(6*Math.abs((Math.round(Variable56*100)/100))+2);
        c01.x = c01.x -(6*Math.abs((Math.round(Variable55*100)/100))+2);
    }
    else if ((Math.round(Variable56*100)/100<-0.009 )&&(Math.round(Variable55*100)/100 >0.009))
    {
        c00.x = c00.x -(6*Math.abs((Math.round(Variable56*100)/100))+2);
        c01.x = c01.x +(6*Math.abs((Math.round(Variable55*100)/100))+2);
    }
    else if ((Math.round(Variable56*100)/100>0.009 )&&(Math.round(Variable55*100)/100 <-0.009))
    {
        c00.x = c00.x +(6*Math.abs((Math.round(Variable56*100)/100))+2);
        c01.x = c01.x -(6*Math.abs((Math.round(Variable55*100)/100))+2);
    }

    .....

    else
    {

        minuteTimer.addEventListener(TimerEvent.TIMER, onTick);
        minuteTimer.start();
        c00.x = c00.x;
        c01.x = c01.x;
        function onTick(event:TimerEvent):void
        {
            wait1();
            trace("tick11" + event.target.currentCount);
        }
    }
}

```

Figure 3.4 A Segment of Computer Code for Running Animation

The researcher's PhD advisor, Dr. Fang, was responsible for tasks 1-3. The fourth and fifth tasks were completed by the researcher of this dissertation and other students in Dr. Fang's research group. For example, the researcher of this dissertation participated in the design and development of seven (out of twelve) CSA learning modules.

Twelve CSA learning modules were developed using Abode Flash Professional CS5.5. These modules build a package of simulation and animation to examine a broad range of topics in engineering dynamics (see Appendix A), including:

- 1) Kinematics of a particle
 - Module 1: Projectile Motion of a Particle I
 - Module 2: Projectile Motion of a Particle II
 - Module 3: Projectile Motion of a Particle III
 - Module 4: Normal and Tangential Components of Curvilinear Motion
 - Module 5: Relative Motion
- 2) Kinetics of a particle: force and acceleration
 - Module 6: Force and Acceleration of 2nd Newton Law
 - Module 7: Force and Acceleration of Normal and Tangential Coordinates
 - Module 8: Force and Acceleration of Cylindrical Coordinates
- 3) Kinetics of a particle: work and energy
 - Module 9: Principle of Work and Energy
 - Module 10: Conservation of Energy
- 4) Kinetics of a particle: impulse and momentum
 - Module 11: Linear Impulse and Momentum
 - Module 12: Angular Impulse and Momentum

The CSA modules are in the form of interactive Flash Movie files and can be run on the internet using a web browser. Each CSA learning module has a stand-alone lesson plan, which includes clearly-stated learning objectives, a problem statement, and a solution.

The Multimedia Design Features of CSA Modules

The developed CSA modules have two-dimensional virtual interface that simulates fundamental principles of engineering dynamics. The modules offer a friendly user interface through a series of interaction objects, such as buttons and scrollbars. Students can easily modify parameters and immediately observe the changes in system motion. The motion of an individual object and its interactions with surrounding entities in a system are quantitatively presented in animation. All animations are based on the results of relevant mathematical calculations. These CSA modules provide a constructivist environment where students can study physical laws, demonstrate mental models, make predictions, derive conclusions, and solve problems.

This study mainly focuses on the assessments of student learning outcomes that are associated with the developed CSA learning modules. Because student learning outcomes are highly associated with the features of the developed CSA learning modules, it is necessary to describe these features.

The eight multimedia design features of the developed CSA learning modules are shown in Figure 3.5. The CSA learning modules use the elements of animation, parameter variation, mathematical modeling and rich representations, and employ a design of example technical problem and step-by-step process to create an interactive learning environment. The uniqueness of the CSA learning modules lies in the connectedness of design features.

Two major connections are used: 1) The connection between mathematical modeling and step-by-step processes; 2) The connection between animations and mathematical modeling through parameter variation. The eight features, through the

above two connections, form the CSA learning modules' entire structure and frame. In improving students' problem-solving skills, the developed CSA learning modules benefit from not only the individual effects of the features, but also the combined effects of the connections.

The main purpose of the developed CSA learning modules is to help students improve their conceptual understanding and procedural skills. To learn with the developed CSA learning modules is an incremental and iterative process. In such a process, the two desired abilities interact with each other and enhance each other. Ultimately, the two abilities will help students bring their problem-solving skills to a higher level at the end of their study.

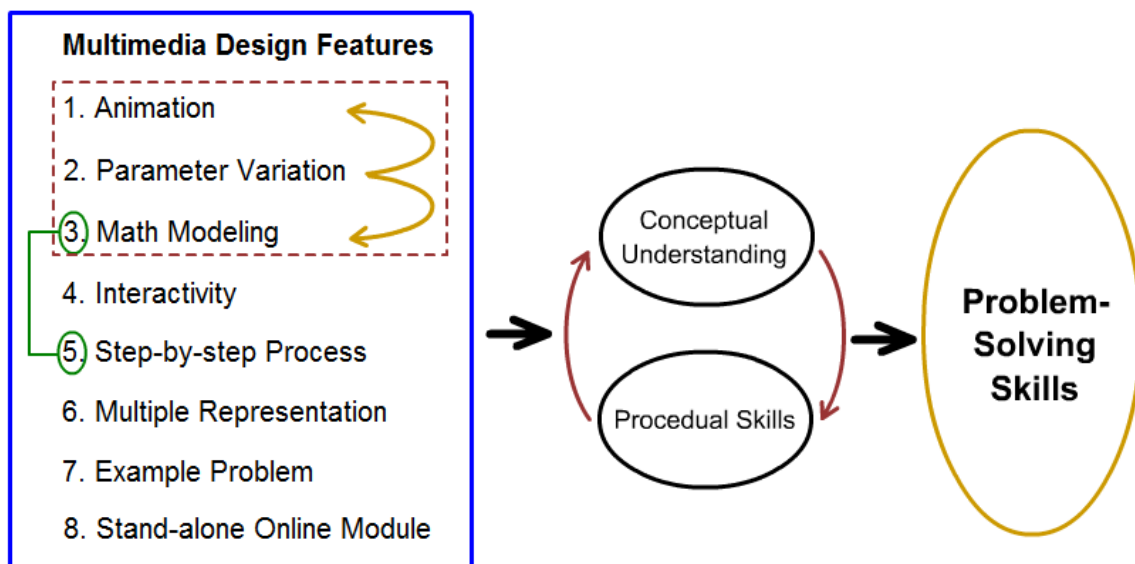


Figure 3.5 Multimedia Design Features of the Developed CSA Learning Modules

The above two connections between features are the most unique and innovative features of the CSA learning modules. When improving students' problem-solving skills,

the developed CSA learning modules benefit from the values of the combined effects of the connections. The values of the connections lie in their coordinated effects on enhancing students' problem-solving skills. A detailed description of the two connections is provided in the following sections.

1. The Connection Between Mathematical Modeling and Step-by-step Process

A dynamics problem generally requires a procedure with a series of mathematical equations to reach the final answer. The integration of mathematical equations and step-by-step procedures provides students with a complete and effective problem-solving procedure. Mathematical equations and calculations required to solve the problem are embedded into the corresponding steps, according to the order of steps in problem solving. Such problem-solving steps include rich representations of mathematical equations, text description and, if necessary, schematic diagrams as well. In this logical and orderly environment, learners are encouraged to reflect on what to do with mathematical formulas in a strategic and systematic process, rather than get immersed in messy calculations. Therefore, students can concentrate on developing and constructing their quantitative reasoning in a dynamics context. Moreover, such a highly structured method can help students reduce their intrinsic cognitive load processing complex problem-solving tasks (Sweller, 1988). Students' perceptions about learning can be promoted by processing smaller chunk of information in working memory at one time. A possible interface for the connection between mathematical modeling and step-by-step process is illustrated with an example problem in Figure 3.6.

Solution

$(V_A)_1 = 2$ m/s

$(V_B)_1 = 2$ m/s

$e = 0$

Step-by-step Process

Step 1: Apply the Principle of Conservation of Linear Momentum

Vector form: $m_A(v_A)_1 + m_B(v_B)_1 = m_A(v_A)_2 + m_B(v_B)_2$

Scalar form: $\rightarrow 160 \cdot 2.0 - 180 \cdot 2.0 = 160(v_A)_2 + 180(v_B)_2$ (Eq. 1)

Math Modeling

Step 2: Apply the equation of coefficient of restitution

Coefficient of restitution is calculated as

$$e = \frac{(v_B)_2 - (v_A)_2}{(v_A)_1 - (v_B)_1}$$

Animation

Return to 1st page

End

Previous

Figure 3.6. The Connection Between Mathematical Modeling and Step-by-step Process

2. The Connection Between Animations and Mathematical Modeling Through Parameter Variation

Integrating animations and mathematical modeling through parameter variation offers the possibility of establishing the relationship between graphical and algebraic representations by making concurrent changes in representations. When students make changes in parameters, they can observe how the changes in animations (graphically), and the changes of variables in the mathematical equations (numerically) immediately respond to the changed parameters. Therefore, when students clearly see “what” happens, they can also understand and explain “why” and “how” it happens (Fang, 2012b). This

connection design enables students to interact with the CSA modules in a generative cognitive processing, by prompting students engage in the selection, organization, and integration of new information (Mayer, 2007).

The learning path is a loop, which starts with parameters, then goes to animation, mathematical equations, and finally ends with parameters. Since parameter variation is allowed, students can run the loop of the learning path multiple times. Through the repeated exposure to the learning materials, students can explore what happens in the motion system under a variety of conditions. Students can test their own hypotheses and build their mental models by going through a series of iterative learning cycles. A possible interface for the connections between animation, mathematical modeling and parameter variation is illustrated with an example problem in Figure 3.7.

Parameter - variation

Solution

$(V_A)_1 =$ m/s

$(V_B)_1 =$ m/s

$e =$ 1

Step 1: Apply the Principle of Conservation of Linear Momentum

Vector form: $m_A(\vec{v}_A)_1 + m_B(\vec{v}_B)_1 = m_A(\vec{v}_A)_2 + m_B(\vec{v}_B)_2$

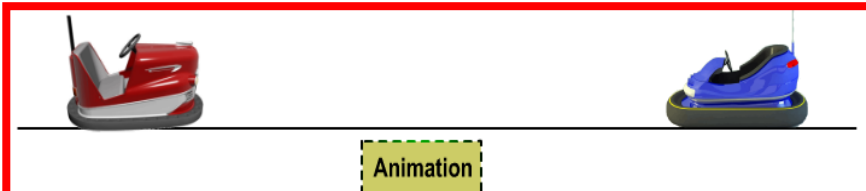
Scalar form: $\rightarrow 160 \cdot 2.0 - 180 \cdot 2.0 = 160(v_A)_2 + 180(v_B)_2$ (Eq. 1)

Step 2: Apply the equation of coefficient of restitution **Math Modeling**

Coefficient of restitution is calculated as

$$e = \frac{(v_B)_2 - (v_A)_2}{(v_A)_1 - (v_B)_1}$$

Animation



← Previous
← Return to 1st page
End →

Figure 3.7. The Connections Between Animation, Mathematical Modeling and Parameter Variation

Students Participants

The participants were sophomore students from the ENGR 2030 Engineering Dynamics class taught in the College of Engineering at Utah State University. The comparison group was made up of students enrolled in fall semester of 2012, and the intervention group was made up of students taking the dynamics course in fall semesters of 2013. The number of students in the comparison group and the intervention group were 74 and 87, respectively. Note that not every student in the class participated in

assessment with all 12 modules. Sample sizes vary from module to module. Table 3.1 shows detailed student demographics in the comparison and intervention semesters. The majority of student participants (Comparison Group N = 65 (87.8%) and Intervention Group N = 78(89.7%)) were males, which is typical in engineering study programs in the USA. The largest participant groups were Mechanical and Aerospace Engineering (MAE) majors. The second largest participant groups were Civil and Environmental Engineering (CEE) majors, or Biological Engineering (BE) majors.

Table 3.1

Student Demographics

Group	Gender		Major			
	Male	Female	MAE	CEE	BE	Other
Comparison	65 (87.8%)	9 (12.2%)	39 (52.7%)	21 (28.4%)	8 (10.8%)	6 (8.1%)
Intervention	78 (89.7%)	9 (10.3%)	53 (60.9%)	14 (16.1%)	11 (12.6%)	9 (10.3%)

Validity and Reliability

Validity refers to how well a test measures what it is purported to measure. Reliability is the degree to which an assessment tool produces stable and consistent results. A pilot study was conducted in this study to check the reliability and validity of measures. The face and content validity of the tests were verified by a panel of an experienced professor and two PhD graduate students from the field of Engineering Education.

The panel was asked to ensure that the crucial conceptual and procedural parts of mechanic dynamics were covered in the test questions. The panel checked to see if there are any ambiguities or if the respondents have any difficulty in responding (De Vaus, 1993). The internal consistency reliability of the tests (12 total) was checked using Cronbach's alpha. The Cronbach's alpha coefficients of the tests ranged from 0.64 to 0.86. The values indicate that the tests had good or acceptable internal consistency. ANOVA/ANCOVA were used to reduce the effects of initial group differences statistically by making compensating adjustments to the post-test means of the two groups involved (Gall et al., 1996; Borg and Gall, 1989). Except for the statistical method, the use of a comparison group also helps to control for the potential threats and reduce the internal validity of the study, such as maturation.

Survey questionnaire and interview were verified to avoid misleading, inappropriate, or redundant questions, to ensure that the information obtained was consistent. Additional feedback from each panel expert was included in the final version. With regards to reliability of the survey and interview, a guide for questions, organizations and discussions was developed for implementation and replication. Triangulating quantitative and qualitative data from different methods also enhance validity of this study.

Approved from the Institutional Review Board

An IRB approval for research on computer simulation and animation in engineering dynamics was obtained from Utah State University before data collection. All participants were informed that they could withdraw from the research at any time during the study without penalty or loss of benefits. Student participants were assured

that participation, non-participation and withdraw from the study would have no effect on their academic grades. Students were informed that their pretest and posttest scores, survey, and interview data were confidential. Each participant completed an informed consent before participating in the research project. Data from the students who did not sign the informed consent form were excluded from the analysis.

A copy of the participant consent form for this dissertation research is given in Appendix B. An IRB approval for this particular dissertation research was subsequently approved, following the successful proposal defense of the researcher of this dissertation.

Mixed-Method Research Design

Quasi-Experimental Research Design

Quasi-experimental design is the same as the classic experimental design except that subjects are not randomly assigned to either the experimental or the comparison group. Quasi-experimental design was selected in the study because random assignment was impractical due to real-world constraints, such as a long-time and discontinuous intervention (12 scenarios that last two months), limitations of budget and resource for the project. Because the PhD advisor of the dissertation study is the instructor of the dynamics course, a practical and feasible plan was to use the CSA learning modules as part of the course bonus homework assignments and use students in his class as participants. According to Gall et al. (1996), although a quasi-experimental design “does not allow the same degree of certainty about cause-and-effect relationships as an experiment does, a well-designed quasi-experiment can provide convincing circumstantial evidence regarding the effects of one variable on another.” Overall, the quasi-experimental design was suitable and practicable for this dissertation study.

A quasi-experimental research design was implemented in this dissertation study to answer the first research question: To what extent are the developed CSA learning modules effective in improving students' conceptual understanding and procedural skills in particle dynamics?

The experiment was carried out in a real university setting. Data has been collected from students in two semesters: a comparison semester (Fall 2012) and an intervention semester (Fall 2013). In the comparison semester, students received traditional lecture instructions only. In the intervention semester, students learned from traditional lecture instructions and the CSA learning modules as well. All the students in the two groups were taught by the same instructor. The CSA modules were used as students' bonus homework assignments. The time taken for the intervention sessions was in addition to that devoted to the regular curriculum. Participants received bonus credits for their participation. The procedure that participants followed was:

1. Participants take pretests.
2. Participants learn from regular classroom lectures only (for the comparison group) or learn from regular classroom lectures and CSA learning modules (for the intervention group).
3. Participants take posttests.

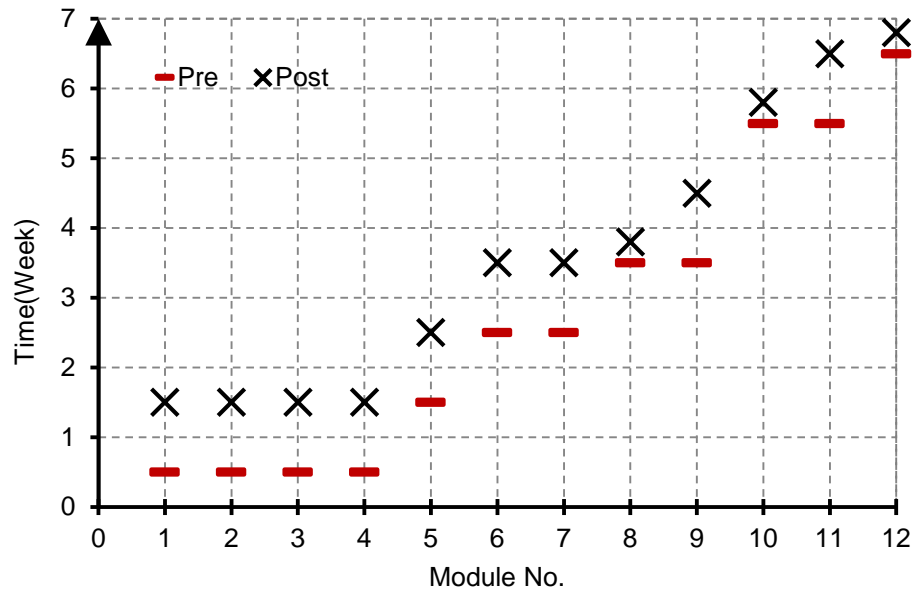


Figure 3.8 Schedule of 12 Comparison and Intervention Sessions

Student participants were exposed to all twelve sessions in 7 weeks. The sessions were scheduled based on the schedule of dynamics course that participants took. Based on the pre-determined class schedule, this educational research does not interfere with regular teaching and learning activities. One session usually took 4 days to 7 days. These sessions were generally conducted in numerical order, but some sessions overlapped with others. Student needed to finish two or more sessions simultaneously in a time period. The schedule of 12 comparison and intervention sessions is presented in Figure 3.8.

The effect of the CSA learning modules on students' problem-solving skills can then be determined by comparing learning gains between students in the comparison semester and in the intervention semester. For each comparison/intervention semester, student learning gain is calculated using the following formula (Hake, 1998):

$$\text{Learning gain} = \frac{\text{Posttest score (\%)} - \text{Pretest score (\%)}}{100\% - \text{Pretest score (\%)}} \quad (1)$$

Average normalized learning gain for a course is defined as the ratio of actual gain to maximum gain for the course. Hake (1998) defined class gains in the following manner: low gain as less than 0.3, moderate gain as 0.3–0.7, and high gain as greater than 0.7.

To determine whether there were any statistically differences between comparison group and intervention group based on the average normalized gains, calculated gains were subjected to parametric (t-test, ANOVA and ANCOVA) and non-parametric (Mann-Whitney U test) statistical tests.

Assessment Questions for Use in Pretests and Posttests

A set of technical assessment questions was developed for each CSA learning module. Two types of assessment questions, conceptual questions and calculation questions, were designed for pretests and posttests to assess students' learning outcomes. The conceptual questions were used to assess students' understanding of particle dynamics concepts and principles, and the calculation questions were used to assess students' performance on procedural skills for solving problems.

Conceptual questions on the tests were designed in a specific context to examine students' understanding of concepts. The conceptual questions required participants to reason about how a variable would behave in the specific condition, how the changes in one parameter would affect other parameters, or how a concept is relevant in the specific condition. If students just memorized a concept without truly understanding its meaning, they experienced difficulty in reaching a correct solution.

Similarly, calculation questions on the tests were also designed in a specific environment. Students were required to think clearly about problem's constraints and structure, and reason how to get answers from constraints with a sequential series of steps. The calculation problems varied greatly in complexity; for example, some questions required only one or two steps to solve, while some questions required the application of a variety of procedures. The calculation questions focused on evaluating students' deep understanding and applications of procedures. Example questions for each type of assessments are shown below.

Example Conceptual Question 1(for CSA Module 11):

- As the coefficient of restitution e increases from 0 to 1, the speed of bumper car A after the collision
 - A) increases
 - B) decreases
 - C) remains the same
 - D) increases first and then decreases

Example Conceptual Question 2 (for CSA Module 7):

- As θ increases from 30° to 90°
 - A) the tangential acceleration of the ball increases, and the normal acceleration of the ball decreases
 - B) the tangential acceleration of the ball decreases, and the normal acceleration of the ball increases
 - C) Both tangential and normal acceleration of the ball increase
 - D) Both tangential and normal acceleration of the ball decrease

Example Calculation Question 1(for CSA Module 9):

- When the box falls down from the initial position to the final position, the gravitational potential energy will

A) increase by 367.9	Joule
B) decrease by 367.9	Joule
C) increase by $(367.9 + 245.3S_{\max})$	Joule
D) decrease by $(367.9 + 245.3S_{\max})$	Joule

Example Calculation Question 2 (for CSA Module 10):

- The maximum compression of the spring S_{\max} is

A) 4.65 m
B) 3.65 m
C) 2.65 m
D) 1.65 m

Qualitative Research Design

Questionnaire Survey and Interview to Assess Students' Learning Attitudes and Experiences

An anonymous questionnaire survey and individual interview were administrated at the end of the intervention semester to answer the second research question: What are students' attitudes toward and experiences with the developed CSA learning modules?

Both the questionnaire and the interview questions were developed to relate students' learning attitudes toward and experiences with the developed CSA learning modules. These questions were developed through collective brain-storming among four members in the research group of this researcher's PhD advisor. Examples for the survey questionnaire and interview question are shown below.

Example Questionnaire Questions:

- Which features of the modules do you like most? Select all that are applicable.
 - A) Animations
 - B) Figures
 - C) Math equations
 - D) Scrollbars
 - E) Color that highlights important items
- Among Modules 1-12 for particle dynamics, which modules did you learn the most from? Why?
- Among Modules 1-12 for particle dynamics, which modules did you learn the least from? Why?

Example Interview Questions:

- Do you have any comments on whether or not CSA modules help improve your *conceptual understanding* of dynamics problems? Any examples?
- Do you have any comments on whether or not CSA modules help improve your *procedural skills* (such as setting up math equations step by step) to solve dynamics problems? Any examples?

The survey questionnaire and in-depth interviews focused on exploring how students learn in the CSA environment, identifying crucial factors that influence the effectiveness of CSA modules, as well as examining strengths and weaknesses of GUI interfaces and students' suggestions for improvements.

Data Collection and Analysis

1. Survey Questionnaire

All participants in the intervention group were asked to complete a survey questionnaire. The survey questionnaire presented a set of Likert-type and open-ended questions (see Appendix C). The data collected by the survey questionnaire was analyzed both qualitatively and quantitatively. For each Likert-type question, the percentage frequencies of students' responses were calculated and the mean value was calculated if need. Figure 3.9 provides an example of Likert-type questions in the survey and its results. In this example, the percent of choice "Easy" was 14%, and the average level of problem complexity was 3.14/5.0.

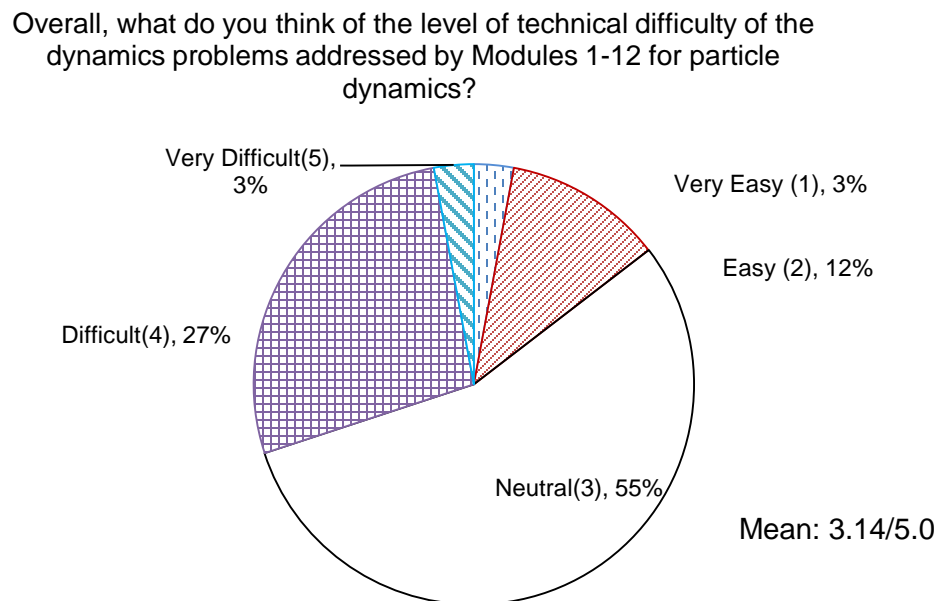


Figure 3.9 An Example of a Likert-type Question in Survey and Results (N = 69)

For students' responses to open-ended questions, the following procedure was used for data analysis. The analysis was conducted question by question. The first step

entailed open coding of the data, with emphasis given to identifying indicators of categories that fit the data. Each relevant event in the data was coded into as many subcategories of analysis as possible. The subcategories had to be able to answer the associated question; therefore the rare and irrelevant ones were removed. The remaining subcategories were refined and combined considering their properties, relationship and other conditions. This integration process was iterative, which was moved back and forth many times until the categories were identified. An example of coding open-ended survey responses was illustrated in Table 3.2. In this example question, four categories were identified and developed through the iterative process. Moreover, results from qualitative survey were used to create a code table for coding interview data.

Table 3.2

Example of Coding Open-ended Survey Responses

Example Response	Category
Number 7 and 12 stand out to me. These were concepts that I didn't fully understand in class, but as I worked through them, it made a big difference in my understanding.	Help students understand concepts
4, 5, 6, and 8 - because I wasn't completely clear on how problems like that should be solved, but the modules helped a lot with my ability to work through problems like those.	Help students solve problems
Problem 8 was hard to conceptualize for me. The module helps me visualize what's happening better.	Help students visualize
I learn the most from modules that are slightly difficult but not overwhelming.	Problem complexity

Note: Question: which modules did you learn the most from? Why?

2. Individual In-depth Interview

The interview participants were randomly selected from the intervention group. The researcher sent an email invitation to the selected student participants to introduce the purposes and procedures of the study. Students voluntarily participated in the study. Before participating, they signed an informed consent which is attached in Appendix B. Each participant received a \$15 honorarium after participating.

Research-involved interviews had a total of 20 student participants. An approximately 30-minute individual interview was conducted with each participant. Semi-structured interviews were used with a fairly open framework in this study. An interview guide was developed to provide a clear instruction for interviews, and provide reliable and comparable qualitative data. Twenty general open-ended questions about students' learning experience and attitudes were prepared for interview discussion (see Appendix D). The interviewer asked additional questions to follow up on the interesting or unexpected answers to the main questions. This semi-structured interview allowed both the interviewer and the students being interviewed the flexibility to probe for more details. The interviewer was the researcher herself, who is knowledgeable about physics and mechanics and has lots of experience of teaching mechanical dynamics.

The following procedures were used in transcribing, coding, charting and interpreting the qualitative interview data.

- Transcription

All interviews were audio-taped. The interviews were transcribed verbatim, including any nonverbal or background sounds. Repeated and attentive listening was involved in transcribing to ensure an accurate transcript of the conversation. All interview

transcriptions were completed by researcher herself and three undergraduate student researchers.

- Coding

The first step entailed open coding of the data. Every core passage of the interviews was studied to determine what exactly had been said and to label each core passage with an adequate code. Simultaneously, the irrelevant participants' statements to the research questions were filtered. This step resulted in a large amount of codes, covering all relevant themes contained in the interviews.

Next step was conducted question by question. Fragments under the same question from different interviews that had been given the same or similar codes were grouped together. The fragments were compared in order to find out whether the same information was repeated or whether new information was given. This comparison process was conducted to develop subcategories and to label them with the most appropriate codes. The relevant properties, dimensions and characteristics of each subcategory were identified and defined. The subcategories were then grouped by similarity to create categories.

An initial coding framework table was constructed, based on the combination of coding results from the interviews and the survey questionnaire. This coding table was constantly reconstructed and updated until the analysis was complete. As shown in Appendix E, the final coding table presents the four core categories: technical design, instructional design, usage pattern and outcomes/ benefits. Based on the coding table, each text category was given a specific number code. An example of coding qualitative interview data was presented in Table 3.3.

