The Effects of Interactive Computer Simulation and Animation on Student Learning of Rigid Body Dynamics: A Mixed Method Study

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THE EFFECTS OF INTERACTIVE COMPUTER SIMULATION AND ANIMATION ON STUDENT LEARNING OF RIGID BODY DYNAMICS:

A MIXED METHOD STUDY

by

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The purpose of this study was to determine if intervention group students studying rigid body dynamics (RBD) with traditional instruction and interactive computer simulation and animation (CSA) modules have higher learning gains than comparison group students studying RBD with traditional instruction only. The study used a mixed method approach and nonequivalent comparison group experimental design on 161 undergraduate engineering students in two different semesters. Ten CSA modules addressing different areas of RBD knowledge were developed in the first phase of this two-phase study. These CSA modules were used as the instructional intervention on the intervention group in the second phase. Nonparametric statistical tools, including Mann-Whitney U and the Wilcoxon Signed Rank tests, Spearman’s correlation test, and Cliff’s effect size, were used to evaluate the mean differences on learning gains between two
groups and the magnitudes of these differences. Surveys and interviews were also conducted on the intervention group at the end of the experiment to elicit students’ attitudes towards and experiences with CSA modules.

Research findings from this study reveal that on average, the intervention group students had the overall learning gain statistically and significantly higher than that of the comparison group students, and that the effect size for this difference was 0.49. On average, the intervention group students also had conceptual understanding and procedural skill learning gains statistically and significantly higher than those of the comparison group students, with the effect sizes for these differences being 0.41 and 0.47, respectively. Although CSA modules increased the intervention group students’ confidence, they did not increase the intervention group students’ motivation of learning RBD. The study concludes that the CSA modules developed in this study are effective instructional interventions for RBD instruction. The study provides instructional developers, engineering mechanics instructors, and researchers with implications on interactive instructional design, classroom instruction, and the use of a measuring instrument in assessing student learning outcomes.
PUBLIC ABSTRACT

The Effects of Interactive Computer Simulation and Animation on Student Learning of Rigid Body Dynamics: A Mixed Method Study

Oai Ha

Engineering Dynamics (ED) courses are known as challenging and demanding for undergraduate students majored in many engineering fields, such as mechanical and aerospace engineering and civil and environmental engineering. The course is built upon the foundation and framework of mathematics and physics and requires students to have strong abstract thinking and reasoning skills. Rigid body dynamics (RBD), the second part of ED, investigates kinematics and kinetics of rigid bodies and is considered as a difficult subject by many undergraduate students because the course requires them to visualize abstract objects in motions. Although there have been many studies reporting the uses of interactive computer simulation and animation (CSA) modules as visual learning tools in RBD instruction, the effectiveness of the CSA modules on student learning of RBD were not rigorously and adequately investigated.

This study employs a mixed method (QUAN – qual) approach and nonequivalent comparison group design to investigate the effectiveness of CSA modules on student learning of RBD, and to explore students’ attitudes towards and experiences with these modules. One hundred and sixty-one students in two recent semesters participated in this
study: 74 in one semester participated in the comparison group and 87 in another semester participated in the intervention group. While the intervention group students studied RBD with CSA modules along with traditional lectures, the comparison group students studied RBD with traditional lectures only. Students in both groups were assessed with pretests and posttests using 10 bonus homework assignments developed to address core knowledge areas of RBD. The study uses a set of nonparametric statistical tools to analyze the pretest and posttest scores, mean differences, and magnitudes of the differences in learning gains between the two groups.

Research findings from this study reveal that the intervention group students showed a significant increase in learning gains of overall knowledge, conceptual understanding, and procedural skills with Cliff’s effect sizes of 0.49, 0.41, and 0.47, respectively. CSA modules increased the intervention group students’ confidence, but they did not increase students’ motivation of learning RBD. This study supports the use of CSA modules as an instructional intervention to improve students’ conceptual understanding and procedural skills in learning engineering dynamics.
DEDICATION

Every challenging work needs self-efforts and supports from those who are very close to our heart. I would like to dedicate this dissertation especially
to my wife, Vivien Nguyen, for all the sacrifices, patience, love, and support she has given me throughout this journey;
to my son, Van Ha, for giving me a wonderful feeling of fatherhood during the final stage of the dissertation;
to my mom and my late dad, for instilling in me an appreciation of education.
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Oai Ha
CONTENTS

ABSTRACT................................................................................................................................. iii
PUBLIC ABSTRACT ...................................................................................................................... iii
DEDICATION................................................................................................................................. v
ACKNOWLEDGMENTS ................................................................................................................ vii
CONTENTS ................................................................................................................................... ix
LIST OF TABLES ......................................................................................................................... xiii
LIST OF FIGURES ....................................................................................................................... xv

CHAPTER

1. INTRODUCTION ...................................................................................................................... 1
   Background of the Study .............................................................................................................. 1
      Engineering Dynamics Course in Engineering Education ....................................................... 1
      Computer Simulation and Animation as Teaching Aids in Engineering Education ............... 3
      Worked Examples in Engineering Education ........................................................................... 5
   Statement of the Problem ........................................................................................................ 6
   Purpose of This Study .............................................................................................................. 7
   Significance of This Study ....................................................................................................... 8
   Research Questions ................................................................................................................ 8
   Definitions .............................................................................................................................. 9
   Assumption of This Study ...................................................................................................... 10
   Limitations of This Study ....................................................................................................... 10
   Logic Structure of This Study .............................................................................................. 11