Table 3.3

Example of Coding Qualitative Interview Data

Interview Question	Step 1: Core Text	Step 2: Category	Step 3: Number Code
What modules did you learn the most from? Why?	“slightly difficult but not overwhelming.”	Problem complexity	2-1.1
	“fairly complex problems”		
	“being tough conceptually” “completely new to me”	Improve conceptual understanding	4-1
Do you have any comments on whether or not CSA modules help improve your conceptual understanding of dynamics problems? Any examples?	“visualize the concept at a deeper level”	Visualization/animation	4-1.2
	“animation helped significantly”		
	“watching the animations” “Animations, and some sort of diagrams or pictures”	Visualization/animation	4-1.2
Do you have any comments on whether or not CSA modules help improve your procedural skills to solve dynamics problems? Any examples?	“adjust values and understand variables affects”	Variables and relationships	4-1.1
	“different scenarios...see the different effects “		
	“put all together” “big Picture”	Connections	4-1.3
Do you have any comments on whether or not CSA modules help improve your procedural skills to solve dynamics problems? Any examples?	“clear step-by-step solutions”	Step-by-step	4-2.1
	“see all steps... see the order to go”		
	“recognize where I had gone wrong” “check where I’m wrong”	Checking mistakes	4-2.3
What challenges did you have in using CSA modules to learn dynamics?	“break down...put them in as a whole”	Analysis and synthesis	4-2.4
	“scrollbars...get stuck and...wouldn’t be able to move”	GUI	1-1.1
	“...go really slow”		
What challenges did you have in using CSA modules to learn dynamics?	“steps in-between...hard to follow”	Hints, tips and reviews	2-3
	“didn’t know where it was derived from”		
	“fit in my screen” “in Canvas it is hard to see”	Access/viewing CSA on canvas	1-3.2

Two coders were engaged in the coding tasks. The two coders coded the first ten interview transcriptions separately. By comparing their codes, it was found that the average inter-rater reliability rate was only 48.6% (see Table 3.4). Then, the coding table was updated according to the two coders' suggestions. Through the coding practice, the coders shared more understanding about the framework and definitions of codes. They re-coded the 10 transcriptions separately using the updated coding table, and achieved average inter-rater reliability rate of 60.3%.

Table 3.4

Inter-rater Reliability Rates of Coding Interview Data

Interview File No.	Time 1	Time 2	Final Polling
1	34.9%	52.4%	85.4%
2	46.7%	60.9%	82.9%
3	56.8%	64.1%	81.0%
4	57.4%	66.0%	88.5%
5	46.3%	55.6%	91.4%
6	37.8%	48.6%	85.3%
7	46.2%	58.1%	92.3%
8	63.6%	71.8%	94.7%
9	55.7%	67.5%	88.9%
10	40.4%	57.5%	86.0%
Mean	48.6%	60.3%	87.6%

Next, the coders and the researcher conferred to identify reasons for disagreements. Some reasons were identified and then the coding table was updated again. Considering the constraints of limited time and limited budget for the project, a polling method was used to speed up the coding process. The two coders polled the disagreements with "Yes" and "No." After that, they achieved the average inter-rater reliability of 87.6%. For a polling result, if the two coders agreed it, it was included in the

final code; while if either or both of the two coders disagreed it, it was excluded in the final code. The polling process and an example of poll results are shown in Table 3.5. Moreover, one of coders was selected to code the remaining half of the interview transcriptions.

- Charting

The coded segments of the transcribed data were arranged into categories that were presented in tables of the themes. The data were shifted from their original textual context and illustrated in tables. The percentage distribution of the categories within one problem is calculated. Percentage distribution referred to the ratio of the number of students in a category to the total number of interview students. An example of percentage distribution of the categories is shown in Table 3.6.

- Interpretation

Consequently, in-depth analyses of the students' responses to the developed categories were carried out. The quantitative results from both measures were synthesized. Furthermore, the qualitative results served as supporting evidence and were triangulated with the quantitative results from pretests and posttests to provide more in-depth discussions.

Table 3.5

Polling Process and Example of Poll Results

Response	Agree	Disagree	Polling for Disagree		Final Code
			Coder 1	Coder 2	
<p>“But the more you do, the more examples you try to work through, the more you increase your understanding of dynamics. But then in connection with the animation and the step by step breaking down of the equations that helps to work other examples because you can take other examples that aren’t broken down and put them into kinda the same scenario and break em down, so, so the modules were very important to, to figure that breakdown out, um and it was more stuff to work. And the more you do it the better you get at it.”</p>	4-3				4-3
	4-4	<i>1-2.1</i>	Yes	Yes	4-4
	4-2.1				4-2.1
					1-2.1
<p>“Well, the graphics from module 8 and module 11. They were both um, it was easy to see the acceleration a little bit more, the velocity, and the end velocity. So it helped to kind of grasp without even having to do the math how it should end and so it was nice kind of giving a visual representation before you had to go and do the math behind it.”</p>	1-2.2				1-2.2
	4-1.2	<i>4-5.3</i>	No	Yes	4-1.2

Table 3.6

Example of Percentage Distribution of Categories

Interview Question	Code	Category	Percentage (Number)
Characteristics of CSA modules students learn the most from	2-1.1	Complexity	100% (20)
	4-1	New concepts involved	85% (17)
	1-2	Visualization/animation	35% (7)
Increase conceptual understanding for learning particle dynamics	4-1.2	Variables and relationships	45% (9)
	4-1.1	Visualization/animation	35% (7)
	4-1.3	Connections	30% (6)
Increase procedural skills for learning particle dynamics	4-2.1	Step-by-step process	90% (18)
	4-2.2	Identifying errors	15% (3)
	4-2.3	Analysis-synthesis process	25% (5)

CHAPTER 4
PRETEST AND POSTTEST RESULTS AND ANALYSIS (PART I)
STUDENTS' OVERALL CONCEPTUAL UNDERSTANDING
AND OVERALL PROCEDURAL SKILLS

This chapter presents, analyzes, and discusses the pretest /posttest results on students' overall conceptual understanding and overall procedural skills across all the CSA modules. In Section 4.1, a detailed comparison of overall conceptual /procedural learning gains of the comparison and intervention group is presented. The overall relationship between conceptual learning gains and procedural learning gains in the intervention group is shown in Section 4.2. This is followed by a comparison of conceptual /procedural learning gains of student performance subgroups in the two groups in Section 4.3.

The quantitative pre-post data collected were analyzed using the SPSS version 22. Descriptive statistics and inferential statistics were used to analyze the data. Parametric (t-test, ANOVA and ANCOVA) and non-parametric (Mann-Whitney U test) statistical tests were used to determine whether there were significant differences of learning gains between the comparison group and the intervention group. ANCOVA using pre-test scores as a covariate to statistically control the initial group differences was used to show any changes after the intervention. The Cohen's *d* effect sizes were calculated to obtain the magnitude of the mean gain difference between the two groups.

4.1 Overall Conceptual /Procedural Learning Gains by Groups

To assess the effects of CSA intervention, scores of conceptual pretests and posttests, and scores of procedural pretests and posttests were examined for the comparison group and the intervention group. The conceptual pretests and posttests

consisted of 13 multiple-choice questions while the procedural pretests and posttests consisted of 57 multiple-choice questions. Example questions have been described in Chapter 3 (page 51-52). Figure 4.1 presents the class-average normalized learning gains of conceptual understanding (CU) and procedural skills (PS) of the two groups.

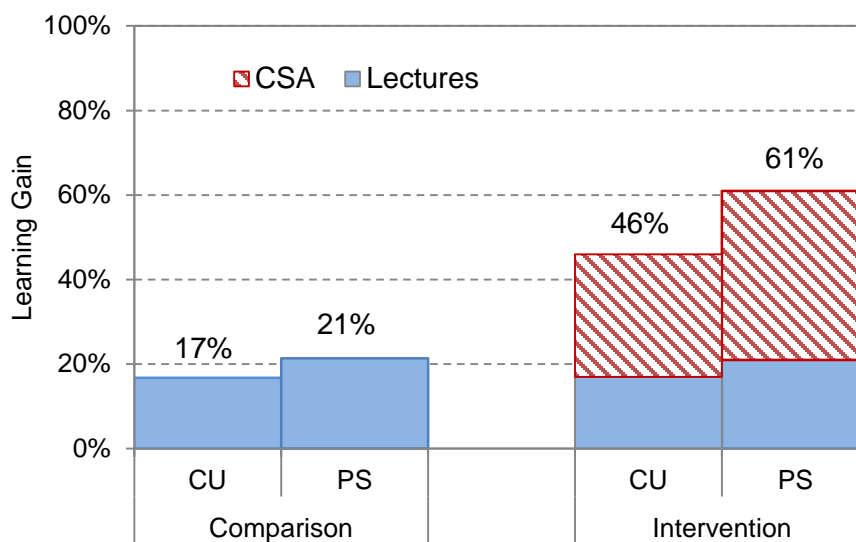


Figure 4.1 Normalized Class-average Learning Gains in CU and PS in the Two Groups

The average conceptual/ procedural learning gain was calculated by taking the average of class-size leaning gains for all conceptual/ procedural questions. In Figure 4.1, we assumed that the average conceptual/procedural learning gain was the same for both the comparison group and the intervention group. The class-average conceptual and procedural learning gains for the comparison group were 17% and 21%, respectively. The learning gains were produced by the traditional lecture-based instruction. The overall class-average conceptual and procedural learning gains for the intervention group were 46% and 61%, respectively. The learning gains were made by the lecture-based approach

(bottom solid box in Figure 4.1) and the CSA approach (top striped box in Figure 4.1). Compared to the comparison group, the extents of conceptual and procedural learning gains made by the CSA method were 29% and 40% on average in the intervention group.

When it came to the two types of learning gains in the intervention group, the CSA method produced a greater learning gain in procedural skills. One reason may be that concepts and procedures were presented in different ways in the CSA modules. Specifically, conceptual knowledge was implicitly demonstrated as a whole and procedural knowledge was explicitly shown step by step. Therefore, conceptual learning required a larger amount of cognitive load to process than procedural learning did, and thus made conceptual understanding more complex. Another possible reason is that students focused on executing action sequences to solve problems rather than understanding the causal relations between variables and outcomes. The primary purpose of student learning might be to get correct answers rather than to obtain real understanding (AAAS, 1989).

In terms of learning gains from the two sources in the intervention group, the CSA method produced greater gains than the traditional classroom method did. However, it does not necessarily mean that the CSA method was more effective, because student learning was increased in the CSA environment on the basis of achievements from classroom instruction. So, it is unreasonable to compare the two quantities directly. Another possible factor is that the two instruction approaches provided different contextual dimensions to students. In the traditional classroom approach, students might need to engage themselves in the “far transfer” due to contextual dimensions with a high degree of difference across lecture materials to pretest/posttest evaluation. Far transfer is

defined as “little overlap between situations, original and transfer settings are dissimilar” (Schunk, 2004). Far transfer is highly challenging especially for student novices. In contrast, contextual dimensions from CSA learning materials to pretest/posttest assessment are similar. It was easier and more natural for students to apply what they learned from CSA modules to assessment tasks.

The conceptual pretest and posttest scores, normalized average learning gains, and standard deviations of both groups are shown in Table 4.1. To determine what statistical techniques to use, normality tests were conducted to see whether the conceptual data were normally distributed. Since the p values of the Shapiro-Wilk test were larger than 0.05, the data sets were normally distributed. A t-test was performed to compare the two groups. The results of t-test reveal that the two groups were not statistically significantly different on pretest scores, $t(13) = 0.126, p = 0.900$. This means that the students in the two groups were comparable. The results also show that the two groups were statistically significantly different on conceptual learning gains, $t(13) = -4.018, p = 0.001$. Moreover, with a Cohen's d effect size of 1.55, it indicates that 72% of the two groups were non-overlapping. The above results imply that the developed CSA modules significantly improved students' conceptual understanding for solving dynamic problems, and also suggest a high practical significance.

Table 4.1

Mean Scores of Conceptual Assessment Questions

Group	N	Pretest		Posttest		Gain	
		Mean	SD	Mean	SD	Mean	SD
Comparison	13	0.42	0.24	0.50	0.25	0.17	0.16
Intervention	13	0.41	0.22	0.66	0.20	0.46	0.21

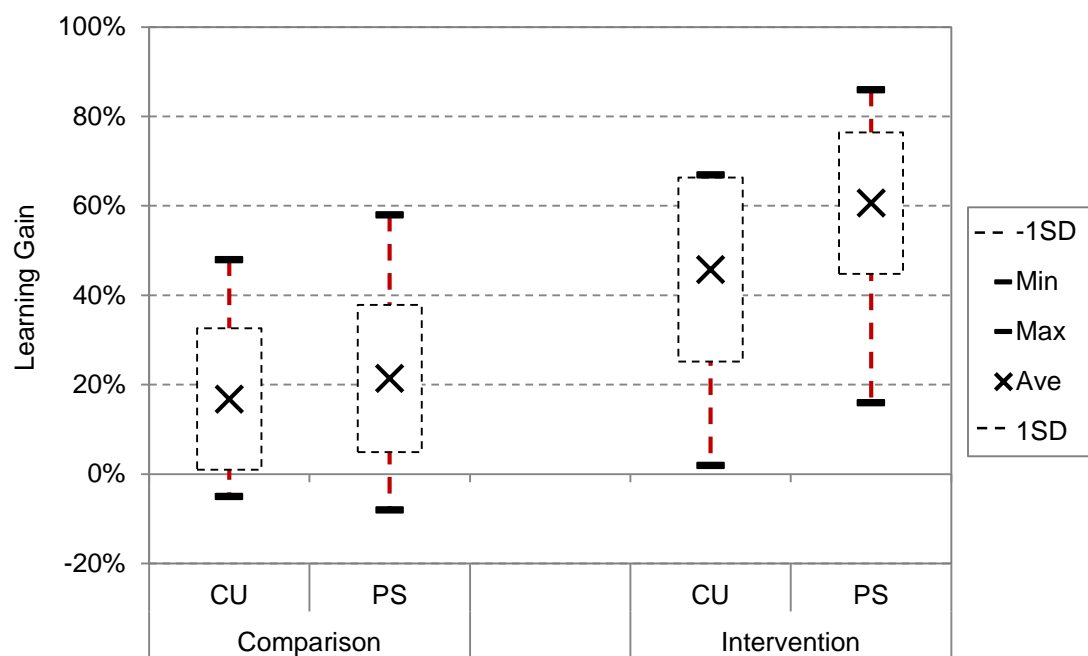
N = Number of Assessment Questions.

Table 4.2

Mean Scores of Procedural Assessment Questions

Group	N	Pretest		Posttest		Gain	
		Mean	SD	Mean	SD	Mean	SD
Comparison	57	0.39	0.20	0.51	0.21	0.21	0.16
Intervention	57	0.38	0.16	0.74	0.15	0.61	0.16

The procedural pretest and posttest scores, normalized average learning gains, and standard deviations for both groups are shown in Table 4.2. The p values of the Shapiro-Wilk test were larger than 0.05, so the procedural data sets were normally distributed. A t-test was also conducted to compare the two groups. The results of t-test reveal the students in the two groups were comparable, $t(57) = 0.542$, $p = 0.559$. The results also show that the groups were statistically significantly different on procedural learning gains, $t(57) = -12.980$, $p < 0.001$. Its Cohen's d effect size of 2.50 indicates that there was a non-overlap of over 80% in the two distributions. The above results imply that the developed CSA modules also significantly improved students' procedural skills for solving dynamic problems, and also suggest a high practical significance.



Note: SD = Standard Deviation; Min = Minimum; Max = Maximum; Ave = Average.

Figure 4.2 Distribution of Class-size Learning Gains in CU and PS in the Two Groups

Figure 4.2 shows the distributions of class-size learning gains in conceptual understanding and procedural skills of the two groups, including mean, standard deviation, minimum and maximum values. The distributions present the following characteristics:

- 1) A large difference of standard deviations in conceptual learning gain exists between the comparison group ($SD = 0.32$) and the intervention group ($SD = 0.41$). The conceptual data set of the intervention group with a higher standard deviation had data spread out over a larger range of values. The standard deviations in procedural learning gain between groups ($SD = 0.33$; 0.31) were close in value, showing that the degree of spread in the two procedural data sets

resembled one another. The results indicate that the CSA approach had different effects in improving students' different levels of conceptual understanding.

- 2) The comparison group had a large number of data in lower values and a few in upper values. Conversely, the intervention group had a huge amount of data in upper values and a few in lower values. The results show the learning gains of complex and moderate questions were crowded in the comparison group, and the learning gains of moderate and simple questions were clustered in the intervention group. The distributions of the two groups imply two different levels of learning ability. The intervention group had a relatively higher level.

Table 4.3 shows the effect sizes of the CSA approach and the standard deviations of learning gains in the intervention at different levels. All the assessment questions were divided into three levels according to students' class-size pretest scores: the simple level with 23 questions, the moderate level with 24 questions, and the high level with 23 questions. Effect size is the magnitude of the difference between groups. It was computed using the means and standard deviations of learning gains of the two groups.

The descriptive statistics show that the effect size measures of different conceptual levels were close ($ES_{\text{simple}} = 1.75$; $ES_{\text{moderate}} = 1.37$; $ES_{\text{complex}} = 1.59$). The statistics show that the moderate level of procedural questions had a greatest effect size measure ($ES_{\text{moderate}} = 3.75 > ES_{\text{complex}} = 2.13$; $ES_{\text{simple}} = 2.70$). The results reflect that the CSA instruction had similar effects on increasing students' different levels of conceptual understanding, and was far more effective in increasing students' moderate level of procedural skills. Moreover, the effect sizes of procedural assessment were larger those of conceptual assessment. This implies that the CSA approach was more successful

in improving students' procedural skills than students' conceptual understanding, at every level.

The statistics (see Table 4.3) show a larger standard deviation of conceptual learning gain at moderate and complex level ($SD_{\text{moderate}} = 0.23$; $SD_{\text{complex}} = 0.25 > SD_{\text{simple}} = 0.10$), and a larger standard deviation of procedural learning gain at complex level ($SD_{\text{complex}} = 0.16 > SD_{\text{moderate}} = 0.12$; $SD_{\text{simple}} = 0.10$). High standard deviations of learning gain reflect variation in the effectiveness of CSA modules. The moderate and complex level of conceptual problems, and the complex level of procedural problems can be considered as measuring high-level learning skills. Therefore, high variability in learning gain of these problems implies that the CSA instruction had a limited educational value in increasing students' high-order learning skills.

Table 4.3

Descriptive Statistics of Learning Gains of CSA Approach at Different Levels

Level	Effect Size		Standard Deviation	
	CU	PS	CU	PS
Simple	1.75	2.70	0.10	0.10
Moderate	1.37	3.75	0.23	0.12
Complex	1.59	2.13	0.25	0.16

4.2 Overall Relationship Between Conceptual and Procedural Learning Gains in the Intervention Group

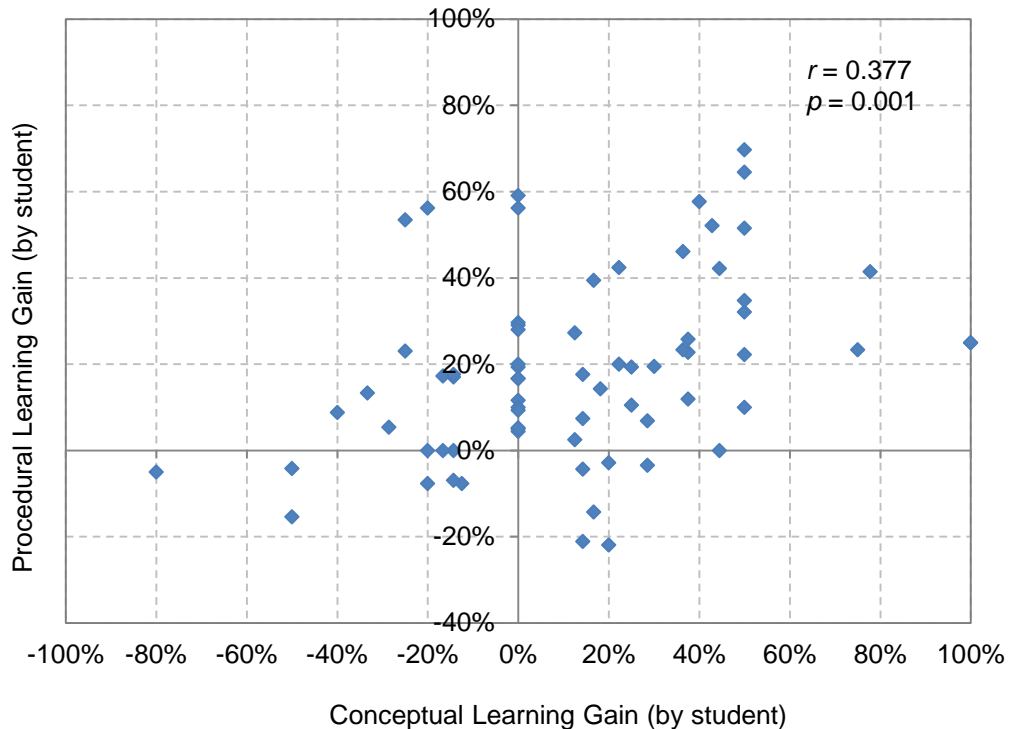


Figure 4.3 Correlation of Learning Gains in CU and PS by Individual Student in the Comparison Group

Figure 4.3 shows the correlation of conceptual and procedural learning gains by individual student in the comparison group. Each dot in Figure 4.3 represents a student. The correlation coefficient for this relation was $r = 0.377$, and the correlation was statistically significant at the $p < 0.01$ level. There was a positive correlation between the two types of learning gains, but their relationship was weak ($r < 0.4$). It was found that the scatter plot seems to show a fairly random pattern, indicating that students' conceptual and procedural knowledge was lacking in connections at this level of learning.

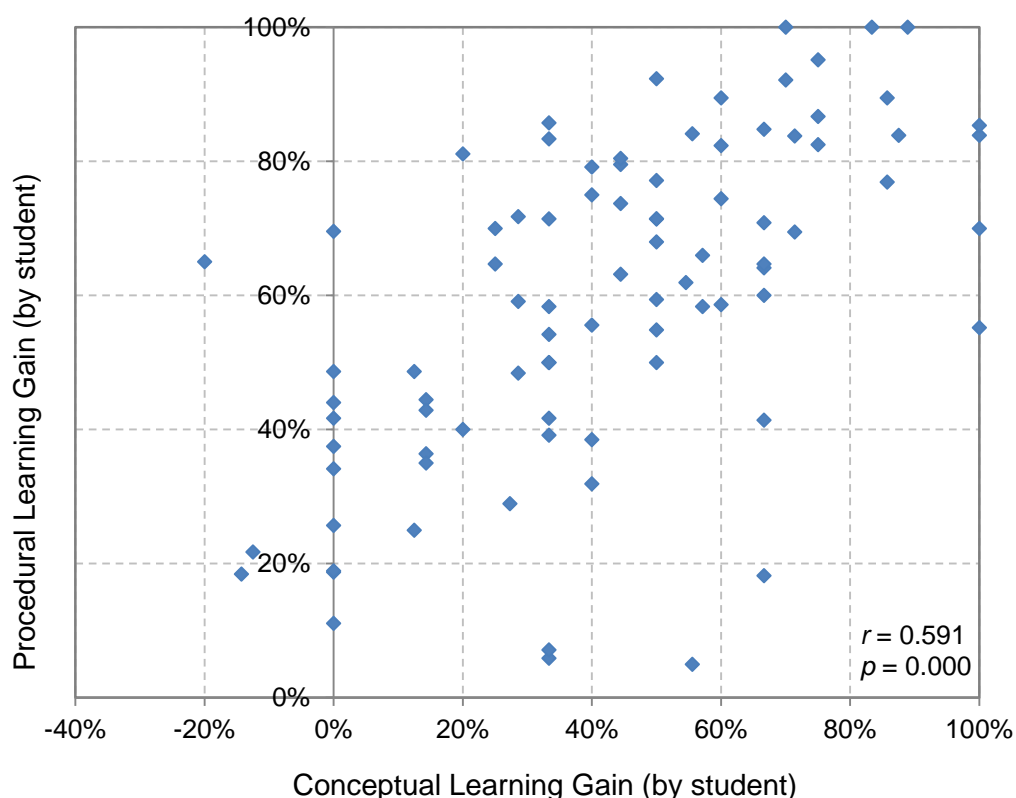


Figure 4.4 Correlation of Learning Gains in CU and PS by Individual Student in the Intervention Group

Figure 4.4 shows the correlation of conceptual and procedural learning gain by individual student in the intervention group. The correlation coefficient for this relation was $r = 0.591$, and the correlation was statistically significant at the $p < 0.01$ level. This correlation represents a moderately strong positive relationship between the two variables ($0.4 \leq r < 0.7$). The two types of learning gain appear to be a trend: as conceptual learning gains increase, corresponding procedural learning gains increase. The results indicate that students' two types of skills had a stronger connection after receiving the CSA instruction.

This correlation indicates that the variations in the two types of learning gain of different students were the results of many factors. The relationship between the

improvements in conceptual understanding and procedural skills is complicated. It may be affected by many factors, including student knowledge bases, abilities, attitudes, course workloads, and so on. Considering so many influencing factors, the correlation of 0.591 represents a fairly strong relationship in the context of education research. To have a detailed understanding of this relationship, the conceptual and procedural learning gains were divided into different levels for further analysis.

Student participants were divided into groups according to their levels of procedural learning gains by every 20 percent of the entire range (0% -100%), which were labeled as levels PS1, PS2, PS3, PS4, and PS5. Note that levels PS1 and PS2 were put together and analyzed as a whole, since they had similar distribution characteristics. The average conceptual learning gain for each level was calculated, as shown in Figure 4.5, and shows an obvious increasing trend: a higher level of procedural improvement is associated with a greater average conceptual learning gain. For example, the average conceptual learning gain in level PS4 was 47%, and it increased to 68% in level PS5.

Since the data of each level was normally distributed, an ANOVA analysis was performed to investigate whether there were significantly different on conceptual learning gains among different levels. The overall analysis was significant, $F(3, 86) = 15.806$, $p < .001$. The post-hoc test results (see Table 4.4) show that there were statistically significant differences between the means of different levels, except levels PS3 and PS4. But note that the two levels had a marginally significant p -value of 0.059. Due to small sample size for each level, its average value was particularly vulnerable to exceptional extreme values. This marginally significant p -value was considered to be significant in this context. In general, the comparison results indicate that there were significant

differences between different procedural levels in conceptual learning gains. The results suggest that the development trend of conceptual understanding is this: as procedural skills increase, conceptual understanding increases. This developmental process should be gradual, incremental, and level-by-level.

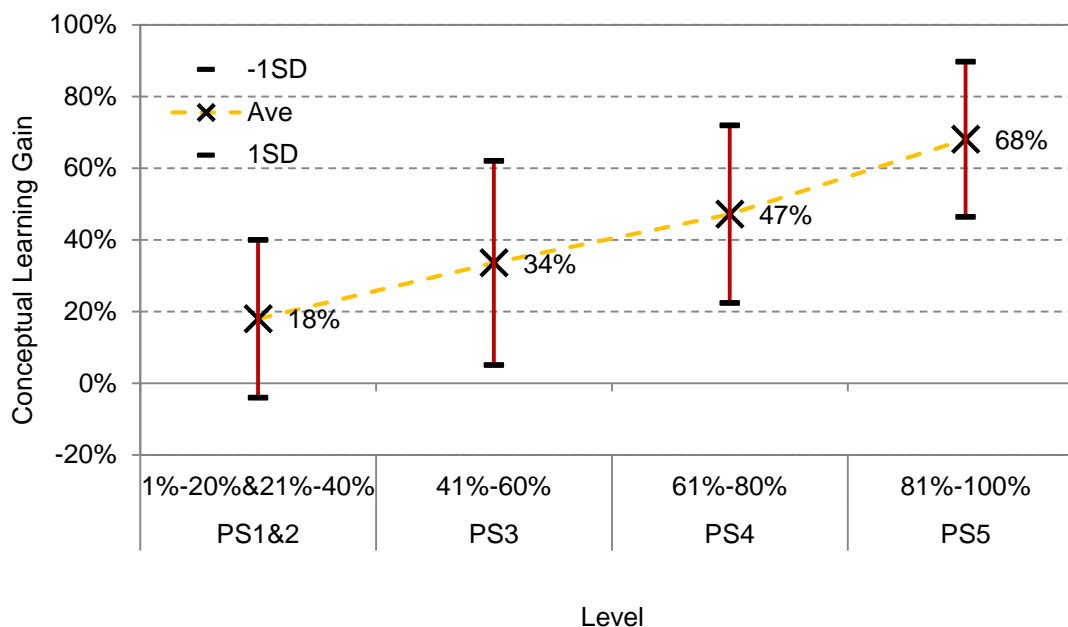


Figure 4.5 Average Learning Gain in Conceptual Understanding by Level in the Intervention Group

Table 4.4

Post Hoc Tests of Average Conceptual Learning Gains by Level

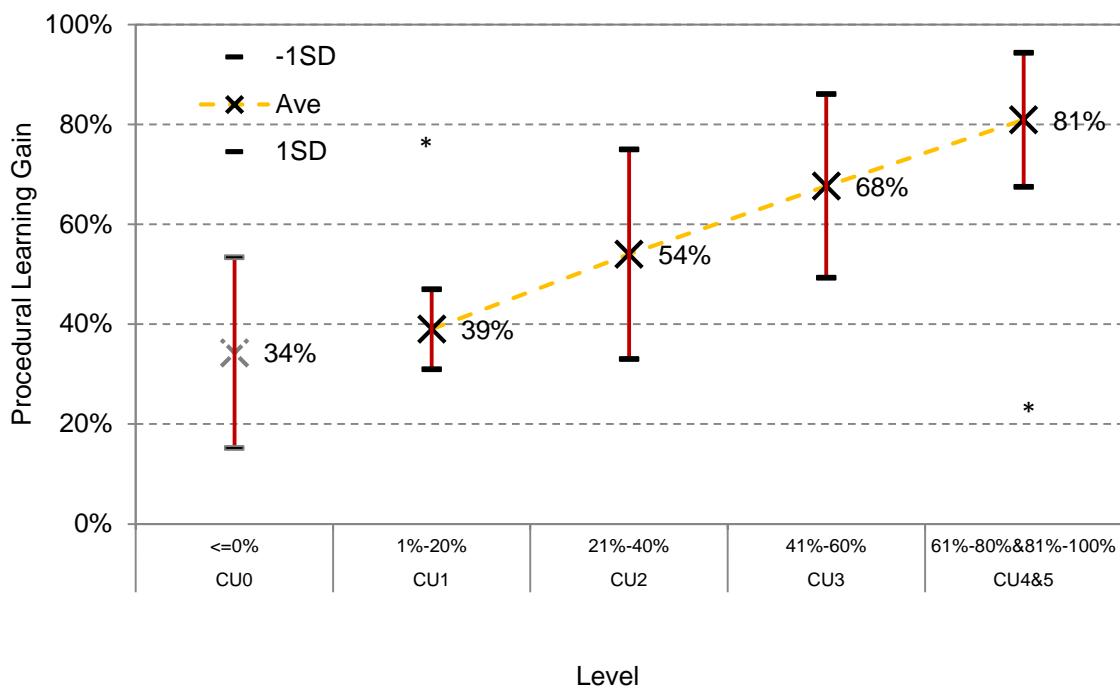
Level		<i>p</i> -value
PS1&2	vs. PS3	0.036
	vs. PS4	0.000
	vs. PS5	0.000
PS3	vs. PS4	0.059*
	vs. PS5	0.000
PS4	vs. PS5	0.006

Note: * Marginally significant

Next, the development of procedural skills with increases in conceptual understanding was examined. Student participants were divided into groups according to their levels of conceptual learning gains by every 20 percent of the whole range (negative to 100%), which were labeled as levels CU0, CU1, CU2, CU3, CU4, and CU5. Due to similar distribution characteristics in the levels CU 4 and CU5, they were put together and analyzed as a whole. Moreover, this analysis only focused on positive levels, so level CU0 was removed. The two outliers in levels CU1 and CU4&5 were excluded from this analysis, as they were far from the middle of the corresponding distribution with extreme values. These outliers were identified by SPSS boxplots. The average procedural learning gain for each level was calculated, as shown in Figure 4.6. The figure illustrates an obvious growing trend: a higher level of conceptual improvement is related to a greater average procedural learning gain. For example, the average procedural learning gain in level CU2 was 52%, and it increased to 68% in level CU3.

The data sets for different levels were tested, and they all followed a normal distribution. An ANOVA analysis was used to determine whether there were any significant differences between the means of procedural learning gains across different levels. The overall analysis was significant, $F(3, 67) = 14.552, p < .001$. The post-hoc tests results (see Table 4.5) reveal that there were significant differences between levels, except levels CU1 and CU2. The two levels had a marginally significant p -value of 0.053. For the same reason mentioned above, this marginally significant p -value was also considered to be significant in this context. Generally, the comparison results suggest that there were significant differences across different conceptual levels in procedural learning gains. The results suggest that the development trend of procedural skills is this:

as conceptual understanding increases, procedural skills increase. This developmental process should be gradual, incremental, and step-by-step.



Note: Two outliers are denoted by “*” and were excluded in the analysis. CU = Conceptual Understanding; PS = Procedural Skills; Ave = Average Value; SD = Standard Deviation.

Figure 4.6 Average Learning Gain in Procedural Skills by Level in the Intervention Group

Table 4.5

Post Hoc Tests of Average Procedural Learning Gains by Level

Level		<i>p</i> -value
CU1	vs. CU2	0.053*
	vs. CU3	0.000
	vs. CU4	0.000
CU2	vs. CU3	0.010
	vs. CU4	0.000
CU3	vs. CU4	0.015

* Marginally significant

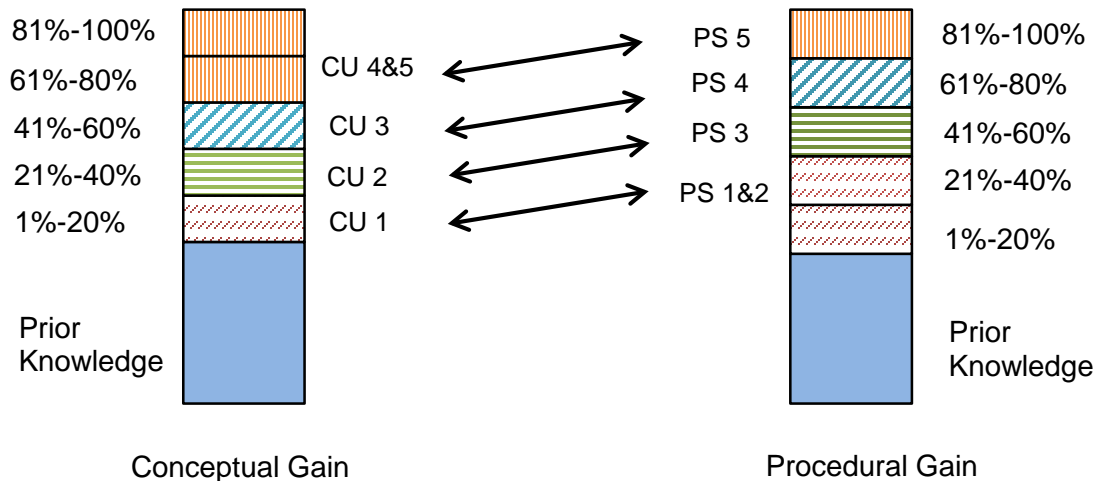


Figure 4.7 Relations of Conceptual and Procedural Learning Gains in the Intervention Group

Synthesizing the above results, the relationships of developing conceptual understanding and procedural skills through the CSA learning environment is reflected in Figure 4.7. Their relationships are presented as follows:

1. A level of conceptual learning gain was always associated with a higher level of procedural learning gain. The two types of learning gains were divided into four levels, respectively. For example, students at the second level of conceptual learning gain obtained the third level of procedural learning gain. Students often acquired a larger amount of procedural knowledge than conceptual knowledge. This might be because students paid more attentions on developing their procedures than concepts in the CSA learning environment.
2. Students developed their conceptual understanding and procedural skills in a gradual, incremental and level-by-level process. Neither type of ability was fully developed at the beginning. The two types of skills were developed iteratively,

that is, increases in one type of skills led to increases in the other type of skill. This finding is consistent with the findings from previous studies (e.g., Rittle-Johnson and Alibali, 1999).

3. The development processes between conceptual understanding and procedural skills were bi-directional and connected. Improved conceptual understanding can lead to improved procedural skills and vice versa. Only by mastering some amount of conceptual and procedural knowledge at a level and then connecting the types of knowledge, students were able to acquire new knowledge at a higher level. At the end of the study, students were more likely to grasp the two types of knowledge and build a cohesive and integrated knowledge structuring.
4. Students might begin to develop their procedural skills first. When developing a certain amount of procedural knowledge, students began to develop their conceptual knowledge as well. In Figure 4.6, level CU0 (the level with zero or negative conceptual learning gains) had an average procedural learning gain of 34%. This reflects that students have developed their procedural skills to some extent when they had not begun to increase their conceptual understanding during the CSA environment. Therefore, acquisition of procedural knowledge might precede that of conceptual knowledge at the beginning of learning.
5. Students might fully develop their procedural skills first. When fully developing their procedural skills, students were more likely to choose to end their CSA learning immediately, although their conceptual understanding still needed to increase. In Figure 4.5, level PS5 (the level with highest procedural learning gain) had an average conceptual learning gain of only 68%. It implies that

students were less likely to continue to improve their conceptual understanding after they had obtained the highest level of procedural skills.

4.3 Overall Conceptual /Procedural Learning Gains by Student Performance Subgroup

The effects of the CSA modules on different performance subgroups are investigated in this section. Students were divided into a low-performing subgroup and a high-performing subgroup on the basis of their pretest scores. The learning gains in conceptual understanding and procedural skills of different performance subgroups were analyzed to determine whether low-performing students differed significantly from high-performing ones.

Table 4.6

Average Learning Gains in Conceptual Understanding by Student Performance

Group	Subgroup	Pretest		Posttest		Gain	
		Mean	SD	Mean	SD	Mean	SD
Comparison	Low-performing	0.39	0.13	0.48	0.19	0.14	0.34
	High-performing	0.49	0.16	0.56	0.21	0.12	0.33
Intervention	Low-performing	0.35	0.12	0.59	0.19	0.35	0.31
	High-performing	0.47	0.15	0.74	0.13	0.48	0.27

Table 4.6 shows the average conceptual learning gains of the low-performing and high-performing subgroups in the comparison and the intervention groups. Four data sets were tested, and they all followed a normal distribution. A correlation analysis was conducted to examine whether the variable of “pretest score” had an influence on the outcome of “learning gain.” The correlation was significant, $r(161) = -0.211, p = 0.007$,

indicating that a correlation appeared to exist between learning gain and pretest score in conceptual understanding. Therefore, the variable of “pretest score” should be included as a covariate so as to remove its influence on learning gain.

An ANCOVA was conducted on conceptual learning gain to determine whether there was a difference between high-performing and low-performing subgroups. The ANCOVA results show that the CSA intervention was highly statistically significant ($F = 32.842, p < 0.001$), and students’ initial performance was also statistically significant ($F = 5.398, p = 0.02$). The results also show that the covariate (CSA intervention* student performance) did not interact ($F = 2.934, p = 0.09$). The estimated marginal average learning gains of conceptual understanding in different subgroups are showed in Figure 4.8. The results confirm the finding that the CSA modules improved students’ conceptual understanding. More importantly, the results imply that students in the high-performing subgroup benefited more from the CSA intervention in learning concepts than those in the low-performing subgroup.

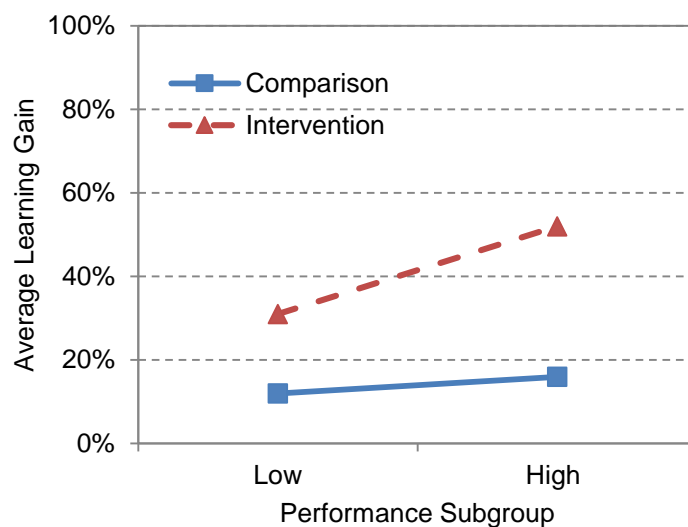


Figure 4.8 Estimated Average Learning Gains in Conceptual Understanding in Different Subgroups

Table 4.7 shows the average procedural learning gain of the high-performing and low-performing subgroups in the comparison and the intervention groups. Four data sets were normally distributed. There was no significant linear correlation between learning gain and pretest score in procedural skills ($p = 0.147$). An ANOVA analysis was performed on procedural learning gain to determine whether there was a difference between high-performing and low-performing subgroups. The statistics show that students' initial performance was statistically significant ($F = 9.309$, $p = 0.003$), and the CSA intervention was highly statistically significant ($F = 109.305$, $p < 0.001$). The statistics also show no interaction between CSA intervention and student performance ($p = 0.541$). The estimated average learning gains of procedural skills in different subgroups are illustrated in Figure 4.9. The results suggest that the CSA intervention improved students' procedural skills, and that students in the high-performing subgroup benefited more from the CSA intervention in learning procedures than those in the low-performing subgroup.

Table 4.7

Average Learning Gains in Procedural Skills by Student Performance

Group	Subgroup	Pretest		Posttest		Gain	
		Mean	SD	Mean	SD	Mean	SD
Comparison	Low-performing	0.28	0.07	0.39	0.15	0.15	0.19
	High-performing	0.52	0.09	0.63	0.14	0.24	0.26
Intervention	Low-performing	0.25	0.06	0.64	0.20	0.52	0.27
	High-performing	0.52	0.13	0.84	0.11	0.66	0.20

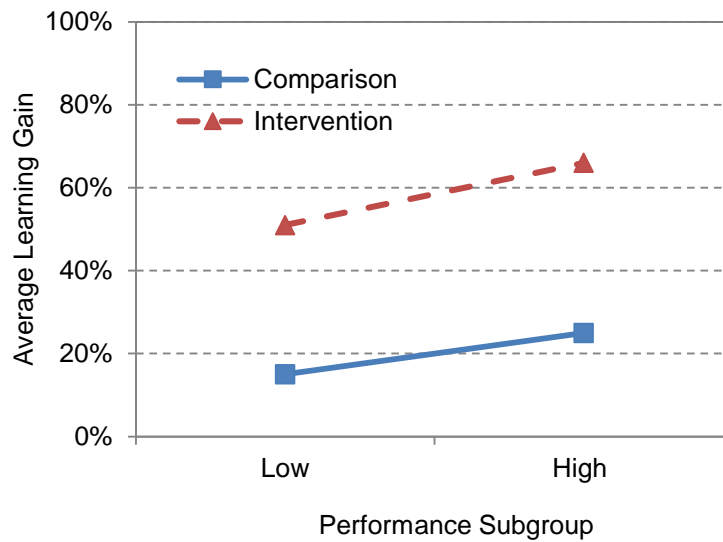


Figure 4.9 Estimated Average Learning Gains in Procedural Skills in Different Subgroups

Students in the high-performing subgroup benefited more from the CSA learning than the ones in the low-performing subgroup. Many factors may have contributed to the performance differences. The following paragraphs describe two factors that may be of special importance for CSA learning.

1. Students' different usage patterns. The developed CSA modules provided multiple features and representations of GUIs that helped learners reach multiple goals in the learning environment. Effective learning strategies must integrate features of a CSA module to maximize their pedagogical value. This way often required a large cognitive capacity for low-performing students to process information. Thus, low-performing learners tended to use features separately in the CSA environment. This way required less memory capacity, however, it was less effective in promoting students' learning. In contrast, high-performing students were more likely to choose the effective way to learn. They were able to

identify essential and non-essential contents, thereby processing information effectively by reducing unnecessary cognitive burden on their working memories. Therefore, high-performers gained more learning than low-performers, through the use of a more effective way of learning.

2. Students' different prior knowledge bases. To learn effectively, students need to activate their prior knowledge and integrate new material into their existing knowledge. Prior knowledge about the content is one of the strongest indicators of how well students will learn new information relative to the content (Bloom, 1976). One of the most obvious differences between students in the two subgroups was their prior knowledge bases. Low-performing students often had deficient background knowledge, and therefore struggled to access and process new learning steps and contents. Especially in some CSA modules with complex problem-solving procedures and difficult concepts, it was more challenging for students who lacked background knowledge to understand. Thus, they were less likely to be engaged in learning. Students' poor academic background contributed to their low performances in the CSA learning.

Therefore, the CSA method could be more efficient for low-performing students, if it provided clearer user-orientated designs to help students easily connect multiple features and provided more explicit instructions to help students integrate new knowledge with prior knowledge.

CHAPTER 5
PRETEST AND POSTTEST RESULTS AND ANALYSIS (PART II):
STUDENTS' CONCEPTUAL UNDERSTANDING AND
PROCEDURAL SKILLS BY CSA MODULE

This chapter presents, analyzes, and discusses the pretest /posttest results of students' conceptual understanding and procedural skills by individual CSA module. In Section 5.1, conceptual learning gain and procedural learning gain by CSA module are presented. This is followed by a detailed description of the two types of learning gains in the intervention group by CSA module, shown in Section 5.2. Finally, a summary of the characteristics of conceptual and procedural learning gains in the intervention group is presented in Section 5.3.

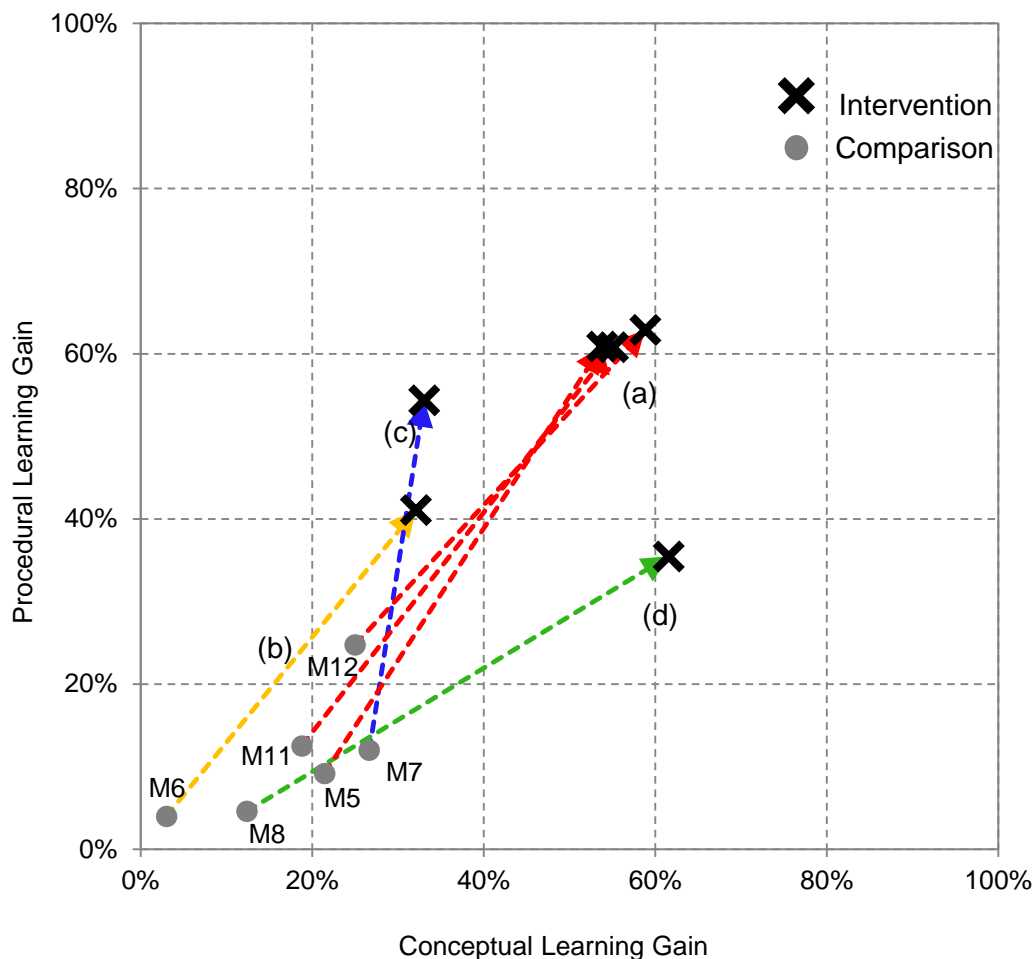
This study had a total of 12 CSA modules, and each module presented one learning topic in particle dynamics. Among all 12 CSA modules, there were six modules in which students' improvements in both conceptual understanding and procedural skills were evaluated. In other modules, only students' procedural skills were measured. This chapter focuses on the above-mentioned six CSA modules, which are:

- Module 5: Relative Motion
- Module 6: Force and Acceleration of 2nd Newton Law
- Module 7: Force and Acceleration of Normal and Tangential Coordinates
- Module 8: Force and Acceleration of Cylindrical Coordinates
- Module 11: Linear Impulse and Momentum
- Module 12: Angular Impulse and Momentum

5.1 Conceptual and Procedural Learning Gains by CSA Module

Figure 5.1 presents the relationship between conceptual learning gain and procedural learning gain by individual CSA module, and the trend towards learning gain from the comparison group to the intervention group. It shows four different increasing trends: (a) Modules 5, 11 and 12; (b) Module 6; (c) Module 7 and (d) Module 8. Modules 5, 11 and 12 had very similar characteristics, thus they were placed together in a group for analysis.

In trends (a) and (b), the two types of skills maintained a relatively balanced development, as there was a small difference between their increasing rates. Procedural skills increased slightly faster than those of conceptual understanding. The trends provide a rough estimate of potential occurrence. When students first fully develop their procedural skills, their conceptual understanding is close to a full potential. In contrast, the two types of skills in trends (c) and (d) appeared developmentally uneven. The growth rate of one skill was significantly faster than that of another skill. The trends suggest that when students have already acquired full competence in one type of skill, they are far from fully acquiring another skill.



Note: Mx denotes a CSA module No., e.g. M5 stands for Module 5.

Figure 5.1 Trend towards Learning Gain from the Comparison Group to the Intervention Group

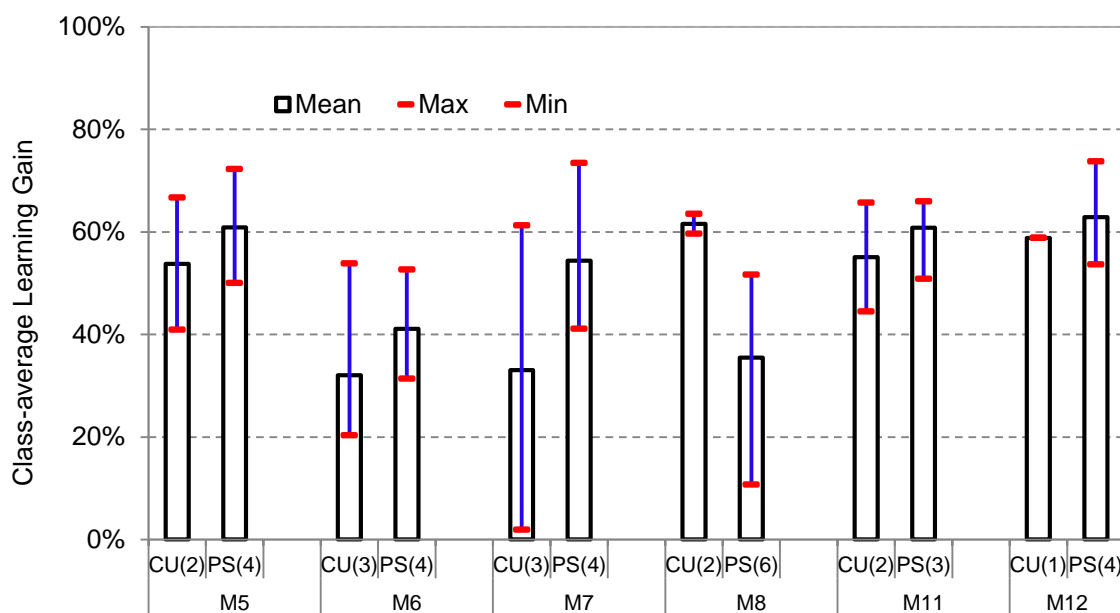
More detailed information about the two types of learning gain in the intervention group is given in Figure 5.2. It shows the class-average conceptual learning gain, class-average procedural learning gain, and their ranges by module. Average conceptual/procedural learning gain was calculated by taking the average of class-size learning gains for all conceptual/procedural questions in a module. For example, in Module 6, its average conceptual learning gain of 32% was the mean of class-size learning gains of

four conceptual questions. The range was computed by taking the difference between the maximum and minimum values of conceptual/procedural learning gains in a module. For example, the range of conceptual learning gains in Module 6 was 34% (the maximum value of 54% minus the minimum value of 20%). Further analysis is provided below.

- *Modules 5, 11 and 12.* Each had a high average conceptual learning gain and a high average procedural learning gain (about 60%). The procedural learning gain was higher than its associated conceptual one, and their difference was small. Moreover, the range of conceptual learning gains was short, and so was the range of procedural learning gains.
- *Module 6.* It had a low average conceptual learning gain and a low average procedural learning gain. Their difference was small. The learning gains among conceptual questions contained a large gap.
- *Module 7.* It had a low average conceptual learning gain and a relatively high average procedural learning gain. Their difference was large. There was a wide range of learning gains among conceptual questions, and among procedural questions as well.
- *Module 8.* It had a low average procedural learning gain and a relatively high average conceptual learning gain. Their difference was large. A huge gap existed in the learning gains among procedural questions.

Among the six CSA modules, the maximum average conceptual learning gain and procedural learning gain reached 62% and 63%, respectively. In summary, a high average learning gain often had a narrow range, indicating a balanced development of knowledge. A balanced increase occurred because the discrete bits of knowledge could be linked as a

connected web. An appropriate connection in conceptual knowledge or procedural knowledge underlying a topic was built. In contrast, a low average learning gain occurred in a wide range, indicating an uneven development of knowledge. The isolated knowledge was enhanced independently, thus inducing a high variance of learning gains. An inappropriate or weak connection existed in conceptual knowledge or procedural knowledge underlying a topic. In addition, when the two types of learning gain in a module are compared, their small difference implies an appropriate and strong link between the two types of skills and their large difference suggests an inappropriate and weak link.



Note: CU(x) means the number of conceptual questions in a CSA module;
PS(x) means the number of procedural questions in a CSA module.

Figure 5.2 Class-average Learning Gains and Range by Module in the Intervention Group

In the following section, the development trend of one type of skill with increases in another type of each module is illustrated. The development trend was examined in order to identify whether the two types of skills in a topic were appropriately linked and

mutually supported. The class-size learning gains of conceptual/ procedural questions are shown by module. The class-size learning gains were calculated and compared to determine whether students built a useful conceptual knowledge structuring or a useful procedural knowledge structuring under a topic, and to identify their main difficulties in learning the topic. Due to similar distribution characteristics in the two types of learning gain of Modules 5, 11 and 12, Module 11 is taken as an example in analysis. Thus, Modules 11, 6, 7 and 8 are discussed in turn in the following.

5.2 Conceptual and Procedural Learning Gains in the Intervention Group by CSA Module

Module 11: Linear Impulse and Momentum



Figure 5.3 Diagram of Technical Problem in Module 11

Module 11 discusses the Principle of Linear Impulse and Momentum. The diagram of its technical problem is shown Figure 5.3. Figure 5.4 (a) shows the development trend of conceptual understanding with increases in procedural skills in Module 11. This trend represents the degrees of procedural skills supporting conceptual understanding. Students were divided into 5 levels according to their procedural learning gains, and then their average conceptual learning gain of each level was calculated. The 5 levels were: PS 0%, PS 33%, PS 50%, PS 67% and PS 100%. Note that this analysis

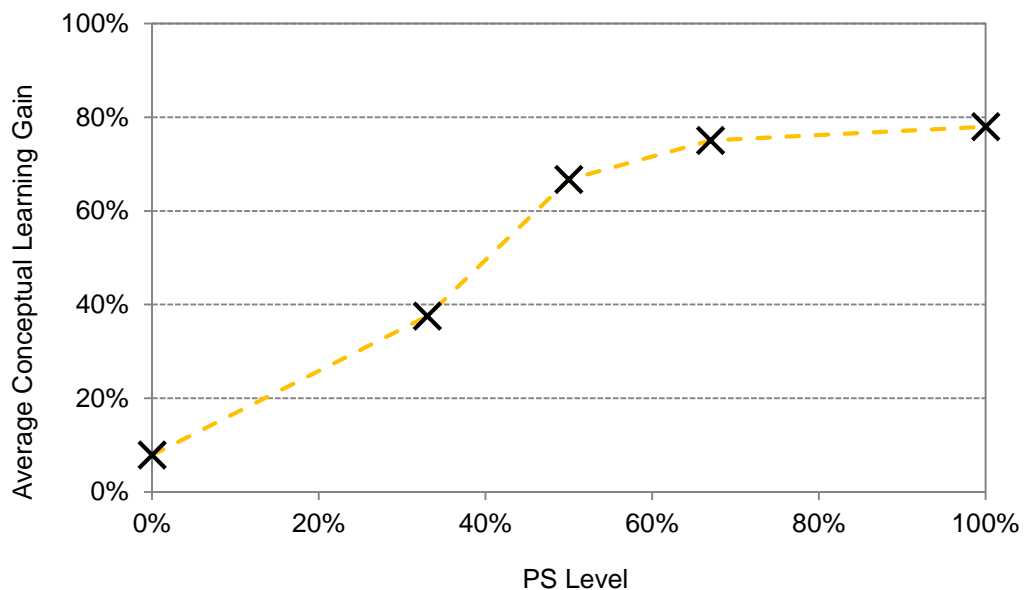
focused on positive levels, thus students with negative procedural leaning gain (that is, $PS < 0\%$) were excluded.

Figure 5.4 (b) shows the development trend of procedural skills with increases in conceptual understanding in Module 11. This trend represents the degrees of conceptual understanding supporting procedural skills. Students were divided into 3 levels according to their conceptual learning gains, and then their average procedural learning gain for each level was calculated. The 3 levels were: CU 0%, 50% and 100%. Similarly, students with negative conceptual leaning gain (that is, $CU < 0\%$) were excluded. This way of categorizing mentioned above was also used in the analysis of Modules 6, 7 and 8.

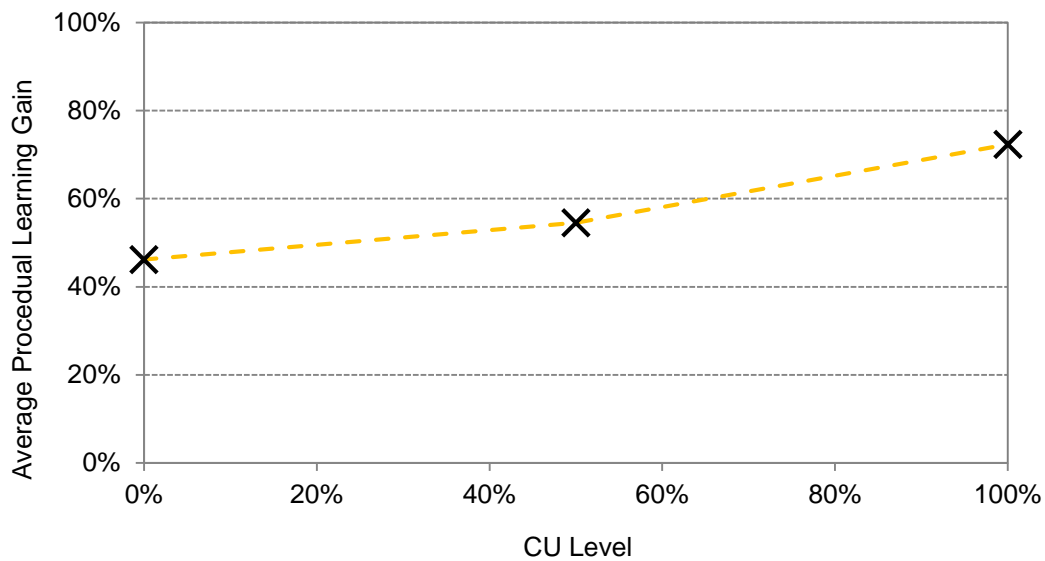
In Figure 5.4, conceptual understanding increases with the improvements in procedural skills, and vice versa. The development of the two types of skills appears to be bi-directional, but not symmetrical. From level PS 0% to level PS 50%, it appears to be a strong link from improved procedural skills to learning gains in conceptual understanding. That means that procedural skills strongly supported conceptual understanding at this phase. Overall, the results indicate that students' two types of skills continuously strengthened each other and built appropriate connections in this CSA intervention module.

Figure 5.5 shows the class-size learning gain of each assessment question in the intervention in Module 11. It includes two parts. The left (green solid) shows the learning gains of conceptual questions, and the right (red slash) shows the learning gains of procedural questions. All the learning gains were relatively close and high in general, ranging from 44% to 66%. The results indicate a balanced development in the two types

of skills. Students were more likely to build a useful conceptual knowledge structure and a useful procedural knowledge structure after completing this CSA learning module.



(a) Average Conceptual Learning Gain



(b) Average Procedural Learning Gain

Figure 5.4 Average Learning Gains in CU and PS by Level in the Intervention Group for Module 11

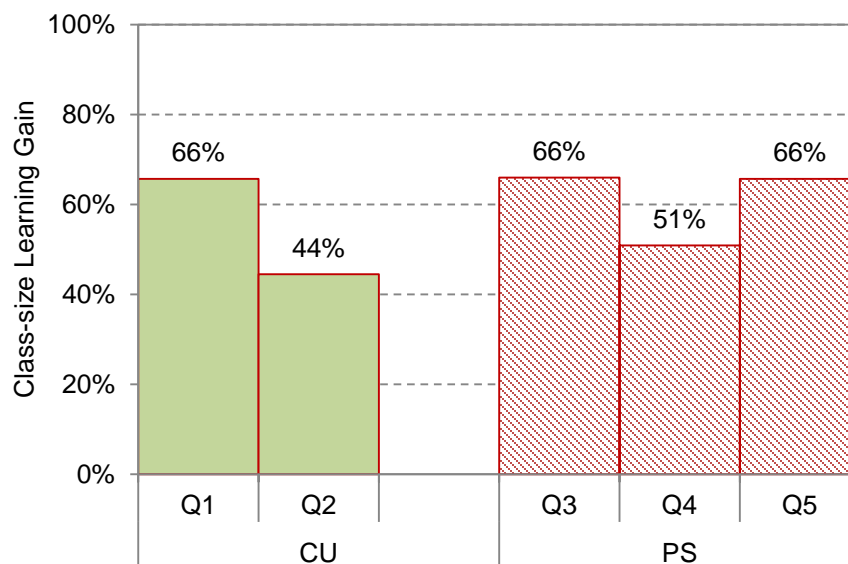


Figure 5.5 Class-size Learning Gains by Assessment Question in the Intervention Group in Module 11

This module addresses a technical problem about two colliding bumper cars (see Figure 5.3). Question 2 and question 3 focused on the understanding and calculation about the coefficient of restitution of two colliding objects, respectively. The coefficient of restitution is an important and difficult concept for students to understand. As shown in Figure 5.4 (a), procedures promote a strong link from improved procedural skills to conceptual learning gains at the first phase. It reflects the process of learning this concept in the CSA learning environment; that is, students tended to comprehend this challenging concept by making sense of the corresponding mathematical equations. Moreover, the learning gain of question 2 (conceptual learning gain) was less than that of question 3 (procedural learning gain). This result further proves that the above-mentioned learning process was from improved procedural skills to improved conceptual understanding. This

learning process suggests that mathematical formulas are important and helpful in understanding concepts of particle dynamics in the CSA modules.

Module 6: Force and Acceleration of 2nd Newton Law

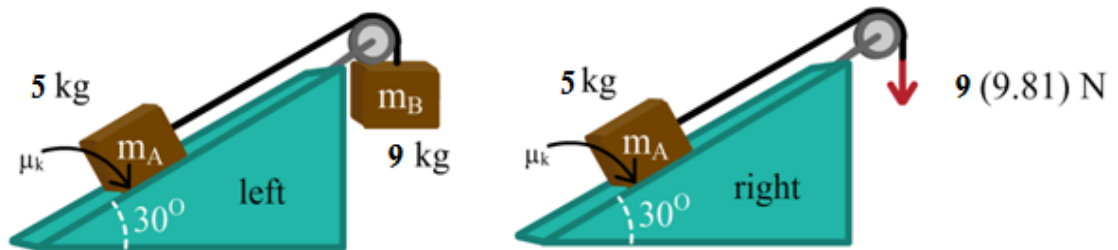
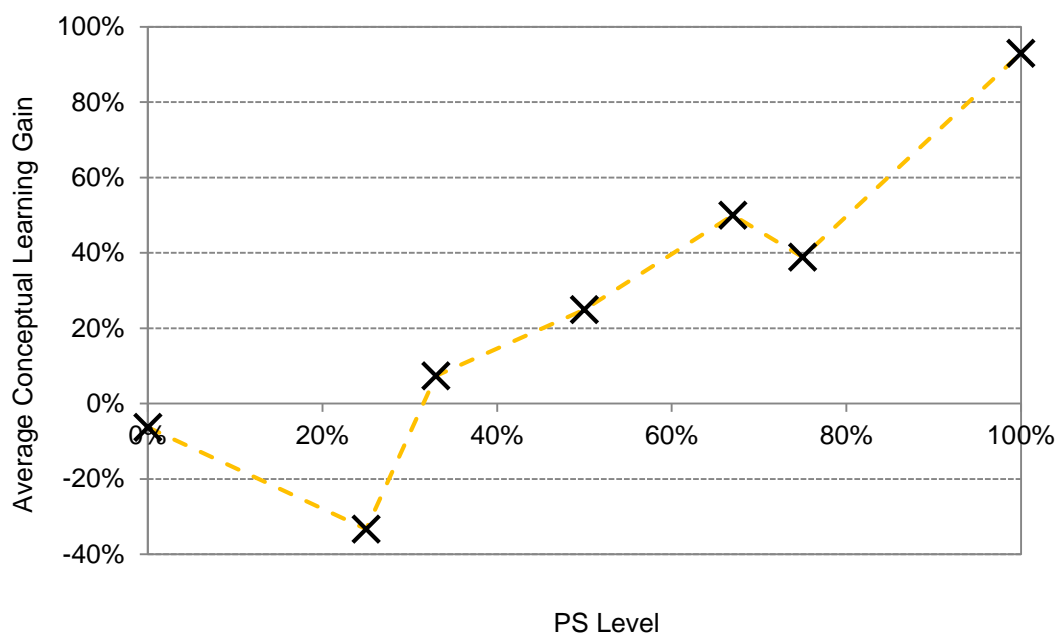
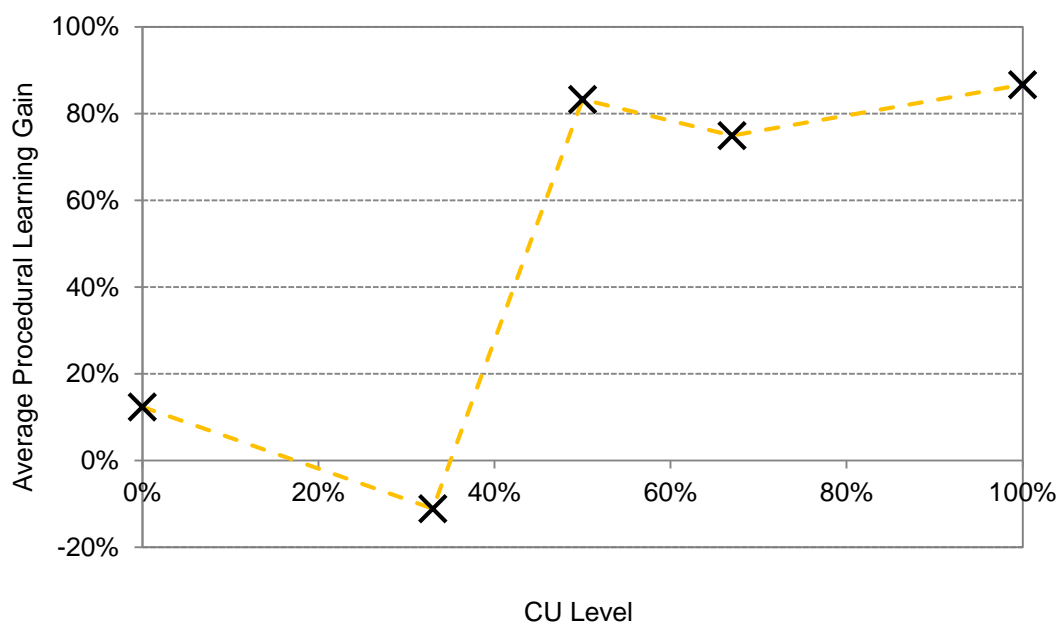


Figure 5.6 Diagram of Technical Problem in Module 6

Module 6 presents how to apply the 2nd Newton law to solve a particle problem. The diagram of its technical problem is shown in Figure 5.6. Figure 5.7 shows the development trend of one type of skill with increases in another type in Module 6. The two trends ascend as a whole, but rare exceptional drops exist in details. Conceptual learning gains appear to be fluctuating in the beginning and two obviously ascending segments followed with improvements in procedural skills. This suggests that procedural skills had little influence on developing conceptual understanding in the first phase of this CSA learning, and had a strong influence in the two following segments.



(a) Average Conceptual Learning Gain



(b) Average Procedural Learning Gain

Figure 5.7 Average Learning Gains in CU and PS by Level in the Intervention Group for Module 6

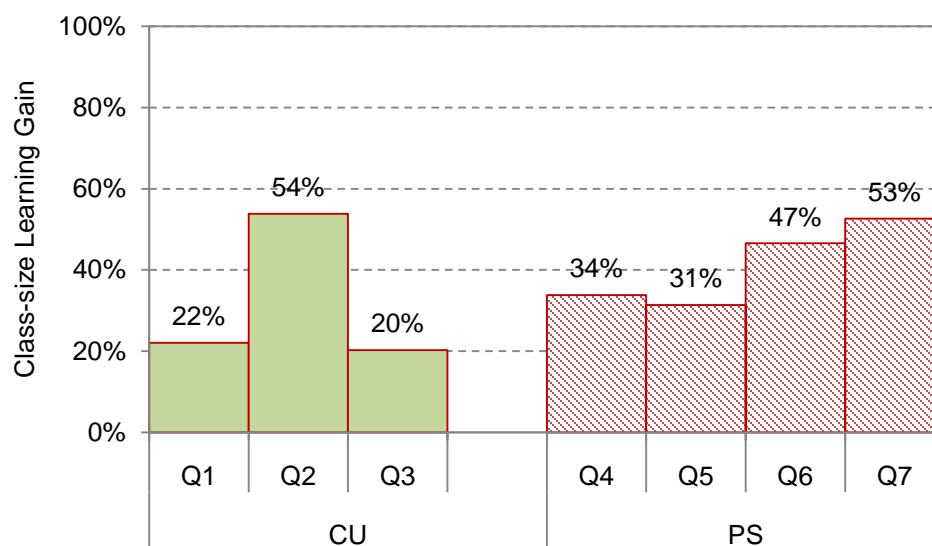


Figure 5.8 Class-size Learning Gains by Assessment Question in the Intervention Group in Module 6

In Figure 5.7 (b), procedural learning gains appear to be a sudden large increase at one segment, and basically maintain smooth in other segments, with increases of conceptual understanding. It indicates that conceptual understanding strongly supported procedural skills at the segment, and weakly supported procedural skills at other segments. Combining the two trends, it was found that in the first phase of this CSA learning, students were more likely to develop the two types of skills independently. As learning continued, the development of two types of skills was bi-directional and asymmetrical. The results imply that the two types of skills discretely supported each other and built some connections in this learning module.

Figure 5.8 shows the class-size learning gains by assessment question in the intervention group in Module 6. The 7 learning gains ranged from 20% to 54%, and most were low. Conceptual learning gains were largely different, showing an uneven growth in

conceptual understanding. This result indicates that students were more likely to make missing connections in conceptual knowledge. Therefore, it was difficult for students to build a useful conceptual knowledge structure. Procedural learning gains were relatively close, showing a relatively balanced growth in procedural skills, indicating that students made some appropriate connections in procedural knowledge. However, considering relatively low procedural learning gains, the results imply that it was difficult for students to build a useful procedural knowledge structuring due to the deficiencies in procedural knowledge.

In Module 6, students had a common misconception. That is, the tension force in the rope is equal to the weight of the block as the block is accelerated (see Figure 5.6). The misconception was addressed in assessment questions 1 and 3. Figure 5.7 (b) shows that procedural skills appear to be an abrupt increase at one segment. It indicates that if students were able to correct this misconception, they were more likely to enhance their procedural skills to a higher level. The low learning gains of questions 1 and 3 reflect that students reduced their persistent misconceptions after learning the CSA module. Their improvements were encouraging, although limited.

Question 5 and question 7 examined students' calculations about the tension forces, and question 3 examined students' understanding of the underlying concept. Question 4 and question 6 focused on the calculations of the acceleration, and question 1 focused on the associated understanding. Figure 5.7 (a) shows that procedural skills appear to be a strong influence on conceptual understanding in two segments. This reflects the processes of learning the two concepts. Students were inclined to first solve calculation questions, and later extract concepts from the experience of solving the

problems. In other words, improved procedural skills led to improved conceptual understanding during the learning processes.

Furthermore, the learning gain of question 3 was less than that of questions 5 and 7, and the learning gain of question 1 was less than that of questions 4 and 6. The results provide further evidence to support the finding that the above-mentioned learning processes resulted from improved procedural skills to improved conceptual understanding. Therefore, understanding difficult concepts of particle dynamics often requires a large amount of procedural knowledge, and mathematics is important to the success of improving conceptual understanding.

A special instructional design aspect of this CSA module included the application of an analogical strategy. Two cases were designed in this module. The two cases shared an underlying principle with similar structures and function. The left one is difficult and the right one is relatively simple, as shown in Figure 5.6. Students were allowed to identify problems and generate solutions about the topics through comparing the two cases and examining their differences. They started learning with the simple one, and then learned the hard one by making a meaningful connection with the easy one. Questions 4 and 5 examined students' calculation abilities with the difficult case, and questions 6 and 7 examined students' calculation abilities with the simple one. A small difference in learning gains between the two cases indicates that students were likely to transfer simple knowledge to complex knowledge using analogical reasoning. Students benefited from analogical strategy with the CSA module. However, because the learning gains of the two cases were not high, much more research is needed to prove this finding.

Module 8: Force and Acceleration of Cylindrical Coordinates

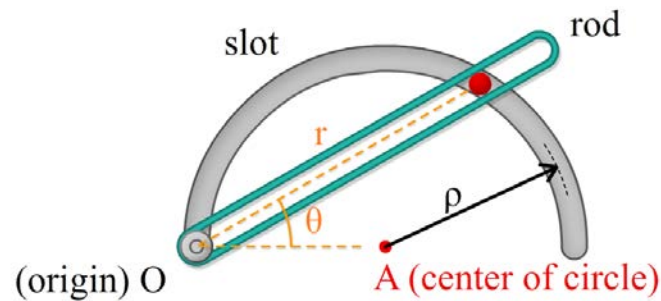
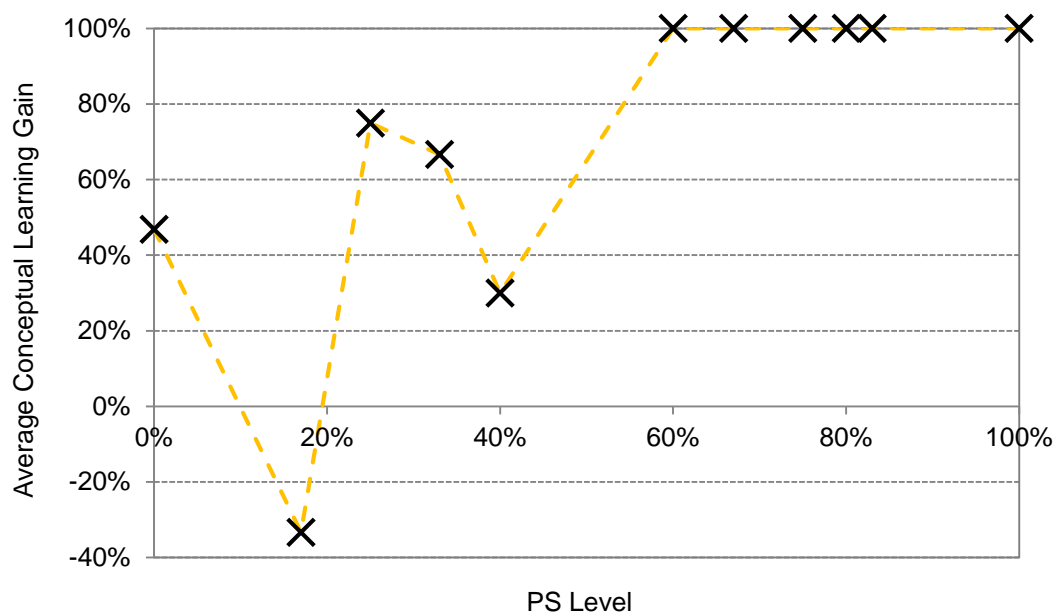
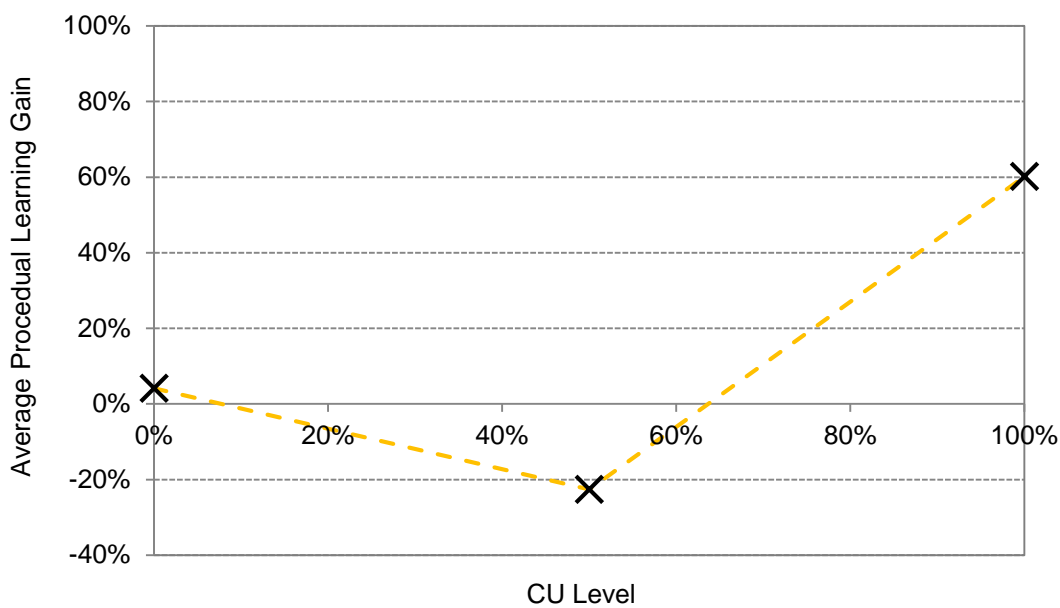


Figure 5.9 Diagram of Technical Problem in Module 8

Module 8 presents the cylindrical polar coordinate system and how it is used in particle mechanics. The diagram of its technical problem is shown in Figure 5.9. Figure 5.10 shows the development trend of one type of skills with increases in another type in Module 8. The development of conceptual understanding appears to a random pattern with increases of procedural skills in the first half of learning process. As learning continues, conceptual understanding is first well-developed, and then guides the construction of procedures for solving problems. This development is consistent with the concepts-first view. The results suggest that students developed their two types of skills independently at the first half of learning process, and then their conceptual understanding provided support to improve their procedural skills with a unidirectional link.



(a) Average Conceptual Learning Gain



(b) Average Procedural Learning Gain

Figure 5.10 Average Learning Gains in CU and PS by Level in the Intervention Group for Module 8

Figure 5.11 shows the class-size learning gains by assessment question in the intervention in Module 8. Conceptual learning gains were high and close, showing a balanced growth in conceptual understanding, indicating that students were more likely to make appropriate connections in conceptual knowledge and build a useful conceptual knowledge structure. Procedural learning gains were low and largely different, showing an unbalanced growth in procedural skills. This indicates that students were more likely to make missing connections in procedural knowledge. Therefore, it was difficult for students to build a useful procedural knowledge structure.

Conceptual questions 1 and 2 focused on the understanding of a free-body diagram and a kinetic diagram. Understanding and drawing the two diagrams are the first steps towards solving the problem. High learning gains for the two questions indicate that the CSA module was successful in helping students grasp a relatively low-level conceptual understanding. Learning this topic, students' main difficulties were in how to build their procedural skills. Procedural questions 3 to 8 were used to examine students' different levels of cognitive abilities, which included application, analysis and synthesis. An extremely low learning gain appeared in question 8. Solving this question required students to synthesize all of their concepts and procedures of the topic. This result implies that the CSA instruction has a limitation in strengthening students' skills for knowledge synthesis.

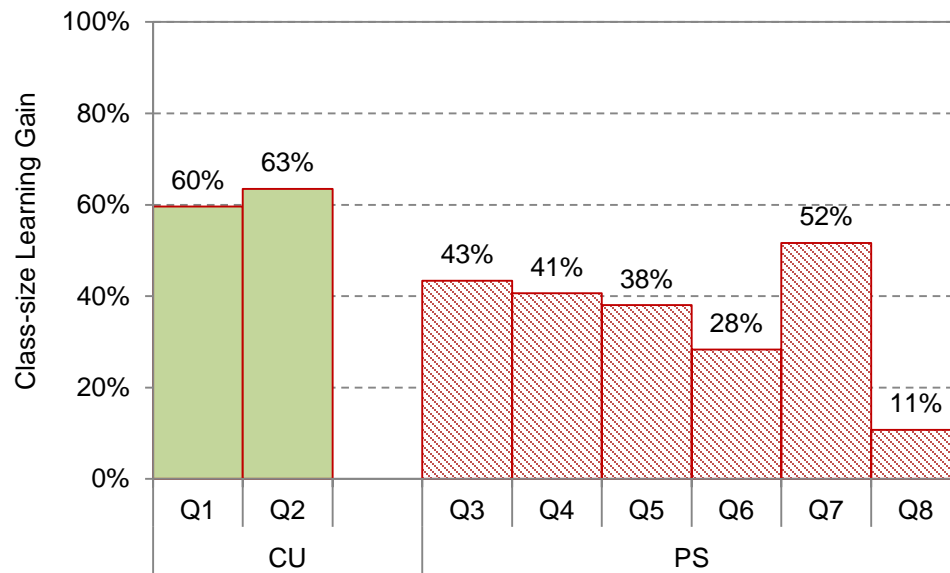


Figure 5.11 Class-size Learning Gains by Assessment Question in the Intervention Group in Module 8

Module 7 Force & Acceleration of Normal and Tangential Coordinates

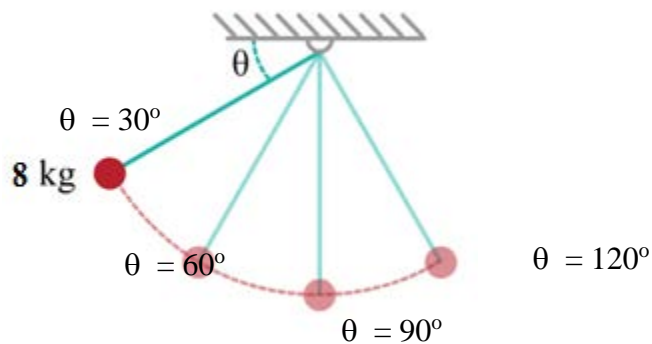


Figure 5.12 Diagram of Technical Problem in Module 7

Module 7 presents the normal and tangential coordinate system and how it is used in particle mechanics. The diagram of its technical problem is shown in Figure 5.12.

Figure 5.13 shows the development trend of one type of skill with increases in another

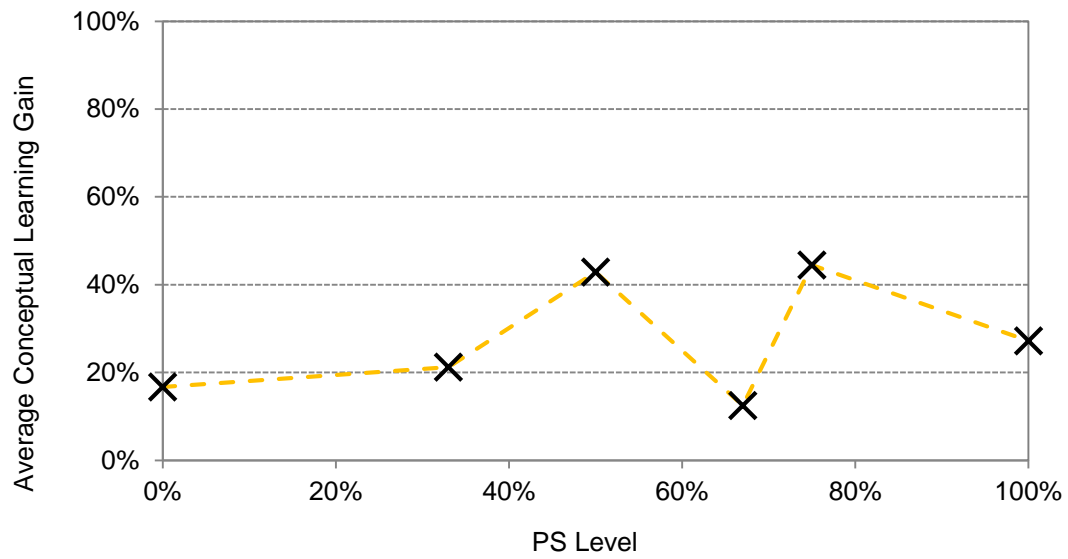
type in Module 7. Generally, as one type of skills increases, another one fluctuates in a small range. It means that students developed their two types of skills independently in this module.

Figure 5.14 shows the class-size learning gains by assessment question in the intervention in Module 7. Conceptual learning gains were extremely different, ranging from 2% to 61%, and procedural learning gains were largely different, ranging from 41% to 73%. The results indicate an unbalanced development in the two types of skills. Students were less likely to make appropriate connections in knowledge. Therefore, it was difficult for students to build a useful conceptual knowledge structure and a useful procedural knowledge structure in this CSA module.

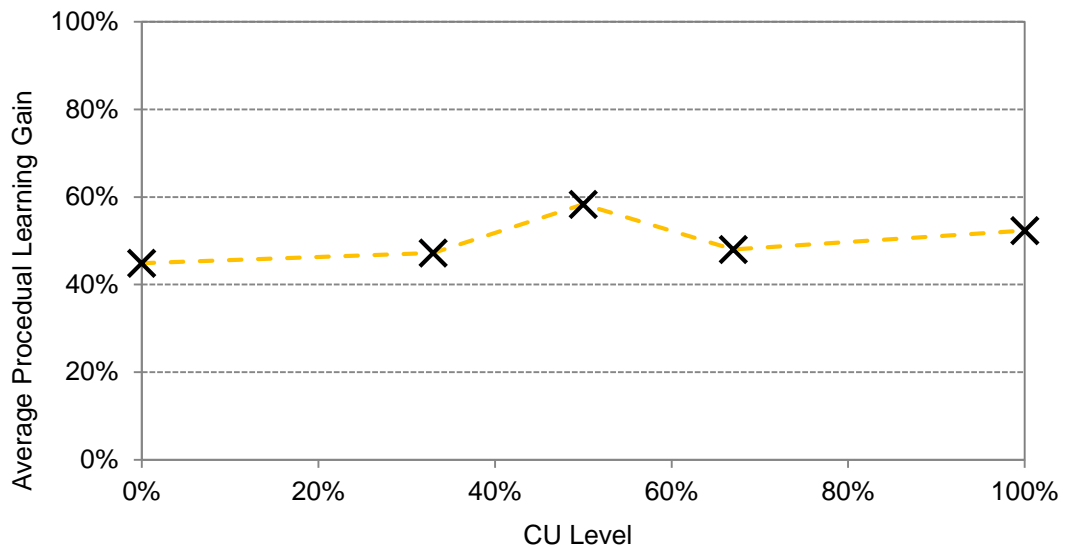
The lowest learning gain of 2% appeared in conceptual question 2, which was the lowest not only for this intervention module, but also for all modules. One possible reason for this lowest learning gain is that a strong confusion existed in understanding the magnitude of the normal acceleration of a swing pendulum. Students misunderstood that the normal acceleration decreases from the bottom to the top as the normal velocity decreases along the path. An extremely low learning gain indicates that students' persistent misconceptions are particularly difficult to correct with a CSA module.

Another possible reason is an inappropriate design of the animation of Module 7. The conceptual understanding of this topic focused on vector analysis of velocity and acceleration. The use of animation seemed to be less effective because it did not provide presentations of geometrical vectors of velocity and acceleration. In addition, the animation did not provide linking with parameter-variations. It could only simply demonstrate one motion with default values. Without parameter-variations, it was

impossible for students to explore animations in various conditions. Thus, students were not able to be engaged in exploring and understanding the meaning of the topic. In summary, the pedagogical values of animation are limited due to the lack of vector presentations and parameter-variations.



(a) Average Conceptual Learning Gain



(b) Average Procedural Learning Gain

Figure 5.13 Average Learning Gains in CU and PS by Level in the Intervention Group for Module 7

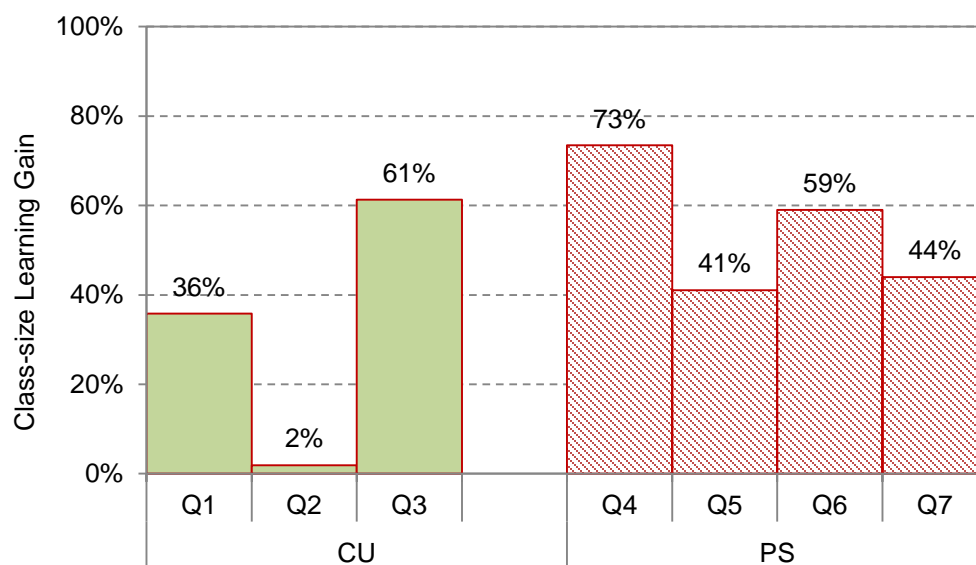


Figure 5.14 Class-size Learning Gains by Assessment Question in the intervention Group in Module 7

5.3 Characteristics of Conceptual and Procedural Learning Gains in the Intervention Group by CSA Module

Table 5.1

Characteristics of Developing CU and PS by CSA Module

Module No.	Overall Mean Gain	Connection between CU&PS	Knowledge Structure	
			CU	PS
11(5, 12)	59% (59%; 62%)	Bidirectional	Appropriate	Appropriate
6	37%	Bidirectional	Inappropriate	Inappropriate
8	42%	Unidirectional	Appropriate	Inappropriate
7	45%	Missing	Inappropriate	Inappropriate

Table 5.1 shows a summary of the characteristics of developing conceptual understanding and procedural skills in the CSA learning environment. The six modules were divided into a high-performing subgroup and a low-performing subgroup based on their overall average learning gains. A module in the high-performing subgroup had a learning gain larger than 50%. The following analysis was performed by subgroup.

a. High-performing Subgroup (Modules 11, 5, 12)

In the high-performing subgroup, students' problem-solving abilities were enhanced through a reciprocal and bidirectional development between conceptual understanding and procedural skills. The two types of abilities reinforced and strengthened each other. Students were more likely to build appropriate links between the two types of skills. Moreover, students' conceptual understanding was developed with balance, and so were procedural skills. Students were therefore more likely to build a conceptual knowledge structuring and a procedural knowledge structuring. When students first fully developed their procedural skills, their conceptual understanding was close to a full potential. Such knowledge structuring and links explain why students obtained high learning gains. Students were able to have a rich clustering of concepts and procedures. Each concept was related to many other concepts, and the relationships between concepts were clearly understood. Similarly, each procedure was associated with many other procedures, and the relationships between procedures were clearly identified. Moreover, students' two types of knowledge were linked with each other. When solving problems, students used concepts to decide the applicability of equations and procedures, and used procedures to achieve a better understanding of underlying concepts.

b. Low-performing Subgroup (Modules 6, 7, 8)

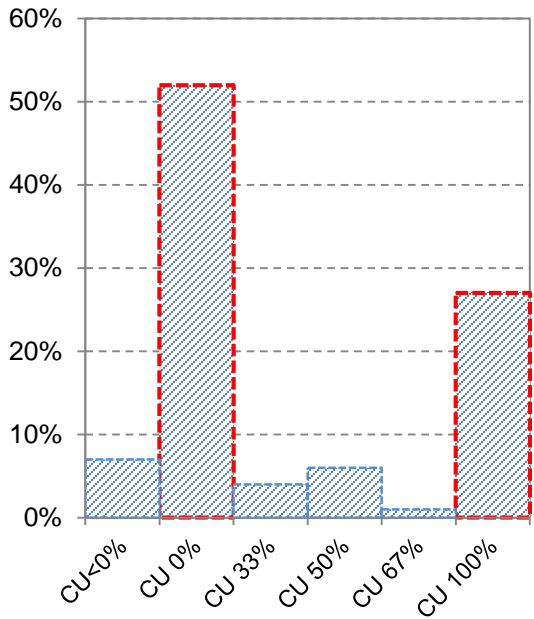
In the low-performing subgroup, students developed their conceptual understanding and procedural skills independently or unidirectionally. Links between the two abilities were non-existent or weak. Either one of the two types of abilities or neither was evenly developed. Therefore, students only built a conceptual knowledge structuring or a procedural knowledge structuring, or none. When students acquired the full competence of one type of skill, they were far from fully acquiring another skill. This knowledge structuring explains why students attained low learning gains. Students had a poor clustering of concepts or procedures. It was difficult for students to understand concepts and choose the appropriateness of equations and procedures to get correct answers.

Based on the above analysis, the effective CSA modules helped students build an appropriate conceptual knowledge structuring and an appropriate procedural knowledge structuring, and also helped students construct bi-directional and strong links between the two types of skills. These functions and effects are crucial for the success of a CSA module. In order to increase the effectiveness of CSA modules, two instructional designs of CSA modules are recommended.

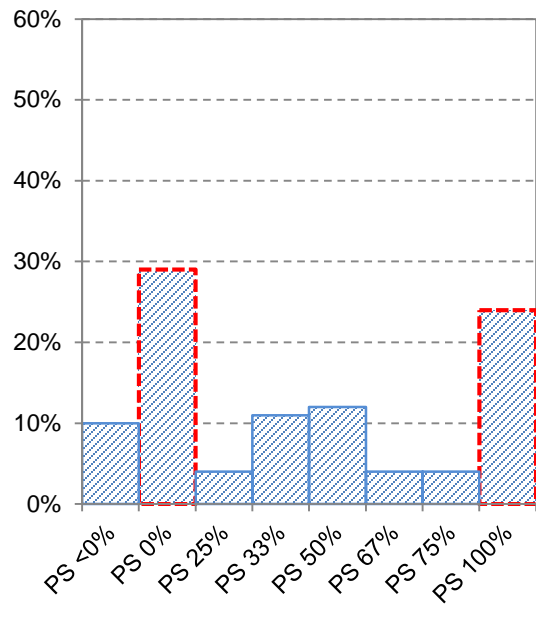
- Providing more explicit and direct instructions for difficult content helps students develop their conceptual understanding and procedural skills in a balanced way. It was found that an uneven development in the two skills was mainly due to the fact that students still had a poor understanding of difficult concepts and procedures after completing the CSA modules. The CSA approach can be more

effective in supporting learning if more explicit instructions on difficult materials are offered to students (for example, hints).

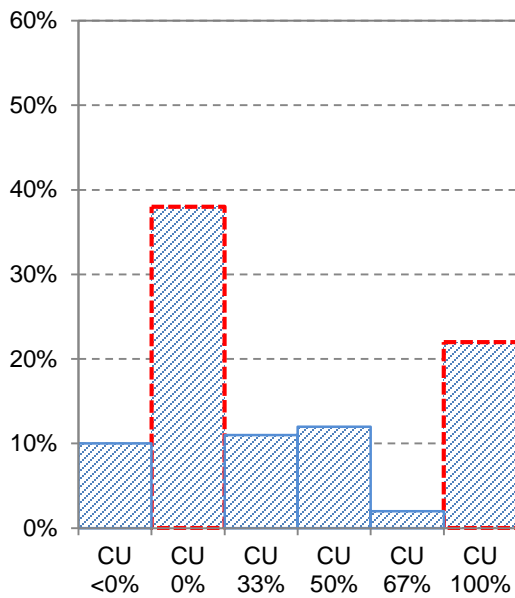
- Designing more effective problem representations helps students link their conceptual and procedural knowledge (Rittle-Johnson, Siegler and Alibali, 2001). Correct problem representation can be a bridge that mediates the relation between the two types of knowledge. When students are inclined to extract concepts from their experiences solving calculation problems, CSA modules can be more effective in supporting learning if they put emphasis on mathematical representations. When students are prone to enhance their procedural skills through correcting their misconceptions, CSA modules can be more effective in supporting learning if they focus on visual representations. It is essential to identify students' ways of learning with different types of knowledge, and then design effective problem representations.



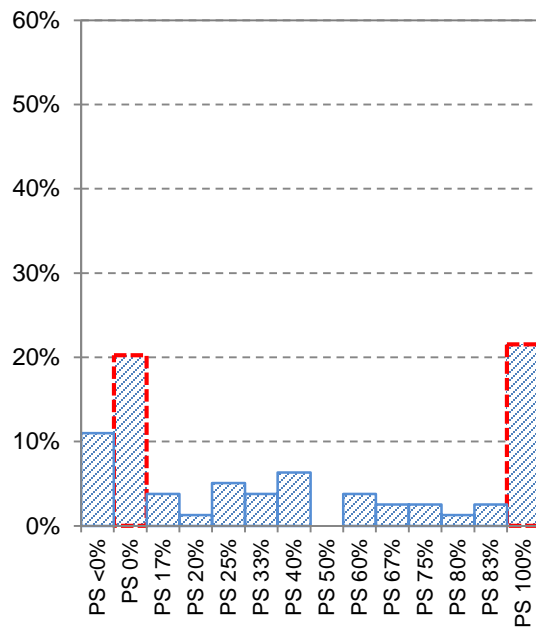
(a) Conceptual Learning Gains in Module 6



(c) Procedural Learning Gains in Module 6



(b) Conceptual Learning Gains in Module 7



(d) Procedural Learning Gain in Module 8

Figure 5.15 Examples of Distribution of Learning Gains in CU and PS in the Intervention Group by CSA Module

In order to further investigate students' difficulties in the CSA learning, the distributions of their learning gains in the low-performing subgroup were analyzed in the following. It was found that students' conceptual and procedural learning gains of a module show a bimodal distribution. Two distinct peaks appear at the values of 0% and 100%. Moreover, the two peaks of conceptual learning gains have dominant frequency. Figure 5.15 shows two examples of the distributions of conceptual learning gains in the intervention (Modules 6 and 7), and two examples of the distributions of procedural learning gain in the intervention (Modules 6 and 8).

An overwhelming majority of students in the class obtained conceptual learning gains of either 0% or 100% in an intervention module. The distribution of their conceptual learning gains presents an approximation to an all-or-none state. That is, the majority of students were more likely to either become proficient in conceptual understanding or learn nothing from a CSA module. The more difficult a module was, the more obvious such distribution was. The results suggest that in a challenging module, students had a huge difficulty in knowing how to get started towards arriving at their understanding. However, once they found an entry point for understanding concepts and got engaged in learning, they were more likely to reach their full potential.

Students' difficulties might be due to the deficiencies in their prior knowledge and the lack of explicit instructions in the CSA modules. The CSA modules could be more effective if they had offered a review section. The review section would help students refresh their knowledge and fill in any gaps, so students could go through new concepts more smoothly. The modules could be more effective if they had provided more explicit instructions, which would help students find an entry point to get started more easily.

Once involved in the CSA learning, students could take advantage of the multiple representations provided by the CSA modules to comprehend a concept in more than one ways and have a complete understanding. This explains why students were more likely to reach a full understanding if they were really engaged in learning.

Comparing the distribution of conceptual learning gains to that of procedural learning gains, more students got a learning gain of either 0% or 100%. The intermediate states (except 0% and 100%) of the distribution of conceptual learning gains took a smaller portion. The results suggest that it was more challenging for students to understand concepts than procedures in the CSA learning environment in general. Just as discussed in the previous sections, conceptual knowledge was presented as a whole, and procedural knowledge was shown step by step in the modules. To understand a complex concept, students often needed to break down the concept into component parts and identify the relationships between the parts. This analysis process led to learning difficulties, because it required a large cognitive capacity. These findings imply that it is necessary to apply instructional technologies or strategies to CSA modules in order to explicitly illustrate conceptual components and their relationships. That would make complicated concepts easier to understand.

In summary, the above results regarding conceptual and procedural learning gains by module reveal several main findings. These findings are:

- 1) In an effective CSA module, the development of conceptual understanding and procedural skills was often bidirectional. Learning gains in one type supported another, and vice versa. The development also appeared to have a specific characteristic: it was asymmetrical. For some knowledge types, conceptual

instructions had a stronger influence on procedures than vice versa. For others, procedural instructions offered more support for conceptual growth than vice versa. Identifying students' ways of learning on different knowledge and applying appropriate problem representations can make the CSA approach more effective.

- 2) An effective CSA module helped students build a useful conceptual knowledge structuring and a useful procedural knowledge structuring. Students were not able to develop an appropriate knowledge structure due to a poor understanding of difficult materials. Providing more explicit instructions for challenging contents in the CSA modules can help students develop their conceptual and procedural knowledge in a more balanced way, thus helping students build an appropriate knowledge structure.
- 3) Learning gain of 0% showed a dominant frequency in the distribution of both conceptual and procedural learning gains in the low subgroup. It implies that many students had huge difficulty in that they did not know how to get started. The CSA modules can be more effective if they offer more explicit instructions to help students find an entry point to get started.
- 4) The use of the analogical strategy in CSA modules enhanced students' understanding. A CSA module can be more effective if it integrates instructional strategies, especially when presenting abstract or difficult concepts. However, much more research is needed to prove this finding.
- 5) The CSA approach has a limitation in strengthening students' skills for knowledge synthesis and correcting students' persistent misconceptions. Knowledge synthesis and misconception correction are great and intrinsic challenges for many

engineering students. Students often performed poorly on conceptual assessment questions with a stubborn misconception involved. They also performed poorly on procedural questions for measuring synthesis skills. These results suggest that the CSA module cannot replace human tutors when teaching high-order thinking and reasoning, because human tutors can offer flexible ways where CSA modules are limited in this aspect.

- 6) The educational value of animations without interactivity or vector presentations is quite limited, especially when presenting difficult topics of mechanical dynamics. Controlling parameters in a CSA is valuable, in that doing it promotes active learning in the CSA environment. However, without interactivity, students only learn by passively watching system motions, rather than by actively doing. Principles in mechanical dynamics often involve vector analysis, such as velocity, force and acceleration. A vector-based animation can properly show the nature of principles. It is one big advantage of using CSA over static pictures of learning dynamics. However, CSA loses its strength without vector presentations when presenting concepts of mechanical dynamics.

CHAPTER 6

PRETEST AND POSTTEST RESULTS AND ANALYSIS (PART III):

STUDENTS' OVERALL PROBLEM-SOLVING SKILLS

This chapter presents, analyzes, and discusses the pretest /posttest results on students' overall problem-solving across all the CSA modules (that is, combined conceptual understanding and procedural skills). A comparison of overall learning gains in problem-solving skills of the comparison and intervention groups is presented in Section 6.1. In Section 6.2, a comparison of learning gains in problem-solving skills of the two groups by CSA module is shown. Finally, a comparison of learning gains in problem-solving skills in the two groups by student performance subgroup is presented in Section 6.3.

6.1 Overall Learning Gains in Problem-solving Skills

In this dissertation study, students' problem-solving skills are defined as "combined conceptual understanding and procedural skills" (see page 8). Students' problem-solving skills were measured with all 70 assessment multiple-choice questions for all 12 CSA modules (that is, conceptual and calculation questions). In order to evaluate the intervention effects, scores in pretests and posttests were examined for the comparison group and the intervention group. Figure 6.1 presents the class-average normalized learning gains of the two groups. The class-average learning gain for the comparison group and the intervention group was 21% and 58%, respectively. Compared to the comparison group, the extent of learning gain made by the CSA method in the intervention group was 37%.

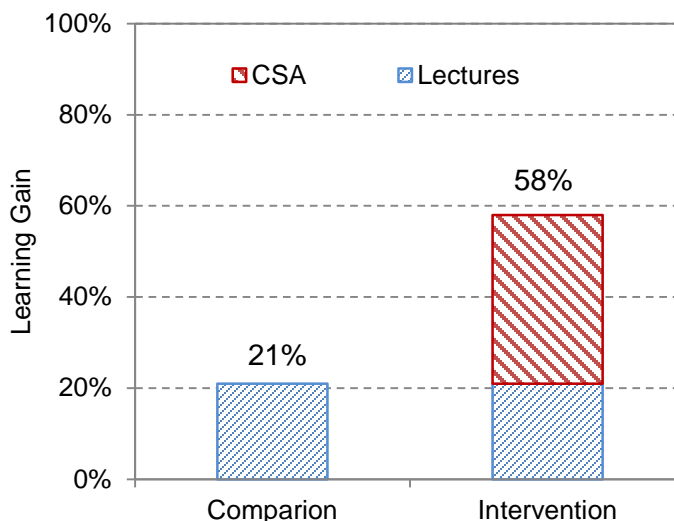


Figure 6.1 Normalized Class-average Learning Gains of the Two Groups

The pretest and posttest scores, normalized average learning gains, and standard deviations for both groups are shown in Table 6.1. Since the p values of the Shapiro-Wilk test were larger than 0.05, the data sets were normally distributed. A t-test was used for comparing the two groups. The results of t-tests reveal that the two groups were not statistically significantly different on pretest scores, $t(70) = 0.531$, $p = 0.596$. This means that the students in the two groups were comparable. The results of t-tests also show that the two groups were statistically significantly different on learning gains, $t(70) = -12.998$, $p < 0.001$. With a Cohen's d effect size of 2.17, it is indicated that over 80% of the two groups were non-overlapping. The above results imply that the developed CSA modules significantly improved students' problem-solving skills in particle dynamics. They also suggest a high practical significance.

Table 6.1

Mean Scores on Assessment Questions

Group	N	Pretest		Posttest		Gain	
		Mean	SD	Mean	SD	Mean	SD
Comparison	70	0.40	0.20	0.51	0.21	0.21	0.16
Intervention	70	0.38	0.17	0.72	0.16	0.58	0.18

6.2 Learning Gains in Problem-solving Skills by CSA Module

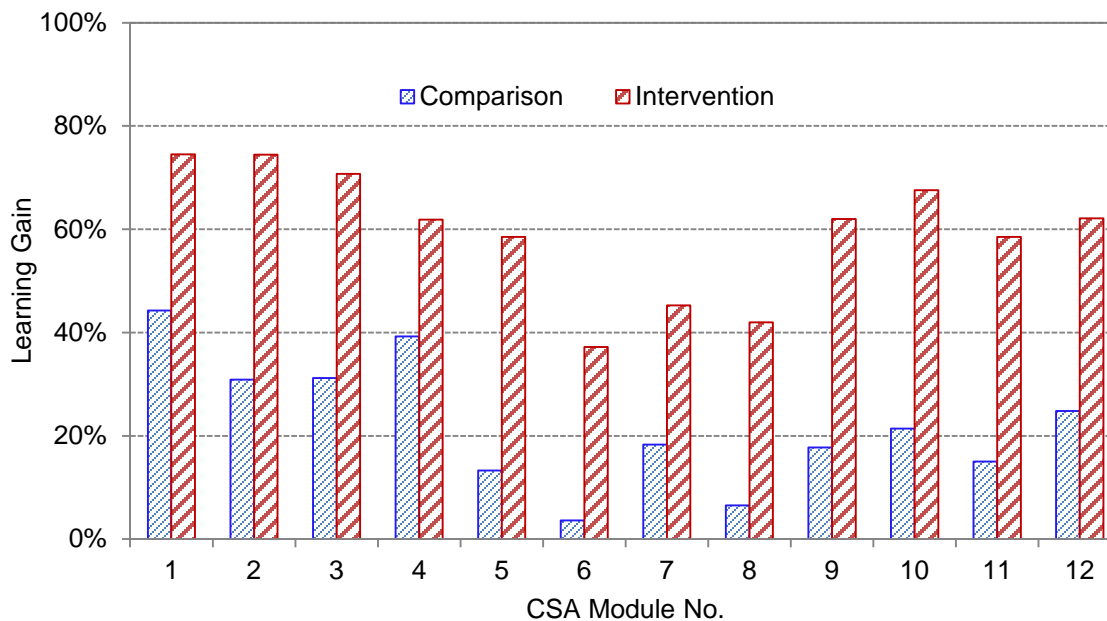


Figure 6.2 Class-average Normalized Learning Gains of the Two Groups by CSA Module

The total 12 CSA modules in this dissertation research present four crucial topics of particle dynamics covered in the Mechanical Dynamics textbook (Hibbeler, 13th edition). Modules 1 to 5 are about kinematics; Modules 6 to 8 present kinetics of force and acceleration; Modules 9 and 10 demonstrate kinetics of work and energy; Modules 11 and 12 are about the underlying principle of impulse and momentum. Figure 6.2

shows class-average normalized learning gain of the comparison group and the intervention group by each CSA module. The average learning gains in the comparison group ranged from 4% to 44%, and those in the intervention group were from 37% to 75%. Apparently, average learning gain of the intervention group was larger than that of the related comparison group in every section.

To further study whether there was a statistically significant difference in learning gains between the two groups for each module, the statistical tests and power analyses were conducted. First, to determine what statistical techniques to use, normality tests were run to see if the data were normally distributed. Since the p values of the Shapiro-Wilk test were all lower than 0.05, the twelve data sets were not normally distributed. The histogram and probability plots show that the data sets were skewed to the left. A non-parametric statistical Mann-Whitney U test and Cohen's d effect size were therefore used for comparing the two groups.

There was no statistically significant difference in pretest results of the two groups for each CSA module, indicating that the two groups were almost uniform. The statistical results of learning gains in each module are shown in Table 6.2. Based on the values of asymptotic significance, the difference of learning gains between the two groups for each module was statistically significant. It implies that each CSA module resulted in a significant increase of learning gain as compared with its associated traditional lecture-based instruction. Overall, the CSA instruction was effective in enhancing students' problem-solving skills in particle dynamics. In addition, the Cohen's d effect sizes of all 12 hypotheses ranged from 1.42 to 4.63 (see Table 6.2), which suggest very high practical significances. The Cohen's d results also imply that the most

effective CSA module was Module 11 and the least effective one was Module 7. This finding is consistent with previous findings in Chapter 5.

Table 6.2

Statistical Results of Learning Gains of 12 CSA Modules

Module No.	Z value	asymptotic significance (2-tailed)	Effect Size Cohen's d
1	-2.481	0.013	2.48
2	-4.080	0.000	3.65
3	-3.422	0.001	2.37
4	-2.129	0.033	2.85
5	-5.293	0.000	2.96
6	-4.526	0.000	2.80
7	-4.400	0.000	1.42
8	-4.780	0.000	2.69
9	-5.804	0.000	4.35
10	-5.667	0.000	3.99
11	-6.035	0.000	4.63
12	-4.562	0.000	4.11

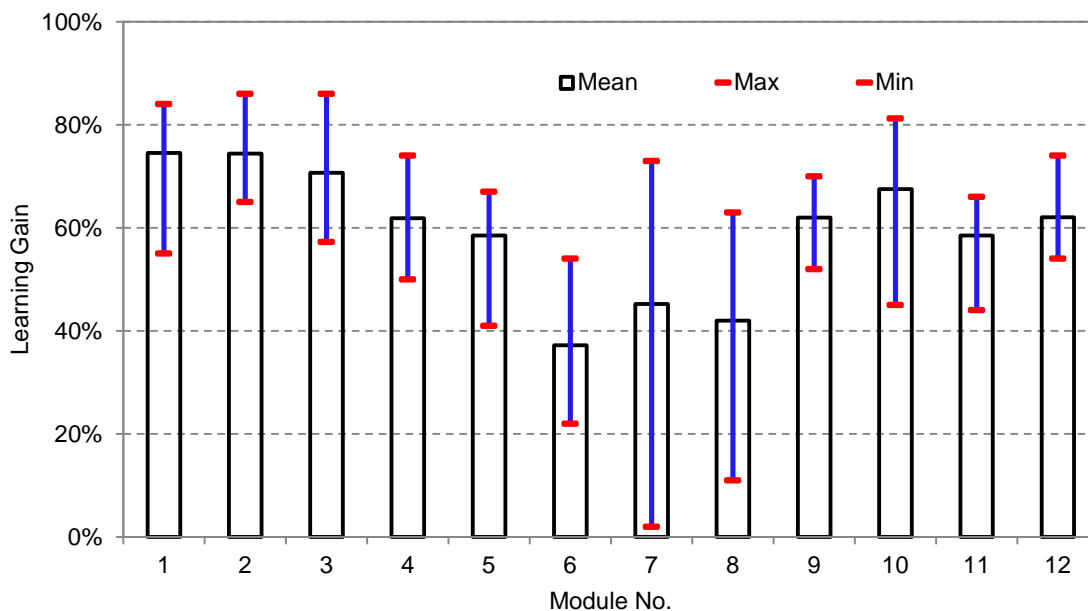


Figure 6.3 Class-average Learning Gain and Range of Learning Gains by Individual Module in the Intervention Group

Figure 6.3 shows the class-average learning gain and the range of learning gains for each module in the intervention group. In this dissertation study, class-average learning gains were distinguished between high ($g \geq 0.7$), moderate to high ($0.7 > g \geq 0.5$), moderate to low ($0.5 > g \geq 0.3$), and low ($g < 0.3$) levels, based on some tentative benchmarks proposed by Hake (1998). The symbol g represents learning gain. In the twelve CSA modules, there were three high-level modules (Modules 1, 2 and 3), six modules with moderate to high level (Modules 4, 5, 9, 10, 11 and 12), and three modules with moderate to low level (Modules 6, 7 and 8). Moreover, those modules with moderate to low level of learning gains had a wide range, while other modules had a relative narrower range in general.

The above results imply that if students achieved a relatively high learning gain in the CSA learning environment, they were more likely to develop their problem-solving skills in a balanced way and thus build an appropriate and deep knowledge structure. In

contrary, students' low improvement was caused by the strongly unbalanced growth of different knowledge underlying a topic. These students were less likely to build an appropriate knowledge structure due to the lack of knowledge.

Figure 6.4 shows the class-average learning gain of each CSA module, produced by the lecture-based approach and by the CSA approach. The average learning gains of the lecture-based method ranged from 4% to 44%, and the extents of learning gain made by the CSA intervention were from 27% to 46%. Compared to the classroom approach, the CSA approach often made a stronger learning gain in every module by quantity, except in Module 1 and Module 4.

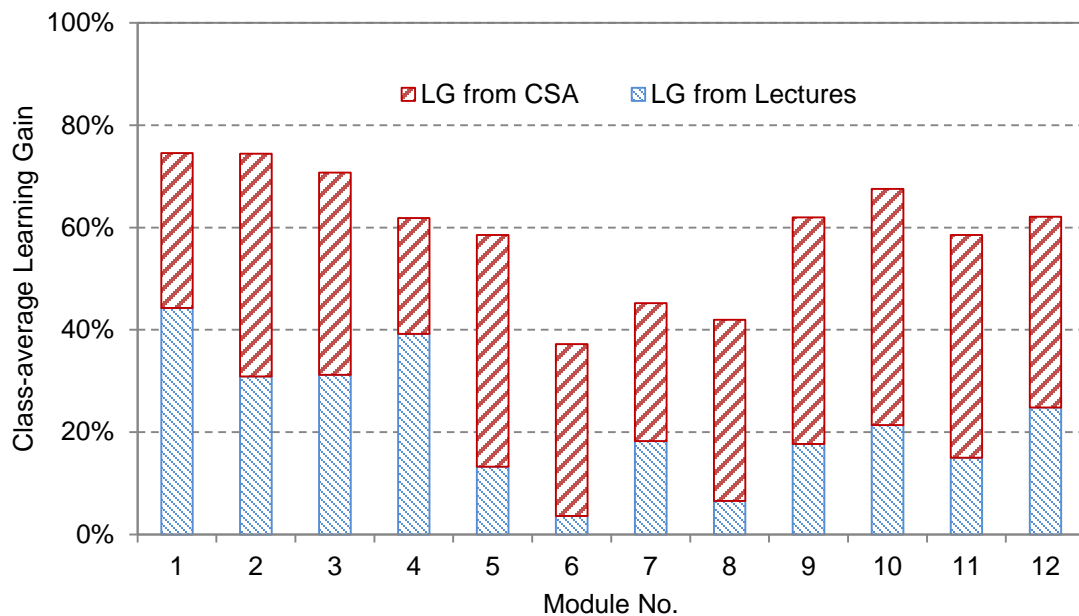


Figure 6.4 Class-average Learning Gains Made by the Two Sources by Module in the Intervention Group

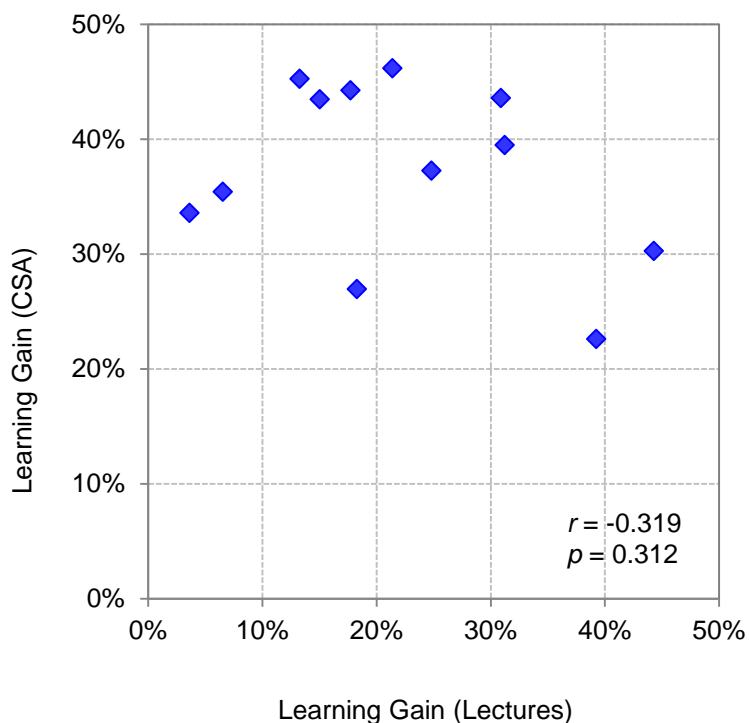


Figure 6.5 Correlation Between Learning Gains of Intervention Modules from the Lecture-based Instruction and the CSA Instruction

The relationship between the learning gains from the two sources was examined in the following. The correlation between the learning gains of intervention modules from the two instruction sessions is shown in Figure 6.5. The correlation measure was not statistically significant ($p = 0.312$), showing that the linear relationship between two results was non-existent. This indicates that student improvements in the classroom had little influence on their learning gains from the CSA instruction.

However, it was found that high CSA learning gains seem to be associated with moderate learning gains of classroom instruction. The result suggests that students were more likely to get a high gain in the CSA learning, if they had made some improvements in the classroom but still needed to improve to obtain their understanding. One possible

explanation for this finding is that the average learning gain of classroom instruction was a good indicator of the difficulty level of learning topic. For example, a topic with low learning gain of classroom instruction often had complicated contents. Students were more likely to receive a high CSA learning gain when they learned with moderate-level learning materials. With simple learning materials, students believed they already had a good understanding from classroom instruction and thus often used CSA modules much less effectively (for example, in Modules 1 and 4). With complex learning materials, students also gained less from the CSA method, as they were not able to make meaning based on their own learning and needed extra help (such as Modules 6 and 8). This finding suggests that the complexity of learning material is a crucial issue for the success of the CSA approach.

Besides the complexity of learning material, there are some other issues which significantly influence on the design and implement of the CSA modules. These issues were identified based on the learning gains of intervention modules from the two sources, shown in Figure 6.4.

Modules 1-5: Kinematics

The first three modules involve hitting a golf ball to a target. Module 1 illustrates a projectile motion on a horizontal plane, and Modules 2 and 3 present a projectile motion on an inclined plane. Solving the second and third technical problem required higher levels of visual-spatial skills than Module 1. The results show that Modules 2 and 3 had lower learning gains of the classroom instruction than Module 1 (Modules 2 and 3: 33%; Module 1: 44%). This reflects the efficiencies of the traditional lecture-based method on improving students' different levels of spatial visualization differed. The

traditional lecture-based method was less effective in improving students' high level spatial visualization than in increasing the low levels. After receiving extra support from the CSA intervention, these differences seemed to be eliminated (the overall average learning gain of Modules 1, 2 and 3: 75%, 74% and 71%), implying that the CSA instruction helped students compensate for deficiencies of spatial abilities, and thus helped them solve problems more effectively.

One possible explanation is that students with low-spatial abilities were also able to accurately visualize projectile motions and construct effective mental models, like high-performers did, with the help of the CSA intervention. In addition, students had been exposed something related to the topics in earlier physics classes. Their considerable prior knowledge about the topic (projectile motion) played an important role in obtaining high-level problem-solving competencies in the three modules. Their rich previous knowledge facilitated the new learning process and led to better learning results.

Module 4 presented the problem of a car running on straights and curves. Module 4 is one of the two intervention sections in which CSA learning gain was lower than the learning gain of the lecture method. One possible reason of the low CSA learning gain is the improper design of its animation. This animation did not explicitly present the changes in vectors along the motion path. When students saw this animated motion, they were not able to capture the dynamic nature of vectors and it seemed to be less effective in helping students understand. This result gives additional evidence that animation has limited educational value without vector presentations when presenting the topics of mechanical dynamics. Another possible reason is one of the lecture problems, which was very similar to the technical problem of Module 4. If students thought they had

understood the topic by lecture, they often used CSA much less effectively and learned much less from it. The degree of similarity between CSA questions and lecture questions is an important issue for implementing CSA instruction. A strong similarity might lead to ineffective use of the CSA approach.

Module 5 presents the concept of relative motion. This topic is one of the most challenging topics of dynamics course. A relative motion is described with respect to other moving objects, and the expression is difficult to interpret in classroom. The high CSA learning gain of Module 5 indicates that the CSA module clearly illustrated the complex spatial relationship of relative motions, and helped students develop a high-level spatial visualization skill. Some topics were more effective in making learning meaningful and useful for subsequent problem-solving skills than other topics when presented in the CSA modules. Relative motion was apparently an appropriate topic that was presented using CSA. Therefore, topic selection is an issue for designing CSA modules. To produce desired learning results, it is essential to select suitable topics for the CSA development.

Modules 6-8: Kinetics of force and acceleration

Modules 6, 7 and 8 show the applications of Newton's Second Law expressed in a Cartesian coordinate system, a normal and tangential coordinate system, and a cylindrical coordinate system, respectively. Their overall average learning gains from the two sources were about only 40%, which were much lower than those of other modules. The learning gains of the lecture-based approach were extremely low in Modules 6 and 8, reflecting that the two technical problems were pretty tough.

Applying Newton's Second Law to dynamic problems at university level is sometime terribly difficult for sophomore students, because they must consider vectors, addition of vectors, coordinate systems, and other such niceties. Furthermore, students' persistent misconceptions of Newton's Second Law make problems more difficult to solve. For example, the misunderstanding of "the tension force equals the weight" was a major issue that hindered problem-solving process in Module 6. Students had great confusion in comprehending a normal and tangential coordinate, and a cylindrical coordinate, which led to inappropriate applications in Modules 7 and 8. Overall, the three technical problems were highly complicated. Novice students were easily overwhelmed by the complexity, thus, they were not willing to spend time and efforts in effectively exploring CSA learning materials. During the learning process, students were more likely to choose to pass through the difficult steps and only see the surface ones. Therefore, it is important to determine how a complex question should be presented to students in a CSA module.

It was noticed that the three modules provided animations without interactivity and vector representations. As discussed above, the lack of interactivity and vector presentations would make animations of limited pedagogical value. This is one possible factor that led to student's low performances in the CSA modules.

Modules 9-10: Kinetics of work and energy & Modules 11-12: Kinetics of impulse and momentum

The underlying principles of technical problems in Modules 9 and 10 are Work and Energy, and Conservation of Energy, respectively. Modules 11 and 12 present the implementation of the Principle of Linear Impulse and Momentum, and the implementation of the Principle of Angular Impulse and Momentum. These concepts are

an outgrowth of Newton's Second Law, but they are more difficult to understand. The previous study (Singh and Rosengrant, 2003) has showed that most students have difficulties in conceptually interpreting basic principles related to energy and momentum, and in applying them in physical situations.

However, students obtained high learning gains in these CSA modules. It means that the CSA modules were effective in helping students learn the topics. There are three main factors of the CSA intervention that contributed to the effective learning. The three factors are described as follows.

- a) The connections between algebraic representations and graphical representations helped students remedy their misconceptions related to work-energy equations and impulse-momentum equations. These associated mathematical equations in the textbook were often misunderstood. According to the equations, students tended to define the concepts as “work is equal to energy” and “impulse is equal to momentum.” In fact, “work equals changes in energy” and “impulse equals changes in momentum.” In the CSA environment, linking algebraic and graphical representations illustrated and explained the changes in energy and momentum of objects. Therefore, it helped students develop a correct understanding of the work-energy and impulse-momentum relationship.
- b) A step-by-step process explicitly presented all components of the mathematical equations, and also showed a linear process similar to the thinking pattern that most students typically exhibit. This step-by-step way is especially suitable for presenting the two topics, because the two concepts could be divided into almost non-overlapping parts. For example, the Principle of Conservation of Energy

consists of initial and final kinetic energy, and initial and final potential energy.

The Principle of Linear Impulse and Momentum includes initial and final momentum, and impulse. The step-by-step process guided students into thinking linearly, and therefore it was easy for students to follow. Moreover, the students who understood the components of the principles were more likely to understand the whole, since they just needed to put parts together follow the process.

- c) It was noticed that the technical problems addressed by these modules were of moderate complexity. Presenting the complex mechanical dynamic concepts through moderate-level technical problems in the CSA environment resulted in a good grasp of understanding and an effective learning.

The above-mentioned factors are crucial for the success of designing and implementing the CSA instruction. They are: animation with interactivity and vector representations, step-by-step problem-solving procedure, links between algebraic and graphical representations, topic selection, degree of similarity with questions in lectures, problem complexity, and students' prior knowledge.

6.3 Learning Gains in Problem-solving Skills by Student Performance Subgroup

Figure 6.6 presents the correlation coefficient and corresponding statistical significance for the relation between students' pretest scores and learning gains in the intervention. The correlation coefficient for this relation was $r = 0.180$, and the correlation measure was not statistically significant ($p = 0.090$). The results indicate that students' learning gains were not correlated with their pretest scores.

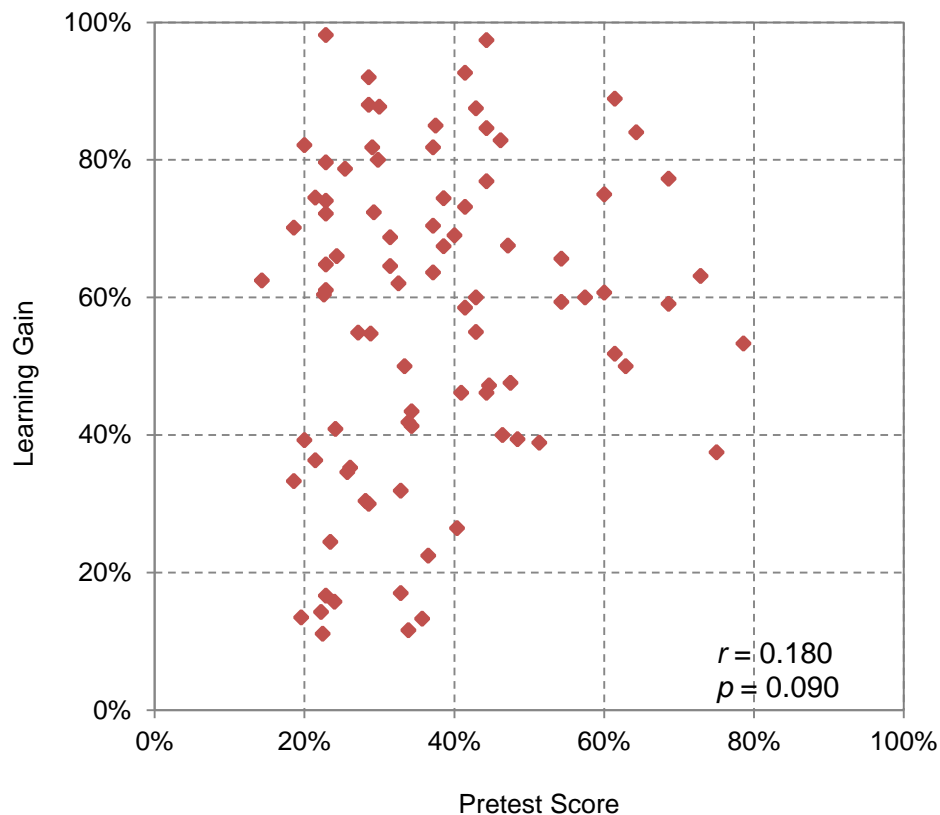


Figure 6.6 Correlation Between Students' Pretest Scores and Learning Gains in the Intervention Group

The effects of CSA modules on different performance groups were investigated in this dissertation research. Students were divided into a low-performing subgroup and a high-performing subgroup on the basis of their pretest scores. An ANOVA analysis was performed on learning gains to determine whether there was a difference between the two subgroups (See Table 6.3). The result shows that the CSA intervention was highly statistically significant ($F = 107.774$, $p < 0.001$), and students' performance was also statistically significant ($F = 8.306$, $p = 0.005$). There was no interaction between CSA intervention and student performance ($p = 0.541$). The results indicate that the CSA intervention greatly improved students' problem-solving skills, and students in the high-

performing subgroup benefited more in learning from the CSA intervention than those in the low-performing subgroup. The estimated average learning gains by student performance in different subgroups are showed in Figure 6.7.

Students with high pretest scores often had a rich knowledge base. Previous studies have found that learning is a process of making connections between new information and prior knowledge (Marzano, Gaddy and Dean, 2000). Having mastered a larger amount of relevant materials, high-performers required a lower amount of cognitive processing to make connections. With the instructional support provided by the CSA modules, students were more likely to get involved in deep exploration of knowledge during learning. In contrast, due to the deficiencies of knowledge, learners with weak background were not able to distinguish important with unimportant information, and therefore were distracted by the surface features of CSA modules. Huge amounts of information to process easily overwhelmed low-performers' cognitive processing capacity. Therefore, they learned much less from the CSA intervention than the students with rich previous knowledge.

Table 6.3

Average Learning Gains by Student Performance in Different Subgroups

Group	Subgroup	Pretest		Posttest		Gain	
		Mean	SD	Mean	SD	Mean	SD
Comparison	Low-performing	0.30	0.05	0.41	0.14	0.16	0.19
	High-performing	0.51	0.08	0.62	0.13	0.23	0.26
Intervention	Low-performing	0.26	0.05	0.63	0.19	0.50	0.26
	High-performing	0.50	0.12	0.82	0.11	0.63	0.18

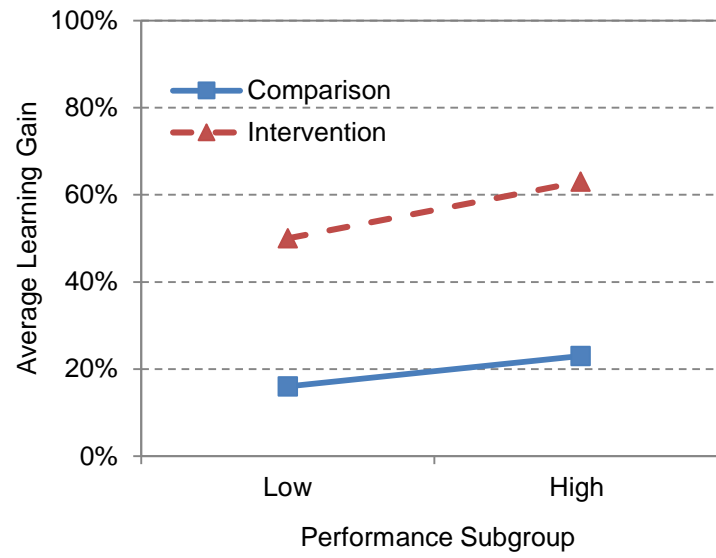


Figure 6.7 Estimated Average Learning Gain by Student Performance Subgroup

CHAPTER 7

SURVEY AND INTERVIEW RESULTS AND ANALYSIS

This chapter presents, analyzes and discusses the qualitative results from the survey questionnaire and the individual in-depth interviews conducted to examine students' learning attitudes toward and experiences with CSA modules. The results are divided into two main sections. The first section presents themes found from the interview data. The second section presents the analysis and discussions of each theme based on the data from the surveys and the interviews.

7.1 Themes Found from the Qualitative Interview Data

Students' learning attitudes toward and experiences with CSA modules were measured through a survey questionnaire and in individual in-depth interviews. A total of 20 interviews were conducted. The specific methods for generating, coding and categorizing data have been described in Chapter 3. A summary of responses to interview questions is provided in Table 7.1. The table shows the main categories and subcategories of students' perceptions to interview questions, as well as the way in which the text-driven categories logically cluster into general themes. The researcher organized the text-based categories into two levels. For example, participants said that they used three ways to enhance their procedural skills in the CSA learning environment, including *step-by-step process*, *identifying errors*, and *analysis-synthesis process*, which were grouped under a main category of *increase procedural skills of learning particle dynamics*.

Table 7.1

Categories of Students' Perceptions to Interview Questions

Interview Question	Number Code	Category	Percentage (Number)
<i>Usage Pattern</i>			
1. Average time spend on a CSA module	3-4.2	Length of access (<=15min)	60% (12)
	3-1.1	Solve, watch, and check solutions and answers	0% (0)
2. An entire process running CSA modules	3-1.2	Watch and get / check solutions and answers	65% (13)
	3-1.3	Combination of both methods	35% (7)
3. Comparison with textbook	1-4.1	Interactivity	55% (11)
	4-1.2	Visualization/animation	70% (14)
<i>Learning Outcomes & Ways to Use</i>			
1. Increase conceptual understanding for learning particle dynamics	4-1.1	Variables and relationships	45% (9)
	4-1.2	Visualization/animation	35% (7)
	4-1.3	Connection	30% (6)
2. Increase procedural skills for learning particle dynamics	4-2.1	Step-by-step process	90% (18)
	4-2.2	Identifying errors	15% (3)
	4-2.3	Analysis-synthesis process	25% (5)
3. Increase motivation for learning particle dynamics	4-3	Enhance motivation to learn	70% (14)
4. Increase confidence for learning particle dynamics	4-4	Enhance confidence to learn	100% (20)
<i>Technical & Instructional Design</i>			
1. Characteristics of CSA modules students learn the most from	2-1.1	Complexity	100% (20)
	4-1	New concepts involved	85% (17)
	1-2	Visualization	35% (7)
2. Features of CSA modules students like most	1-1.1	Scrollbars	55% (11)
	1-2.1	Animation	50% (10)
	1-2.2	Graphics	10% (2)
	1-7.1	Equations	30% (6)
	1-5.3	Highlight color	20% (4)
3. Students' feedback on CSA modules	2-3	Hints, tips, and reviews	25% (5)
	1-3.4	Unresponsive features	20% (4)
	1-3.2	Access/viewing CSA on canvas	70% (14)
	2-4	Other feedback	60% (12)

Note: N = 20. The percentage refers to the percentage of sub-category in the interview sample.

Students' perceptions were divided into three main themes, *usage pattern*, *learning outcomes & ways to use*, and *technical & instructional design*. The themes are presented here as section headings, and the text-driven categories as subsection headings in Table 7.1. Next, a detailed analysis and discussions of categories and subcategories are presented in section 7.2.

7.2 Analysis and Discussions of Each Theme

This section is organized following the themes shown in Table 7.1. In this section, the data from the surveys and interviews were integrated to provide more findings. Specifically, the findings emerged from the quantitative survey data, the qualitative survey data and the qualitative interview data.

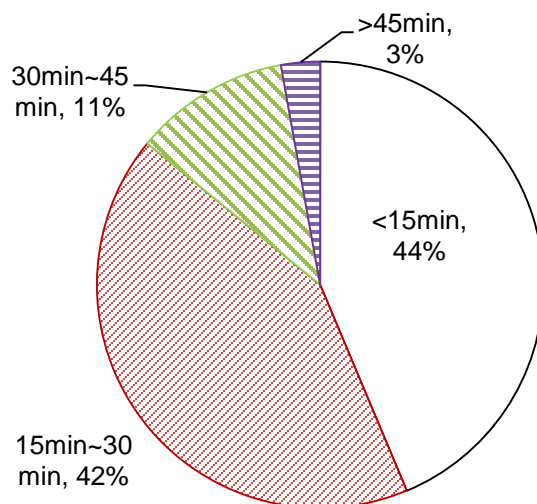
Usage Pattern

Average time students spent on a CSA module

A correlation analysis related to average time students spent on a CSA module was conducted to identify its relationship with student academic performance and their attitudes. This analysis was performed using the quantitative survey data. The results show that the mean time students spent on a module was significantly correlated with students' confidence ($r = 0.705, p < 0.001$), their motivation ($r = 0.607, p < 0.001$) and their academic performance ($r = 0.456, p < 0.001$). The results indicate that the more time students spent on a module, the higher levels of self-confidence, motivation and better academic improvements they had. Therefore, average time is a key criterion that influences the effectiveness of student learning in CSA environment.

Figure 7.1 shows that 44% of the students spent a mean time of less than 15 minutes on a CSA module, 42% of the students with 15 to 30 minutes, and 14% of the students with more than 30 minutes. Students were categorized into three groups

according to their different time ranges. Based on their responses in the surveys and interviews, three major issues related to their usage patterns were identified, including students' primary purposes of using CSA modules, sequences of running a CSA module, and ways of using scrollbars and other GUI features.



(data from Survey; N = 71)

Figure 7.1 Average Time Students Spent on a CSA Module

- Group 1: Less than 15min

Example 1

“I usually start it, read the problem, I put the scrollbars...Then I briefly go to look at equations there more answers given, then I pull out the hard copy (bonus homework), then I go back to specific...looking for the answers bonus homework looking for.”

Example 2

“...I open it, and then I scroll all around, make sure I can see everything. And that, if I think I need to review that information then I look

at. Then I just click next and then usually go to the equations...I usually don't play the animation, I usually don't see it going, I just see where the equations are headed. What I need to set up. So I just look for the equations and then I pretty much just look through the equations and then do my own work, see if I get the right answer, and if not I just go back to the equations and try again. And then I close it, if I get it right.”

In this group, students spent a mean time of less than 15 minutes on learning a CSA module. Their purposes of using CSA modules might be only to complete assessment questions to receive course credits. They were not actively engaged in learning process, thus they used the CSA modules less effectively. When students ran a module, they rushed through the slides, kept moving forward and never went back to check on previous slides. This linear learning process was less effective. An effective learning should be non- linear and subjective. Furthermore, students often saw mathematical formulas and passed over other GUI features. They mechanically copied mathematical equations provided by CSA modules to solve assessment questions without really understanding them.

- Group 2: 15min to 30min

“I would open the module and go through it step by step.... I would look at the animation, make sure I knew what was actually happening in the problem and then I would go through and solve along with the module to make sure that what I had done before was what was supposed to be done. So I followed along with equations.....”

“I would try to change one at a time and see how it was affecting the answers or sometimes I would change 2 and see if it’s the third one that’s affecting the problem or it’s those 2 that I changed affecting the problem. So just kind of used them to see what’s going to make the difference in the problem.”

Students in this group spent 15 to 30 minutes on learning a CSA module. During the learning process, they went through all the slides of a CSA module in a sequential order. They also selected to use a less-effective linear learning method. Specifically, they kept moving forward without looking back, even though they occasionally needed to go back to find important points they missed. Unlike students in Group 1, they used almost all critical GUI features for learning, such as, changing scrollbar values, watching animations and solving mathematical formulas. Students used these features, but they might only partially benefit from the educational values of the features. Their primary purpose of using CSA module was to receive credits rather than to learn something.

- Group 3: More than 30min

“I usually open it and click next until I get to the end, just kind of get a really quick idea of how long it’s gonna take me to do the module, Umm... and then... I usually go back to the beginning and then skim over the information in each one and kinda look at what the questions were for each problem, whether or not they’re conceptual or if they’re asking for a number... And then I’ll go back to the beginning again, and then...that is when I will start to actually look at the details of the module, and I’ll hit the

simulate button...After I do those first two quick run through just to kind of get an idea of what's going on, I will then begin to try to solve the problem. I usually look at the equations or at least...get an idea of what the processes are, and then try to solve it. And then compare what my solutions or my equations are to what's given on the module. And if it's different, then I'll try to figure out why they're different...if it's wrong then I can go back and try to fix that mistake and not make it again.”

“If there were 3 (scrollbars), I would take the top one move it to the middle and then run it. Then move it to end, and then run it. And then push it back to the left and take the second one and move it to the middle and then run it, and then it to the end, and run it. So I'd run the different, so that would be 7 different scenarios, and then I would analyze the data, and what the different changes in the variables meant to the end result...”

In this group, students spent more than 30 minutes on learning a CSA module. They first quickly ran a module to get a general idea of what it presents, and then went back and started the loop over with meticulous details. On the second attempt, students frequently revisited materials when they needed to go back to previous slides to understand what they had missed. They used an effective iterative learning process and were actively engaged in learning. Specifically, they were able to explore the effects of parameters in various situations by manipulating scrollbars, construct mental models by watching animations, and develop quantitative reasoning skills by understanding mathematical formulas. They were more likely to maximize the educational values of key GUI features through repeatedly using them. In the example shown above, the

student developed a deep understanding of the underlying principles of the motion phenomena by exploring seven different scenarios in a CSA module. Students in this group really learned something new and made great efforts to achieve success.

In summary, only when students spent more than 15 minutes in a CSA module, did they start to learn something from the module. When students spent more than 30 minutes in a module, they were more likely to be involved in deep learning and maximize the educational benefits of the module. The results shown in Figure 7.1, suggest that over half of the participants (55%) in the intervention group were able to benefit from the CSA learning.

Using CSA modules as a supplement to lecture-based instruction

“... I’ve really learned a lot from these. I think that, I would definitely like to continue doing this because it’s just an extra thing to help us learn it better, and so it’s been helpful for me.”

“They were used as a supplemental, like, you know, like, with lecture notes, and some other way to learn the material.”

“It’s an additional resource to use... or maybe we didn’t cover something very detailed, I see it as a useful additional resource that can be used... That’s how I feel about the modules.”

In this study, the CSA instruction was a useful supplement to traditional classroom instruction, as students said above. Compared to the lecture-based method, students agreed that the CSA modules had two distinctive advantages that were helpful in increasing their learning. First, the CSA approach provided an outside classroom environment. Since students were not restricted to campus for learning, they enjoyed the

freedom of learning at their own convenience and at a pace right for them. The second advantage of the CSA method is its high-level interactive features and dynamic presentations. Learners were allowed to interact with CSA modules through manipulating variables and observing their effects on system motions. As far as dynamic presentations were concerned, animations illustrated dynamic motions and the changes of key variables during the entire trajectory. In the learning environment, students were more likely to be actively engaged in learning through observing, exploring, discovering and building.

“The modules were helpful to be interactive with... the textbook it’s kind of hard to visualize what’s happening in the problem... in the modules you were able to actually see where everything was working.”

“I think they’re helpful I think having an interactive part is a lot more exciting and intriguing than just learning from a textbook... I think it’s good to get real life examples and real animations to know how dynamics applies to real life situations, real moving situations.”

“...the textbook aren’t necessarily visual they can’t make things move, and they can’t show you how the different movement is going to, to make this different. And so the modules are beneficial to me because I can see it move, I can see why something is making it different.”

Students' Perceptions of Learning Outcomes and Their Ways of Learning

Table 7.2

Student Responses to Survey Questionnaire

Survey Question	Mean	SD
Increase confidence for learning particle dynamics	3.34	0.62
Increase motivation for learning particle dynamics	3.12	0.43
Increase conceptual understanding for learning particle dynamics	3.57	0.84
Increase procedural skills for learning particle dynamics	3.46	0.66
Increase learning of particle dynamics	3.55	0.81

Note: Likert Scale: 5 = Strongly Agree 1= Strongly Disagree

Five survey questionnaire questions were used to probe students' perceptions of learning outcomes in the CSA environment. Using a 5-point response Likert-type scale (5 = Strongly Agree and 1 = Strongly Disagree), students were asked to indicate how much they agreed that these CSA modules increased their confidence, motivation, conceptual understanding, procedural skills and overall learning. Responses to this scale are displayed with mean and standard deviation in Table 7.2. It was seen that all responses had a mean above three.

Students agreed that the CSA instruction improved their conceptual understanding (M = 3.57), procedural skills (M = 3.46), and overall learning (M = 3.55) of particle dynamics. Students also agreed that learning with the CSA method gave them a little more confidence (M = 3.34). Students were more inclined to a neutral attitude that learning with CSA modules increased their motivation (M = 3.12). Overall, the responses indicate that students had a positive perception of CSA learning.

The following discussions focus on how students improved their learning in the CSA environment, based on students' responses in the surveys and interviews.

- Improving Students' Conceptual Understanding

Students said that their conceptual understanding was improved through two main processes. First, the CSA instruction helped students identify and overcome their misconceptions and then helped them reconstruct an accurate framework. The second process is that the CSA modules helped students deepen their understanding of new concepts.

“...they were problems in which the module helped me because I had some misunderstandings or misconceptions about the core concepts applied to the problem.”

“Being able to see the principles happening helps me understand what is happening. Helps remove false ideas I previously had and reinforce the new material.”

“They made me think and weren't always as straight forward or as intuitive as I thought...on module 6, it has two different cases... I remember when I did that problem I just assumed that they were the same and then when I did the modules I discovered that they weren't.... ”

“Because ...were completely new to me... I had no idea what was going on with them, but that module helped a lot.”

“These were concepts that I didn't fully understand in class, but as I worked through them, it made a big difference in my understanding.”

Based on students' responses, it was found that students used three main ways to increase their conceptual understanding: 1) visualization, 2) manipulating variables and 3) connecting various GUI features.

a. Visualization

“Animations, and some sort of diagrams or pictures that show what's going on helps a lot.”

“It helped me visualize the world better, because I see things... the motion, the whole overall process from the beginning to the end.”

“...the concept got across to me in the way it needed to and that's what the animation provided... I could understand the concept with what was provided.”

“Watching the animations helped me to visualize the motion a lot better, which helped my understanding of what it was that I was really looking for from a conceptual standpoint.”

“I thought that those modules were useful in helping me to conceptualize the dynamic aspect of the problem. While watching the animation, it helped me to wrap my mind around what was physically occurring.”

“Just how there were diagrams pointing out the important information and the interactive parts where you could see how things moved and functioned. This helped the visual learner in me to actually see instead of trying to imagine how things are supposed to work.”

“I am very visual person it helps me to be able to see what’s going on. And then if I can see what’s going on I understand concepts and their use, and why we use them in this way...”

Visualization is the most important way to enhance students’ concepts in the context of this study. Previous studies have revealed that most engineering students are visual learners. They learn knowledge most effectively when they are able to see something, such as diagrams, pictures, films and videos. One main advantage of the CSA intervention is its ability to visualize abstract and complex concepts. The main difficulty of an abstract and complex concept in mechanical dynamics lies in its dynamic characteristics. When students saw an animated motion in the CSA environment, they were more likely to make sense of the principle associated with it. Besides animation, the CSA instruction also provided multiple other visual representations to elucidate abstractions of concepts and helped students form visual interpretations of what the concepts mean. Moreover, animations with interactivity had a great potential to increase the effectiveness of the CSA method in learning concepts. Many students agreed that they benefited greatly from this way of learning.

b. Manipulating Variables

“The modules show how the concepts are affected by allowing you to change different values such as mass and speed and still view how the movement is affected overall, thus, helping in the process of making conceptual connections.”

“I really like the scrollbar because your values change... the ones on the top of the modules where you change your values of, like, weight... and then I can get a conceptual idea of different situations.”

“They illustrated a concept, how things work and what is going on ... allowing me to adjust values and understand how different variables affected it.”

“I verify the conceptual ideas first by moving the scroll bars just kind of back and forth..., some of those were more confusing to me but using the scroll bar made it very easy to see that something would change or something wouldn't change.”

“Because one of the hard things of dynamics is to recognize what is tied to what else... that those variables are tied together, that was really helpful to me.”

“Well, they had different inputs that you could put in... you could put in different, all sorts of different scenarios ... so that's when the modules became a lot more, um... instructional to me, was when I could put in all those different numbers and see the different effects that took place.”

The second way of learning concepts is to explore how changes in the key variables affect system motion phenomena. The choice of parameters that can be manipulated is one of most important features of CSA modules. By manipulating parameters, students were able to interact with the CSA modules and were thus more likely to be actively engaged in understanding. By limiting the key parameters that can be controlled, the CSA modules helped students appropriately scaffold their understanding. Through investigating the effects of variables under various conditions, students were more likely to construct a deep and broad understanding of the underlying concepts.

c. Connecting Various GUI Features

“By linking the visual diagrams with animated motion and the algebraic or mathematic work gave me the "Big Picture" that I needed.”

“...the modules helped me to put the picture, mathematical equations, animations and concepts together in my head...”

“...in connection with the animation and the step by step breaking down of the equations that made me think and kinds solidify that concept in my mind.”

“My conceptual understanding got improved, definitely from the combination of those features..., the way its set up is you input the values first, but then you have the animations with the mathematical equations right underneath it. That way you can visualize what each equation is saying. I really like that part about it.”

“... I can see what’s happening, then relate the equations to what’s happening then that helps me to...to figure out dynamics...what it is, how and when things are in motion what forces and all the stuff is working on it...”

“I think it was between, you know, like, you had the free body diagrams in there, that had also connected the animation to the equations. And just all together it was very helpful...”

The third way of improving students’ conceptual understanding is to connect different GUI features, especially by linking between animations and mathematical equations. Students were able to see what happened by watching animations and then explain “why” and “how” it happened by making mathematical equations meaningful.

Providing multiple features and representations supported students' learning of different concept aspects. Integrating different features and representations to form a coordinated whole, students were able to build a correct and appropriate mental model of concepts. As a result, students were able to get a "big picture" perspective of concepts.

- Improving Students' Procedural Skills

Based on students' responses, it was found that students used three main ways to increase their procedural skills: 1) following a step-by-step process, 2) identifying mistakes and 3) analysis-synthesis process.

a. Following a Step-by-Step Process

"My procedural skills were enhanced by working with modules as they showed me the steps to problems that I would otherwise not know how to approach."

"They had clear step-by-step solutions themselves, giving a concise process for solving problems."

"It showed step by step ways to get to the correct solution. They can kind of be like a road map for some problems."

"With some of the more complicated problems, it can be a little overwhelming at first and when you see the steps all written out I am able to see the order to go and when I do the problem step by step it isn't as overwhelming. "

"After seeing it written down in a step-by-step manner in the modules, I was able to repeat the process in other problems in order to come up with correct answers."

“That helped because sometimes I would look at a problem and have no idea of where start, so the procedure helps me to look and see how to start. So I can have a start point, know the direction to go.”

Following a step-by-step process is the most important way to enhance students' procedural skills in the CSA learning environment. Each CSA module presented an entire problem-solving procedure, starting from drawing a free-body-diagram to the completion of final answers. This procedure showed not only the contents of each step, but also the organized structures and logical relations between steps. Every CSA module provided a step-by-step roadmap to help students get started, continue, and arrive at final answers. In the learning process, the CSA instruction helped students appropriately scaffold their thinking and reasoning. Moreover, if students were able to fully understand a step-by-step procedure, they were highly likely to positively transfer it to new tasks.

b. Identifying Mistakes

“There were multiple times when I got stuck on problems because I forgot about an equation or missed a force on a FBD, but the modules helped me to recognize where I had gone wrong in my process and what steps I was missing.”

“It is lined out that way I can usually see where I made an error, which is usually not a big error that I made, but it was still enough to affect the solution and seeing them in the modules kind of makes me realize...”

“I have the procedure ... then I can check where I'm wrong and where I'm right...where in here I can see exactly where I need to change so, in the procedures.”

“...if you can't see what you're doing wrong, sometimes it gets frustrating. But this is, helps you see exactly what you're doing, and that, where you're making those mistakes so that later you don't make the same mistake again.”

The second way to increase students' procedural skills is to identify mistakes that they made during the problem-solving process. When students got stuck and needed help during the learning process, the CSA instruction helped them identify errors that they were making, and also helped them find out how to correct errors. Deficiencies or missing links of students' procedural knowledge generally led to their problem-solving mistakes. With the process of identifying and correcting mistakes, students gradually filled in their knowledge gaps. As a result, students built an appropriate and strong procedural knowledge structuring. Therefore, they would not make the same mistakes again.

c. Analysis-synthesis Process

“They helped me to break down the problem into clear steps leading to the solutions. The problems became less complicated to solve.”

“...it's good to help you break it down and look at the different parts, and so it's more clear what the, um, the procedure is for solving certain types of problems...”

“...were a little bit more difficult problems. But I think this one did a really good job at making it simpler, you know. It took a complex problem and made it look simple by breaking it down, and organizing your solution process.”

“...being able to break down the different forces and the different parts of the problem... it helps your procedure like to just know where to start and how to solve...”

“...when I’m solving the problem, and think about each part, and then put them in as a whole, versus just trying to solve it as a whole.”

“They showed how to move from one step to another. They did help in showing the relationships of one to another. ”

“...the way to set up... break down the equations, then you combine them together, to see the higher equations there, and then you get the whole process... to know exactly what you have, what you try to find... I think that’s all helping me.”

“...they were in a progression, a step by step progression. The breakdown of the equations... and kind of helps you put everything together, so the process was really, really helpful.”

The third way of learning procedures is the use of an analysis-synthesis process. This process consists of two steps, breaking down a whole problem into components and then combining separate elements to form a coherent whole. Each CSA module offered an organized step-by-step problem-solving procedure. This structure divided a complex process into several elements with low-complexity, which made difficult procedures easier to learn. Next, students put all components together based on the logical structures that the CSA modules provided to complete a correct solution. In turn, the use of an analysis-synthesis process helped students develop a deep understanding of the knowledge and structures of the underlying procedures.

- Increasing students' confidence and motivation

“My confidence definitely increase, my motivation, I think dynamics is interesting when using simulation, so I say neutral in motivation.”

“It doesn't increase my motivation, but it does help understand things, that, I guess, increases confidence..., just a little bit.”

“The modules probably didn't increase my motivation...they didn't boost my confidence a lot higher, but it made me more confident.”

Students' confidence is reflected in whether they believed that they could do better in solving problems after receiving the CSA instruction. Students expressed a little more confidence during learning dynamics in the CSA environment ($M = 3.34$, see Table 7.2). Students developed effective practices for learning dynamics in the CSA environment; therefore the CSA modules increased their confidences toward learning dynamics.

Students' motivation in CSA use is reflected in whether they were willing to learn dynamics. Students were more inclined towards a neutral attitude that CSA modules increased their motivation to learn ($M = 3.12$, see Table 7.2). Previous research has revealed that students suffer learning anxiety and lack interest when facing tough courses. This negative perception is often strong and persistent. Mechanical dynamics is considered to be one of the most challenging courses taken during students' undergraduate study. Obviously, it was difficult to change students' negative perception only through a dozen CSA learning modules.

Students' Perceptions of Effectiveness of Instructional and Technical Designs

Characteristics of CSA modules that students learn the most from

While the effectiveness of a CSA module is influenced by a number of variables, the technical and instructional designs of the module are a major focus of this analysis. Based on students' responses to the questions in the surveys and interviews, three main factors of a successful CSA module were identified, namely: 1) complexity of technical problem, 2) new or difficult principles/materials involved, and 3) high-quality visualization. These factors were discussed in detail individually in terms of their impacts on and effectiveness on learning.

- **Complexity of Technical Problem**

“I learn the most from modules that are slightly difficult but not overwhelming.”

“They also were fairly complex problems which allowed me to better understand how to solve other problems that are less complex.”

Previous research has shown that problem complexity is a crucial issue for the success of computer-based learning approach (Leung, 2003). When designing a CSA module, designers should pay much attention on how a complex question should be presented to learners. Students thought that they learned most from the modules of moderate to slightly high complexity. Conversely, students learned less from the ones with overly low or overly high level of complexity.

a. Low Complexity

“I learned the least from these problems because I was initially more exposed to the content of these problems from previous physics

classes. The processes were clearer to me so solving these problems was more of a review instead of a learning process.”

“I learned the least from the first 3 modules because the concept was already straight forward and the module didn’t seem necessary for my understanding.”

“the one’s I spent less time with were the ones I learned the least from, because I was more familiar with that principle... it was easy to go through, so the room for improvement was last parts.”

For some materials or topics in a dynamics course, such as the projectile motion of Modules 1, 2 and 3, students had experienced exposure in previous physics class. Students thought they already had a good understanding of the contents before receiving the CSA instruction. In the CSA learning process, students often passed through a series of phases and therefore did not really get involved in effective learning. Therefore, if students thought they understood the contents of a CSA module, they often used it much less effectively and learned less from it.

b. High Complexity

“I think I learned the least from module 8 because that’s the one that was complicated, I didn’t understand what was happening. So I wasn’t really able to learn from it, like I just knew the answer I was supposed to get, but I didn’t really know how to get there.”

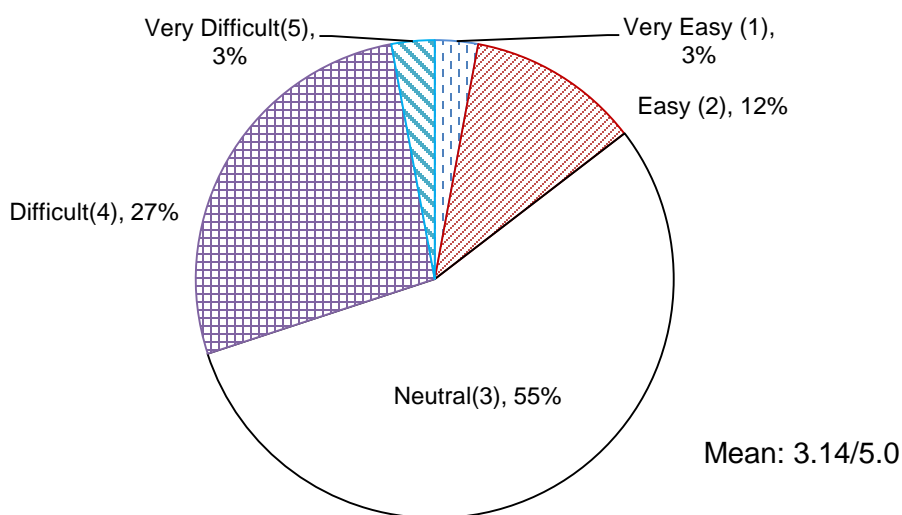
“...module 12 was extremely complicated and I felt like the module didn’t help me understand the principle any better.”

“...number 4 was confusing. It wasn't till 2 days ago (the very end of semester) that I was able to understand how it worked and that was because I got help from a friend of mine.”

Students commented that they learned less from the modules with extremely high complexity, such as Modules 8 and 12. Overly complex contents being addressed in a module required high cognitive demands, and therefore increased students' cognitive workloads in solving the problem. Particularly, learners with weak background might easily be overwhelmed by the complexity, and might have no idea about where and how to get started. They had to seek additional help outside the module to make learning meaningful.

In summary, the complexity of a technical problem is a crucial factor affecting students' academic performance in the CSA learning environment. It is important to determine how a complex problem should be presented to students. Students' responses suggest that moderate to slightly high complexity is most appropriate for an effective CSA module.

Based on students' ratings in surveys, the result shows the average difficulty level of technical problems addressed by Modules 1 -12 was 3.14(1-Very easy and 5-Very difficult), as shown in Figure 7.2. It implies that students exhibited a neutral attitude towards the complexities of technical problems. According to the findings above, the CSA modules might be more effective if their average difficulty level was somewhat increased.



(1-Very easy and 5-Very difficult; N = 69; data from Survey)

Figure 7.2 Average Difficulty Level of Technical Problems Addressed by Module 1-12

- New or Difficult Principles/Materials Involved

“I learned the most out of 10-12 since this was a harder subject for me to learn...and therefore the most useful.”

“...number 8 was the most useful of these ones. I remember that problem being tough conceptually and I spent a lot of time in the module trying to understand the forces.”

“It seemed like in the later ones, as the concepts got a little more difficult, I relied more heavily on the modules.”

“Module 5 was completely new to me... I had no idea what was going on with them, but that module helped a lot.”

“These were concepts that I didn’t fully understand in class, but as I worked through them, it made a big difference in my understanding.”

“I liked module 6 the most, because I had a grave misconception thinking the blocks would move equally as quickly...”

Some principles and materials in mechanical dynamics are very complex, and become great challenges to understanding. Examples include relative motion (Module 5) and angular impulse and momentum (Module 12), as student comments demonstrate. These principles consist of some hidden mechanisms which are outside our direct experience, and involve many different types of knowledge, including spatial, casual, and dynamic knowledge. These principles are therefore difficult to illustrate and explain in a lecture-based classroom. The CSA instruction just has strength in this respect. It shows a dynamic movement in a spatially precise manner, making complex understanding straightforward and intuitive to students. Therefore, the CSA approach made a big difference in helping students understand these complex concepts.

- High-quality Visualization

“They provided a good visual that I needed to understand what was happening in the problem.”

“These modules gave me the opportunity to visualize the concept at a deeper level.”

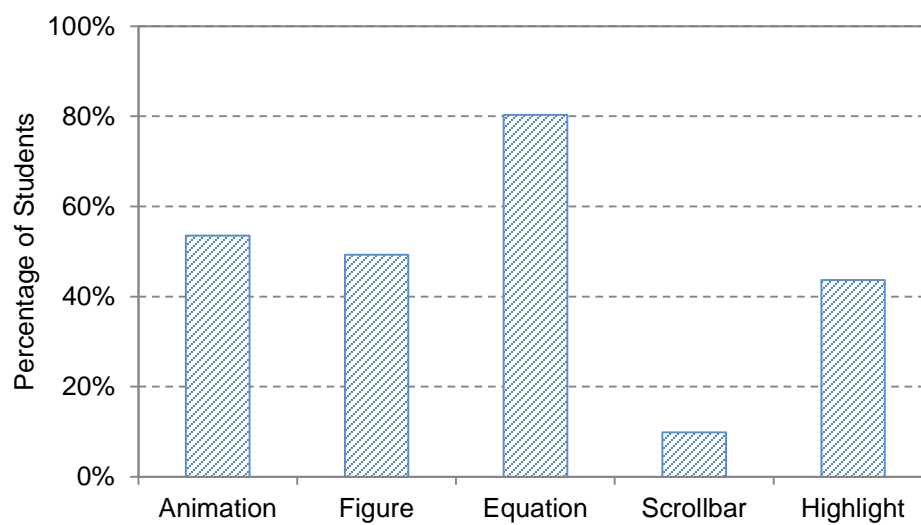
“The selected problems had clear visualizations that helped me better understand the problem.”

“It made those problems easier to visualize and understand what was going on.”

“I was having a hard time picturing the question and the animation helped significantly.”

As discussed above, visualization is one of most important ways to understand concepts for learners in the CSA learning environment. The qualities of visual representations have a significant impact on students' learning. Student commented that high-quality and effective visualizations helped them clearly understand problems, and helped them understand concepts to a higher level. Obviously, the quality of visualization is an important issue for developing successful and effective CSA modules.

Students' feedback on CSA modules



(N = 71; data from Survey)

Figure 7.3 Multimedia User Interfaces of CSA Modules Students Like Most

Figure 7.3 shows the five multimedia user interfaces of the CSA modules that students like most. Every student usually liked more than one features. The features students like are often the features which were most helpful for their learning. The results show that students liked mathematical equations the most (80%), and they liked scrollbars the least (10%). This suggests that the educational values of mathematical formulas were significant and the educational values of scrollbars were limited in the

CSA environment. As far as scrollbar were concerned, students explained why they liked the feature less:

“I didn’t like the scroll bars or the sliders. I thought that they were a little hard to click on the right spot on them to make them move and to have them move smoothly.”

“I’d try and move it, and it would, like, get stuck and you wouldn’t be able to move it. So you had to go really slow...”

“I didn’t like that I had to use a scroll bar inside of a window in canvas that already has a scroll bar of its own... It is hard to scroll.

“I don’t really like how the scroll bar works, the scroll bar on your computer screen and then you have a scroll bar on canvas, I think it would be more helpful...just be using one scroll bar to go up and down.”

“If you could make all the variables a slider-selectable value I think that would help.”

“If you maybe changed the scroll bar to an input box that the students could type numbers into, that would help a lot with the technical issue I was having...”

Students pointed out that scrollbars were not user-friendly, for example, they responded slowly. More importantly, they gave some suggestions on how to fix the issue. Their suggestions focused on the following three aspects: a) making scrollbars move smoothly; b) changing horizontal scrollbar to input box, and c) removing vertical scrollbars. Other student feedback and suggestions regarding the technical and

instructional designs of CSA modules are discussed below, including explicit instruction, screen fitting, and clear screen layout.

- Explicit Instruction

“I thought that some of the problems were pretty difficult, e.g. module 8, the transverse and radial components are confusing ...I think some of the theory could be explained in the modules to better improve learning.”

“...I kind of think that a hint as to why they are like that would be really helpful...Like very concise hints to the mathematical equations portions of it, ...why the mathematical equations worked out the way they did.”

“I think basically just the equations when there would be some sort of equation that I didn't know where it was derived from. I think that was the hardest part to understand... maybe that would be good, to have a button we could push so that if we are stuck we could push it and then it would explain.

“I think those steps in-between it was hard to follow what was actually happening ...you know that there should have 2 steps in-between there, but nothing was shown. So sometimes the equations were just solved too quickly. You don't know what happened to variables they just went away or something. So showing those steps in-between where all those variables went and what you're plugging in would be helpful.”

“A well done movie relating the theory and the equations would be helpful. Just a quick 20 second video to explain things might help a little.”

“It might be helpful if there was a review box at the end to explain any really important parts that should have been learned from the modules...”

Some students complained that they were not able to get through some steps in-between, and that they needed more and more specific information on the underlying problem-solving procedures. They suggested that it would be very helpful if the CSA instruction provided hints or short videos for steps that were hard to understand, or a review box at the end of solution page. When learners needed specific supports, they could click these buttons to receive a detailed explanation.

- Screen Fitting

“It would help if these could be formatted to fit a smaller laptop screen. When it is in Canvas it is hard to see the full picture all at once.”

“But it seemed like the animation or the image was much larger than what would fit in my screen. And so, if I wanted to do this animation right here I would have to scroll down to run button, and hit it. And then I’d have to scroll up to see it. So sometimes by the time I hit run and then scrolled back up it would...The animation was already going and it would be half way over...”

“But I can’t see everything at same time... I have to go back to look at that other thing... so that was a little bit frustrating. I think the window should be a little bit bigger...to view the full module box.

“...if there was some way I could like have it pop out into its own window, that would, like, fill up more of my screen, instead of having to take my canvas screen and shrink it so that it would fit.”

In terms of the issue of screen fitting, students commented that some animations and images were too large to fit on their laptop screens, which caused a big inconvenience when running CSA modules. They had to shrink items on the screen or scroll down to match. This technical problem caused students frustration and impeded their learning.

- Clear Screen Layout

“...seeing too much information in one slide... I think I would pay less attention to it...”

“You could split the problem-solving page into a couple of pages, so as to make it more understandable and easy to follow.”

“Make the window of the modules the same size as the browser page to keep it simple and clear.”

Students also suggested that CSA modules should not include too many contents on a single screen slide. Students might easily feel disoriented and become distracted by irrelevant information. It is essential to provide a clear, simple and balanced layout that helps students focus on important contents and understand contents more easily.

CHAPTER 8

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

The goal of this dissertation research was to improve students' conceptual understanding and procedural skills in particle dynamics, and therefore improve their problem-solving skills by developing, implementing, and assessing a total of 12 interactive CSA learning modules. This final chapter summarizes the results of this study to answer the two research questions, as well as discusses the instructional and technological implications. It concludes with an exploration of possible future directions for the research. The two questions form the basis for this study, and are given as follows:

Research question 1: To what extent are the developed computer simulation and animation modules effective in improving students' conceptual understanding and procedural skills in particle dynamics, therefore improving students' problem-solving skills?

Research question 2: What are students' attitudes toward and experiences with the developed CSA learning modules?

8.1 Answer to Research Question 1

The first research question is related to whether student learning gains were significantly different according to the instructional methods used. Based on the results of a quasi-experimental research design that involved pretests and posttests in the comparison group and the intervention group, the 12 CSA learning modules developed from this study increased students' class-average conceptual and procedural learning gains by 29% and 40%, respectively. Findings from pretest/posttest evaluations include the following:

- a. Students' conceptual understanding and procedural skills were divided into three levels: simple, moderate and complex. The CSA instruction had similar effects on increasing students' different levels of conceptual understanding, and was far more effective in increasing students' moderate level of procedural skills.
- b. Student participants were divided into a low-performing subgroup and a high-performing subgroup. Students in the high-performing subgroup benefited more from the CSA instruction in learning concepts and procedures than those in the low-performing subgroup.
- c. Students developed their conceptual understanding and procedural skills in a gradual, incremental and level-by-level process in the CSA environment. The development process was bi-directional and asymmetrical in general.
- d. When properly designed, the CSA modules helped students build appropriate conceptual knowledge structures and appropriate procedural knowledge structures.

8.2 Answer to Research Question 2

The second research question was intended to explore students' attitudes toward and experiences with CSA learning. Findings from survey questionnaires and interviews include:

- a. Students agreed that the CSA instruction improved their conceptual understanding and procedural skills in learning particle dynamics. Students also agreed that learning with the CSA method slightly increased their confidence. Students were more inclined to a neutral attitude that learning with CSA modules increased their motivation. Overall, students had a positive perception of CSA learning.

- b. Students used three main methods for increasing their conceptual understanding: 1) visualization, 2) manipulating variables, and 3) connecting various GUI features. Students used three main ways to increase their procedural skills: 1) following a step-by-step process, 2) identifying mistakes, and 3) analysis-synthesis process.
- c. Only when students spent more than 15 minutes on a CSA module did they start to learn something from the module. When students spent more than 30 minutes on a module, they were more likely to be involved in deep learning and maximize the educational benefits of the CSA modules.
- d. Students learned most from the CSA modules with moderate to slightly high complexity. Students made big gains in understanding complex concepts in the CSA environment with high-quality and effective visualizations.
- e. Students' suggestions for improving CSA modules focus on: explicit instruction in-between steps, screen fitting, and clear screen layout.

8.3 Educational Implications

Student participants of this study were all from the College of Engineering at Utah State University. The findings of the study may vary when applied to other conditions. Based on the findings of this study, as well as student perceptions and feedback, several important educational implications are made. Specifically, the educational implications include:

1. Students' competencies in engineering dynamics require both conceptual understanding and procedural skills. It is important that developing both types of abilities should be included in instruction. If instruction focuses on developing one

type of ability and downplaying another one, students will not be fully competent in solving dynamics problems (Rittle-Johnson, Siegler and Alibali, 2001).

2. Conceptual understanding and procedural skills should be developed in a bidirectional, gradual, and level-by-level process. Some educators treat the relations between the two types of skills as unidirectional. They claim that conceptual knowledge can support improved procedural knowledge, but not vice versa. Therefore, they tend to help students fully develop conceptual understanding first and then develop procedural skills (Rittle-Johnson, Siegler and Alibali, 2001). It was found that the relation between conceptual understanding and procedural skills are iterative. The development process of the two types of skills is bidirectional and gradual. Effective instruction should present only small amounts of materials at a time and highlight iterative development of the two types of skills.
3. Students should be encouraged to continue to improve their conceptual understanding when they have fully developed their procedural skills. The results of this study show acquisition of procedural knowledge might precede that of conceptual knowledge during the learning process, and therefore procedural skills might be fully developed first. Students were more likely to discontinue improving their conceptual understanding after mastering procedural skills. At this phase, students may be able to get correct answers for some questions but without fully understanding the questions. However, they can only perform successfully on routine questions. Insufficient understanding will lead to difficulties in transferring procedures to new contexts.

4. The CSA approach cannot replace human tutors when teaching high-order thinking and reasoning. The educational value of the CSA approach for increasing high-level learning skills might be limited. The results of this study show that the developed CSA modules have limitations in strengthening students' skills for knowledge synthesis and correcting students' persistent misconceptions.

8.4 Implications for CSA Design

The implications for CSA design include:

1. Providing more explicit and direct instructions for difficult content helps students develop their conceptual understanding and procedural skills in a balanced way. It was found that an uneven development in the two types of skills mainly lies in the fact that students still had a poor understanding of difficult concepts and procedures after learning with CSA modules. The CSA approach can be more effective in supporting learning if more explicit instructions on difficult materials are offered to students, for example, by giving hints.
2. Designing appropriate problem representations helps students link their conceptual and procedural knowledge. When students are inclined to extract concepts from their experiences solving calculation problems, CSA modules can be more effective in supporting learning if they put emphasis on mathematical representations. When students are prone to enhance procedural skills through correcting their misconceptions, CSA modules can be more effective in supporting learning if they focus on visual representations.
3. CSA should provide multiple representations to help students learn concepts and procedures. The results of this study show that different students learn concepts

and procedurals in different ways. Providing multiple ways can meet diverse needs. Moreover, by combining different representations with different properties, learners are not limited by the strengths or weaknesses of one particular representation. Thus, they are able to reason more flexibly when solving a problem.

4. The CSA approach can help low-performing students better learn if it offers a review section of background knowledge. The results of this study show students in the high-performing subgroup benefited more from the CSA learning than the ones in the low-performing subgroup. One important factor contributing to the performance differences is students' different prior knowledge. The review section can effectively help low-performing students refresh their knowledge and fill in any gaps, so they can work through new concepts more smoothly.
5. Animations should include interactive features and vector presentations when presenting physical motions. With interactivity, students are able to learn by actively doing, rather than by passively watching system motions. A vector-based animation can properly show the nature of concepts of mechanical dynamics. It is one big advantage of using CSA over static pictures of learning dynamics.

8.5 Recommendations for Future Research

Based on the findings from this dissertation study, several recommendations for future work are made as follows.

1. The first recommendation for future study is to conduct a similar study in various locations. In this study, all student participants were from Utah State University, therefore, it is difficult to generalize the findings of this study to a broader

population. Further research should be conducted in other states and in other countries.

2. The second recommendation is to investigate the impact of CSA approach on female engineering student learning and minority engineering student learning. Student participants in this study were predominantly white males (90%). Generally, there are different learning styles and thinking strategies between white males, minority males and females. Engaging more female and minority participants will help increase the generalizability of the results. This will also help design more effective CSA modules for these underrepresented students.
3. The third recommendation is to use a systematic random sample. This study used convenience sampling to select participants. In a random assignment environment, many factors other than independent and dependent variables can be controlled; consequently, it is easier to estimate the effect of the intervention on student learning.
4. The fourth recommendation is to develop more CSA modules for each dynamics principle, especially for some difficult topics such as relative motion. A dynamics principle was generally presented with a single CSA module. As students suggested in the interviews, only one learning module sometimes provided an insufficient understanding of concepts and procedures. Learning with multiple modules corresponding to a principle or topic should be more helpful in improving their problem-solving abilities, especially for difficult principles or topics.
5. The last recommendation for future studies is to improve the designs of the CSA modules. Participants provided some valuable feedback on improving CSA

modules in terms of technological and instructional designs. For example, the CSA modules would be more effective if they provide hints in solution steps, a clear screen layout with less information, and more user-friendly input options.

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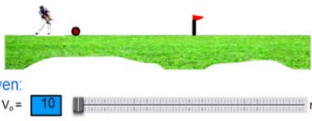


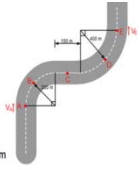
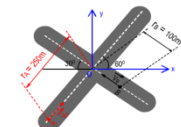
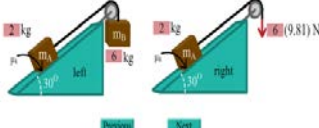
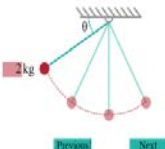
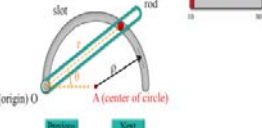
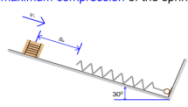


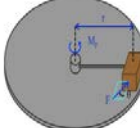
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APPENDICES

Appendix A

Representative Computer Graphical User Interfaces for 12 CSA Learning Modules

 <p>Given: $V_0 = 10$ m/s $\theta = 10$ deg.</p> <p>Find: Total travel time t_{total} Total travel distance s The maximum height</p> <p>Run Animation</p>	 <p>Given: $V_0 = 10$ m/s $\theta = 30$ deg.</p> <p>Find: The initial velocity V_0 at which the ball hits the target</p> <p>Run Animation</p>	 <p>Given: $V_0 = 30$ m/s $\theta = 10$ deg.</p> <p>Find: The initial angle θ at which the ball hits the target</p> <p>Run Animation</p>
<h2>CSA Module 1</h2>		
<p>Given:</p> <ul style="list-style-type: none"> The car decelerates at a constant rate along a curved road ABCDE Initial speed $V_i = 40$ m/s Final speed $V_f = 20$ m/s Arc length: $S_{AB} = 200(\frac{\pi}{2}) = 157$ m $S_{BC} = 200(\frac{\pi}{2}) + 50 = 364$ m $S_{CD} = S_{BC} + 50 + 400(\frac{\pi}{4}) = 728$ m $S_{DE} = S_{CD} + 400(\frac{\pi}{4}) = 1,042$ m <p>Find:</p> <ul style="list-style-type: none"> Velocity at B, C, D Acceleration at B, C, D 	 <p>Given:</p> <ul style="list-style-type: none"> The initial position of car A: $t_{A0} = 250$ m The initial position of car B: $t_{B0} = 100$ m Car A moves at a constant speed of $V_A = 20$ m/s Car B moves at a constant speed of $V_B = 10$ m/s <p>Find: At time $t = 1$ seconds</p> <ul style="list-style-type: none"> Positions r_A and r_B (in vector forms) Velocities \vec{V}_A and \vec{V}_B (in vector forms) Relative position \vec{r}_{AB} (in vector form) Relative velocity \vec{V}_{AB} (in vector form) 	<p>Given: $m_A = 2$ kg, $m_B = 6$ kg. Coefficient of kinetic friction between block A and the ground, $\mu_k = 0.2$</p> <p>Find: The acceleration of Block A.</p>  <p>Previous Next</p>
<p>Given: Ball mass $m = 2$ kg. Find: Tension force at $\theta = 60^\circ, 90^\circ, 120^\circ$</p> <p>Initial angle $\theta = 30^\circ$ The length of the cord is $l = 2$ m The ball is at rest in the initial position O</p>  <p>Previous Next</p>	<p>Given: A rod is used to move a smooth particle along a circular slot in the horizontal plane. The radius of the circular slot $\rho = 0.3$ meter. The mass of the particle $m = 0.2$ kg. $\dot{\theta} = 0.5$ rad/s. The rod rotates at a constant angular speed $\dot{\theta} = 2$ rad/sec. Neglect friction.</p> <p>Find: Acceleration of the particle and the force the rod acts on the particle at angle $\theta = 100$ deg</p>  <p>Previous Next</p>	<p>Given: Mass of the box $m = 25$ kg Initial position of the box $S_0 = 6$ m Spring constant $k = 150$ N/m and the spring is initial uncompressed Initial speed of the box v_1 (variable) Coefficient of kinetic friction between the box and the inclined plane μ_k (variable)</p> <p>Find: The maximum compression of the spring S_{max}</p> 
<p>Given: Mass of the box $m = 25$ kg Spring constant $k = 150$ N/m and the spring is initially uncompressed No friction between the box and the ground surface Initial speed of the box v_1 (variable)</p> <p>Find: The maximum compression of the spring S_{max}</p> 	<p>Given: Mass of bumper car A $m_A = 160$ kg Mass of bumper car B $m_B = 180$ kg Initial velocity of bumper car A (V_{A1}) (variable) Initial velocity of bumper car B (V_{B1}) (variable) Coefficient of restitution between the two bumper cars e (variable)</p> <p>Find: Velocity of bumper car A after the collision (V_{A2}) Velocity of bumper car B after the collision (V_{B2}) Average force between the two cars if the collision takes place in 0.05 seconds</p> 	<p>Given:</p> <ul style="list-style-type: none"> Mass of block $m = 2$ kg Moment $M_0 = (25 \cdot t)$ N·m (t is time) Force $F = (3 \cdot t)$ N Radius $r = 6$ meters Ignore friction and the size of the block Initial velocity of block $v_1 = 11$ m/s Angle $\theta = 60$ deg <p>Find: Velocity of the block v_2 at $t = 4$ seconds</p> 

Appendix B

Letter of Informed Consent



Department of Engineering Education
4160 Old Main Hill
Logan UT 84322-4160
Telephone: (435) 797-2948



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USU IRB Approval: Jan. 3, 2014
Approval Terminates: 01/02/2015
Protocol #5584
IRB Password Protected per IRB Administrator

INFORMED CONSENT

Interactive Computer Simulation and Animation Learning Modules: a Mixed-Method Study of Their Effects on Students' Problem Solving in Particle Dynamics

Introduction/ Purpose Professor Ning Fang in the Department of Engineering Education at Utah State University is conducting a research study to find out more about if and how computer simulation and animation impact student learning and problem solving in Engineering Dynamics. You have been asked to take part because you are enrolled in ENGR 2030 Engineering Dynamics course. There will be approximately 400 participants at this site. There will be approximately 800 total participants in this research. A student researcher Yongqing Guo will also be involved in this study.

Funding National Science Foundation

Procedures This project consists of two phases. Phase I is the period of the project when the researcher will develop a set of computer simulation and animation (CSA) modules. Phase II of the project is when the researcher will implement and assess the developed CSA modules. If you agree to be in this research study, the following will happen to you. If you are in Phase I, you will be treated as a student in the control group and will be asked to give the researcher your permission, by signing this Informed Consent, to use your mid-term and final exam scores in Dynamics as the control-group data. You will also be asked to take a pre-post test on a set of dynamics problems; complete a survey on student learning styles; complete a survey on motivated strategies for learning. If you are in Phase II, you will be treated as a student in the quasi-experimental group and will be asked to do the following:

1. Run the CSA modules and take a pre-post test to assess your learning gains.
2. Respond to an anonymous questionnaire survey to assess your attitudes towards and experiences with the CSA modules.
3. Take an online survey on student learning styles.
4. Give the researcher your permission by signing on this Informed Consent, to use your mid-term and final exam scores in Dynamics as the quasi-experimental data.
5. A limited number of students (that is, not all students) will be selected for interview to ask about their attitudes towards and experiences with the CSA modules.
6. For selected students who agree to participate in Phase II of the study, there will be two groups. Each group will conduct pre-post tests that include a set of dynamics problems. One group will use the traditional pen-and-pencil method to solve the dynamics problems; the other group will be provided computer simulations to help solve the dynamics problems. The think-aloud, problem-solving process of students in these groups will be video-recorded, and the video transcripts as well as your written responses to those dynamics problems will be coded for subsequent analysis. A semi-structured interview will also be conducted for those students in these groups in order to understand how students solve those dynamics problems with or without the assistance of computer simulations. A semi-structured interview will also be conducted for those students in these groups in order to understand how students solve those dynamics problems with or without the assistance of computer simulations.

It will take approximately 20 minutes to run each CSA module and complete the corresponding pre-post test; 10 minutes for responding to the questionnaire survey; 30 minutes for being interviewed (if you are selected as an interviewee); 10 minutes for responding to the online survey on learning styles. It will

V7 06/15/2011



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INFORMED CONSENT

Interactive Computer Simulation and Animation Learning Modules: a Mixed-Method Study of Their Effects on Students' Problem Solving in Particle Dynamics

take approximately one hour to complete think-aloud, problem-solving activities (if you are willing to participate in these activities).

New Findings During the course of this research study, you will be informed of any significant new findings (either good or bad), changes in the procedures, risks or benefits resulting from participation in the research, or new alternatives to participation that might cause you to change your mind about continuing in the study. If necessary, your consent to continue participating in this study will be obtained again.

Risks Participation in this research is considered minimal risk; however, some students who do not perform well in pre-post tests may feel a little bit frustration about their learning. This frustration is typical for beginners learning any subject of study. Other than this potential frustration, there is no other risk. Student participation will not impact your class grade.

Benefits There may or may not be any direct benefit to you from these procedures. The investigator, however, may learn more about the effectiveness of computer simulation and animation in improving students' problem solving. The findings from this research may improve the scientific understanding of how computer simulations and animations impact student learning and their problem-solving skills.

Explanation & offer to answer questions Professor Ning Fang has explained this research study to you and answered your questions. If you have other questions or research-related problems, you may reach Dr. Ning Fang at (435) 797-2948 or by email at ning.fang@usu.edu

Payment/Compensation If you choose to participate in the study (either Phase I or Phase II), you will be paid \$10 to thank you for your time for completing the questionnaire surveys. If you are selected for an interview during the Phase II project, you will be paid \$15.00. If you are willing to participate in think-aloud, problem-solving activities and be interviewed, you will be paid \$25.00.

**(Note: If you will receive payments, gift cards or similar items of value for participating in this research, the Internal Revenue Service (IRS) has determined that if the amount you get from this study, plus any prior amounts you have received from participating in research studies at USU since January of this year, total \$600 or more, USU must report this income to the federal government. If you are a USU employee, any payment you receive from this study will be included in your regular payroll).*

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigator and the graduate student researcher will have access to the data which will be kept in a locked file cabinet or on a password protected computer in a locked room. To protect your privacy, personal, identifiable information will be removed from study documents and replaced with a study identifier. Identifying information will be stored separately from data and will be kept.

V7 06/15/2011


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Interactive Computer Simulation and Animation Learning Modules: a Mixed-Method Study of Their Effects on Students' Problem Solving in Particle Dynamics

After the data have been gathered and the analysis is completed, the coding sheet linking the students to this study will be destroyed immediately. All video/audio records (digital files) will be kept confidential in a laptop computer in a locked filing cabinet in Dr. Fang's office. Only the researchers of this project will have access to these video/audio records to ensure confidentiality. These digital files will be destroyed immediately after data analysis is completed within the period of this research.

IRB Approval Statement The Institutional Review Board for the protection of human participants at Utah State University has approved this research study. If you have any questions or concerns about your rights or a research-related injury and would like to contact someone other than the research team, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu to obtain information or to offer input.

Copy of consent You have been given two copies of this Informed Consent. Please sign both copies and keep one copy for your files.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."



 Ning Fang, Principal Investigator
 4350787-2347, ning.fang@usu.edu



 Yongqing Guo, Student Researcher
yq.guo@aggiemail.usu.edu

Signature of Participant By signing below, I agree to participate.

Participant's signature

Date

Participant's last name, first name (please print)

Appendix C
Survey Questionnaire

Accessibility and functionality of CSA modules

1. Where did you typically use CSA modules?
 - A) On-campus
 - B) Off-campus

2. How often did your use these modules?
 - A) I used them only when I need to complete bonus homework, and then I did not visit them again.
 - B) I used them to complete bonus homework, and also visited them again later.

3. Did you run these modules prior to exams in order to better prepare for exams?
 - A) Yes, I always run these modules before each exam.
 - B) Yes, I sometimes run these modules before some exams.
 - C) No, I did not run any module prior to any exam.

4. How long did you usually spend on a module?
 - A) Less than 15 minutes
 - B) Between 15 and 30 minutes
 - C) Between 30 and 45 minutes
 - D) More than 45 minutes

5. Did you use CSA module individually or in team?
 - A) Always individually
 - B) Most often individually, sometimes in team.
 - C) Always in team
 - D) Most often in team, sometimes individually

6. Are the modules easy to navigate?
 - A) Very easy
 - B) Easy
 - C) Neutral
 - D) Difficult
 - E) Very difficult

7. Which features of the modules do you like most? Select all that are applicable.
 - A) Animations
 - B) Figures
 - C) Math equations
 - D) Scrollbars
 - E) Color that highlights important items

8. If you have any comments on the **computer graphical user interfaces designs** of the modules, please provide below:

Motivation and confidence of student learning

9. Do you agree with the statement: "Overall, these modules increase my **confidence** for learning engineering dynamics"?

- A) Highly agree
- B) Agree
- C) Neutral
- D) Disagree
- E) Highly disagree

10. Do you agree with the statement: "Overall, these modules increase my **motivation** for learning engineering dynamics"?

- A) Highly agree
- B) Agree
- C) Neutral
- D) Disagree
- E) Highly disagree

Interactivity

11. Please describe **how** you run CSA modules, i.e., describing the entire process from the beginning to the end. For example, how did you find solutions to posttest bonus homework assignments? Did you try to work out the solutions on your own first, and then use the modules to validate your solutions; or did you heavily rely on the modules to find out the solutions?

Quality of the technical dynamics problems designed for CSA modules

12. Among the 12 modules for particle dynamics (**Modules 1-12** that cover textbook chapters 12, 13, 14, and 15), which **technical dynamics problems** designed for modules do you like most? Select all that apply:

Among the following 10 topics for particle dynamics:

- 1) Technical problem addressed in Module 1
- 2) Technical problem addressed in Module 2
- 3)
- 12) Technical problem addressed in Module 12

13. Explain why you like those technical problems that you have selected in answering the above question.

14. Among **Modules 1-12** for particle dynamics, which **technical dynamics problems** designed for the modules can be re-designed and improved? Why?

15. Overall, what do you think of the level of technical difficulty of the dynamics problems addressed by **Modules 1-12** for particle dynamics?

Student learning outcomes associated with CSA modules

16. Among **Modules 1-12** for particle dynamics, which modules did you learn **the most** from? Why?

17. Among **Modules 1-12** for particle dynamics, which modules did you learn **the least** from? Why?

18. Do you agree with the statement: "Overall, **Modules 1-12** increase my *conceptual understanding* of particle dynamics problems"? "Conceptual understanding" means the understanding of dynamics concepts and principles.

- A) Highly agree
- B) Agree
- C) Neutral
- D) Disagree
- E) Highly disagree

19. Please provide a few examples of how **Modules 1-12** increase your conceptual understanding of particle dynamics problems.

20. Do you agree with the statement: "Overall, **Modules 1-12** increase my *procedural skills* of solving particle dynamics problems"? "Procedural skills" means the skills of solving dynamics problems step-by-step, such as drawing necessary diagrams and setting up math equations to obtain a numerical solution to dynamics problems.

- A) Highly agree
- B) Agree
- C) Neutral
- D) Disagree
- E) Highly disagree

21. Please provide a few examples of how **Modules 1-12** increase your procedural skills of solving particle dynamics problems.

22. Do you agree with the statement: "Overall, **Modules 1-12** increase my *learning* of particle dynamics"? Learning is defined as all aspects such as conceptual understanding, procedural skills, building connection between conceptual understanding and procedural skills, motivation, interest, and so on.

- A) Highly agree
- B) Agree
- C) Neutral
- D) Disagree
- E) Highly disagree

23. How do you compare the ways in which you learn from **Modules 1-12** and from textbook problem examples?

24. What challenges did you have in using **Modules 1-12** to learn particle dynamics?

25. Provide your comments on how to make the design of **Modules 1-12** better. Also provide any other comments that you want us to be aware of.

Appendix D
Interview Questions

1. Accessibility and functionality of CSA modules

- Where did you typically use CSA modules (on-campus or off-campus)?
- When and how often did you use CSA modules? (Did you use CSA modules for completing bonus homework only? Or for other purposes also? How long did you usually spend on a CSA module?)
- Did you use CSA module individually or in team?
- Are CSA modules easy to navigate? Which navigation features (e.g., *animations, figures, math equations, and scrollbars*) do you like most? Why?
- Do you have any comments on the computer graphical user interfaces designs of CSA modules?

2. Motivation and confidence of student learning

- Overall, do you think CSA modules increase or decrease your motivation and confidence for learning engineering dynamics?

3. Interactivity

- How did you run CSA modules? Please describe the entire process from the beginning to the end. (How did you find solutions to post-test bonus homework assignments?)

4. Quality of the technical dynamics problems designed for CSA modules

Among the following 10 topics for particle dynamics:

- Projectile Motion of A Particle
- Particle Kinematics: Normal and Tangential Components of Curvilinear Motion
- Particle Kinematics: Relative Motion
- Particle Kinetics: Force & Acceleration
- Particle Kinetics: Force & Acceleration Normal and Tangential Coordinates
- Particle Kinetics: Force & Acceleration Cylindrical Coordinates
- Particle Kinetics: Principle of Work and Energy
- Particle Kinetics: Conservation of Energy
- Particle Kinetics: Linear Impulse and Momentum
- Particle Kinetics: Angular Impulse and Momentum

- Which technical dynamics problems designed for CSA modules do you like most? Why?
- Which technical dynamics problems can be re-designed and improved? Why?
- What do you think of the level of technical difficulty of the dynamics problems addressed by CSA modules?

5. Student learning outcomes associated with CSA modules

Among the 12 CSA modules designed for particle dynamics:

- What modules did you learn the most from? Why?
- What modules did you learn the least from? Why?
- Do you have any comments on whether or not CSA modules help improve your *conceptual understanding* of dynamics problems? Any examples?
- Do you have any comments on whether or not CSA modules help improve your *procedural skills* (such as setting up math equations step by step) to solve dynamics problems? Any examples?
- How do you compare the ways in which you learn from CSA modules and from textbook problem examples?
- What challenges did you have in using CSA modules to learn dynamics?
- Overall, do you think CSA modules help improve your learning of dynamics?
How to make the design of CSA modules better?

6. Do you have any other comments that you want us to be aware of?

Appendix E
Coding Table

	Features	Contexts
1. Technical design	1. Graphics User Interface 1.1. Scroll bars 1.1.1. Vertical 1.1.2. Horizontal 1.2. Input Fields 1.3. Navigation buttons	Add “type-in” input fields – an alternative use for scroll bars Viewing with Canvas: Visibility (and consequently, interactivity with modules) in Canvas environment
	2. Visualization 2.1. Animation 2.2. Graphics 2.3. Free body diagram	
	3. Hardware or software related issues 3.1. Download CSA from Canvas 3.2. Access/Viewing CSA on Canvas 3.3. CSA runs slow on Canvas 3.4 Unresponsive features	Technical issues relate to hardware or software (viewing/running modules in Canvas environment, modules don’t fit inside Canvas).
	4. Interactivity 4.1. Manipulation/Interaction	Students can interact with modules and manipulate parameters to experiment their effects on motions and final outcomes, things textbook cannot do. Students found that manipulation of scrollbars help them understand procedural skills.
	5. Editing 5.1. Numerical Errors 5.2. Wording 5.3. Text use (font, size, color)	
	6. Playable on other devices	Students mention to the possibility to access Modules from other electronics devices (iPad) rather than PCs
	7. Others	
2. Instructional Design	1. General contents 1.1. Difficulty level 1.1.1 Too easy 1.1.2 Too Complicated 1.2. Matching In class instruction 1.3. Matching test, exams	
	2. Integrate assessments or quizzes in the modules 2.1. Quick quizzes 2.2. Answer feedback	Integrate assessments/ quizzes and provide timely feedback
	3. Hints, tips, and reviews	Provide hints, tips, and scaffolding strategies
	4. Others	

	Features	Contexts
3. Usage Pattern	1. Running CSA 1.1. Solve, Watch, and Check solutions and answer 1.2. Watch and Get / Check solutions and answer 1.3. Combination both methods	Students solve the BHs first without the CSA's help. Then they run, watch, and interact with the modules. Finally, they plug in parameters in CSA (scrollbars) and check their work (solutions and answers) with CSA's results. Students do not solve the BHs. They run, watch, and interact with the modules. Finally, they plug in parameters in CSA (scrollbars) and get the solutions and answers from the modules. Students use both strategies depending on their time budgets and their understandings about the module's contents.
	2. Locations 2.1. Access at Home 2.2. Access at Campus	
	3. Group/Individual 3.1. Run module with group 3.2. Run module individually	
	4. Others 4.1. Assess For that specific HW 4.2. Assess For HW & review exam 4.3. Length of access 4.4. Prior exposure to animation	Assess Frequency For that specific HW For HW and review exam Rough number of minutes Yes or No
4. Benefits/Outcomes	1. Improve conceptual understanding 1.1. Variables and relationships 1.2. Visualization /animation 1.3. Connection	
	2. Improve procedural skills 2.1. Step-by-step 2.2. Identifying Errors 2.3. Analysis-Synthesis Process	
	3. Enhance motivation to learn	
	4. Enhance confidence to learn	
	5. Others 5.1. Most liked module 5.2. Most liked feature 5.3. Most learned module 5.4. Most difficult module 5.5. Least liked module 5.6. Least liked feature 5.7. Least learned module	List module numbers List features List module numbers List module numbers List module numbers List features List module numbers

Curriculum Vitae

Yongqing Guo

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Email: yq.guo@aggiemail.usu.edu Phone: (509) 714-6129

Education

- PhD in Engineering Education Aug 2015
 Utah State University, Logan, Utah, USA GPA: 3.8
 Dissertation: "Interactive Computer Simulation and Animation Learning Modules: a
 Mixed-Method Study of Their Effects on Students' Problem Solving in Particle
 Dynamics."
 Advisor: Dr. Ning Fang
- M.S. in Civil Engineering Dec 2008
 University of Idaho, Moscow, Idaho, USA
- B.S. in Civil Engineering Jul 2004
 China University of Mining and Technology, Xuzhou, China

Research and Teaching Experience

- Teaching Assistant, Utah State University, Logan, UT Jan 2012 – Aug 2015
- Delivered lectures to undergraduate students
 - Answered questions in TA sessions
 - Delivered examinations
 - Graded homework and exams
 - Analyzed students' scores
- Research Assistant, Utah State University, Logan, UT Jul 2011 – Aug 2015
- Developed and evaluated computer simulation and animation modules
 - Developed and evaluated intelligent tutoring system
 - Developed surveys and interviews
 - Analyzed quantitative and qualitative data
 - Recruited and trained undergraduate students to participate in studies
- Research Assistant, National Institute for Advanced Transportation Technology (NIATT),
 University of Idaho, Moscow, ID Jan 2007 – Dec 2008
- Simulated signalized intersection operations
 - Analyzed quantitative data

Work Experience

- ITS Transportation Engineer Intern, Trans Consulting Service Inc.,
 Sacramento, CA Jan 2009 – Jul 2009
- Used VISSIM to simulate traffic operations
 - Analyzed motor vehicle crash data

Work Safety Engineer, Work Safety Bureau, Dongying, China

July 2004 – July 2006

- Construction and traffic safety inspection
- Conducted research to improve safety inspection programs
- Wrote monthly and yearly summary reports
- Cooperated with other government departments

Publications

1. Guo, Y. and Fang, N. (2015). Interactive computer simulation and animation (CSA) for improving student learning of particle kinetics in an undergraduate engineering dynamics course. *Submitted to Journal of Computer Assisted Learning*.
2. Guo, Y. and Fang, N. (2015). Interactive computer simulation and animation (CSA) to improve student learning of projectile motion in an undergraduate engineering dynamics course. *Proceedings of the 7th International Conference on Computer Supported Education*, Lisbon, Portugal, May 23-25. Accepted.
3. Guo, Y., Ha, O., and Fang, N. (2014). Pedagogical design of interactive computer simulation and animation (CSA) to improve student learning in engineering dynamics. *Proceedings of the 2014 Intellect base Multi-Disciplinary Academic Conference*, Las Vegas, NV, December 17-19, 2014.
4. Fang, N. and Guo, Y. (2013). A web-based interactive intelligent tutoring system for enhancing student learning in a foundational engineering dynamics course. *International Journal of Engineering Education*, vol. 29(6), pp1503-1513.
5. Fang, N. and Guo, Y. (2013). A web-based interactive intelligent tutoring system for undergraduate engineering dynamics. *Proceedings of the 2013 Frontiers in Education Conference*, Oklahoma City, Oklahoma, October 23-26, 2013.
6. Guo, Y. and Fang, N. (2012). WIP: An intelligent tutoring system for improving student learning in a sophomore engineering dynamics course. *Proceedings of the 2012 Frontiers in Education Conference*, Seattle, Washington, October 3-6, 2012.
7. Guo, Y.Q. (2012). The relationship between freeway safety and geometric design elements. *Advanced Materials Research*, vol. 424-425, pp 215-219.
8. Guo, Y.Q. (2011). Effects of ramp spacing on freeway mainline crashes. *Applied Mechanics and Materials*, vol. 97-98, pp 95-99.
9. Guo, Y.Q. and Abdel-Rahim, A. (2009). A real-time performance monitoring system based on data logging device for signalized intersections. *IRI'09 Proceeding of the 10th IEEE international conference on Information Reuse & Integration*, p 252-255.
10. Guo, Y.Q. and Abdel-Rahim, A. (2009). Using high-resolution data logging device to monitor signalized intersection operations. *The 14th International Conference of Hong Kong Society for Transportation Studies*, Hong Kong.
11. Guo, Y.Q. and Abdel-Rahim, A. (2009). Real-time high-resolution data logging and performance monitoring device for signalized intersections. *The 6th International Conference on Cybernetics and Information Technologies, Systems and Applications*, Orlando, Florida.
12. Guo, Y.Q. (2008). Real-time high-resolution data logging and performance monitoring devices for signalized intersections. MS thesis, University of Idaho, Moscow, ID.

Talks and Presentations

1. An intelligent tutoring system for improving students' problem solving in engineering dynamics course. 2012 Graduate Engineering Education Consortium for Students and NSF EEC Awardees Conference, Blacksburg, Virginia (March, 2012).
2. WIP: An intelligent tutoring system for improving student learning in a sophomore engineering dynamics course. 2012 Frontiers in Education Conference (October, 2012).
3. An intelligent tutoring system for improving student learning in a sophomore engineering dynamics course. Intermountain Graduate Research Symposium, Logan, Utah (April, 2012).
4. Interactive Computer Simulation and Animation Learning Modules: Their Effects on Students' Problem Solving in Particle Dynamics. Intermountain Graduate Research Symposium, Logan, Utah (April, 2014).
5. Work in Process: Interactive Computer Simulation and Animation Learning Modules: A Study of Their Effects on Students' Problem Solving in Particle Dynamics. Department Research Seminar (April, 2014).
6. Interactive Computer Simulation and Animation Learning Modules: A Study of Their Effects on Students' Problem Solving in Particle Dynamics. Department Research Seminar (February, 2015).

Software and Programming Languages

SPSS/SAS/Stata
VISSIM
SYNCHRO

AutoCAD
Visual Basic
ArcGIS

Adobe Flash
C/C++
Matlab

Related Courses

- Finance and Grant Writing
- Research and Evaluation in Instructional Technology
- Foundations of Curriculum
- Interactive Multimedia Production
- The Role of Cognition in Engineering and Technology Education
- Educational and Psychological Research
- Research Design and Analysis
- Internationalizing Institutions of Higher Education

Awards and Leadership

- Presidential Fellowship, Utah State University, 2011-2012
- Travel Award, Graduate Engineering Education Consortium for Students, 2012
- Travel Award, Utah State University, 2012
- Scholarship, China University of Mining and Technology, 2001, 2002 and 2003
- Vice President of Information, ASEE at Utah State University, USU, 2013-present