2. REVIEW OF LITERATURE .................................................................................................... 12
   What Are Computer Simulation and Animation? .................................................................... 12
      Computer Simulation and Animation in the Development of Conceptual Understanding ....... 14
         Computer Simulation and Animation for Abstract Concepts and Complex Motions .......... 15
         Computer Simulation and Animation for Time-dependent Motions .................................. 16
         Computer Simulation and Animation for Spatially Dependent Concepts .......................... 18
         Implications for This Study .............................................................................................. 19
      Cognitive Load Theory ......................................................................................................... 20
         Cognitive Load Theory and Worked Examples ............................................................... 21
         Implications for This Study .............................................................................................. 23
         Cognitive Load Theory and Instructional Animation ....................................................... 24
         Implications for This Study .............................................................................................. 26
      Current Trends of CSA Usage in Engineering Mechanics Instruction ................................... 26
CSA Development and Assessment .................................................. 27
Authoring Tools and Development Software Package .......................... 27
Mathematic Equations Presentation .................................................. 29
Experimental Design ........................................................................ 30
Summarized Study Characteristics of CSA Literature in Engineering Mechanics ....... 31
Implications for This Study .............................................................. 35
General Conclusions of Literature Review ....................................... 35

3. RESEARCH METHODOLOGY .................................................................. 37
Design and Development of CSA Modules for Rigid Body Dynamics .................. 37
    An Example of Work Plan for Module 13 ........................................... 39
    Learning outcome and target audience of CSA Module 13 ..................... 39
    Analysis and design of CSA Module 13 ............................................. 40
    The objectives of CSA Module 13 development .................................. 41
    Finished products and timeline ....................................................... 41
    Storyboard .................................................................................. 42
Concurrent Mixed Method Research Design ......................................... 43
    Quantitative Method ...................................................................... 47
    Qualitative Method ..................................................................... 50
Intervention Instrument ..................................................................... 50
Assessment Instrument ..................................................................... 50
Measuring Instrument ..................................................................... 55
    The Single-student Learning Gain g ................................................ 55
    The Average Student Learning Gain g-ave ...................................... 55
    The Course Average Learning Gain <g> ........................................... 56
Participants and Procedure ............................................................... 59
    Participants ................................................................................ 59
    Procedure ................................................................................ 60
Data Collection ................................................................................ 63
    Pretests and Posttests ................................................................... 63
    Survey ........................................................................................ 64
    Semi-structured Interviews .......................................................... 66
Data Analysis .................................................................................... 66
    Pretest and Posttest Data Analysis ................................................. 66
    Semi-structured Interviews Data Analysis ....................................... 67
        Steps of coding and analyzing interviews data ............................... 67
        Example of code polling .......................................................... 71
        Advantages and disadvantages of virtual negotiation .................. 73
    Survey Data Analysis .................................................................. 75

4. RESULTS AND ANALYSIS OF LEARNING GAINS ...................................... 77
Introduction……………………………………………………………………………………………………77
Exploration and Preliminary Analysis of Pretest and Posttest Scores………………78
  Matched Pretest and Posttest Scores………………………………………………78
  Normality Test………………………………………………………………………………80
  Preliminary Analysis with Pretest and Posttest Scores……………………………83
Results and Analysis with Overall Learning Gains……………………………………87
  Handling Outliers .........................................................................................94
  Correlations Between Pretest, Pre-posttest Gain, and Learning Gain …………….95
Results and Analysis with Conceptual Understanding and Procedural Skills Learning Gains…………………………………………………………………………99
  Learning Gains of Conceptual Understanding and Procedural Skills ………….99
  Correlation Between Conceptual Understanding and Procedural Skills
  Knowledge ........................................................................................................107
Results and Analysis with Low and High Performing Students …………………….108
Results and Analysis with Three Most Challenging Bonus Homework………………116
  Results and Analysis of Bonus Homework 13……………………………………….117
  Result and Analysis of Bonus Homework 14 and 15………………………………120
Discussions........................................................................................................124
  Spatial Abilities for Conceptual Understanding of Rigid Body Dynamics………126
  Competency of Mathematics Tools in Solving Rigid Body Problems……………128
Summary of Findings .......................................................................................130
5. RESULTS AND ANALYSIS OF SURVEYS AND INTERVIEWS………………………...133
Introduction........................................................................................................133
Survey Data ........................................................................................................134
  Accessibility and Functionality of CSA modules…………………………………134
  Students’ Motivation, Confidence, and Learning Activities………………………137
  Quality of the Technical Dynamics Problems Designed for CSA Modules………141
  Student Learning Outcomes Associated with CSA Modules ……………………..145
Semi-structured Interview Data ................................................................………151
Summary of Findings .......................................................................................161
6. CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS…………………………164
Conclusions ........................................................................................................164
Implications .......................................................................................................167
  Implications for Future Instructional Design for Engineering Mechanics Course..167
  Implication for Future Research ……………………………………………………168
Recommendations ............................................................................................169
  Recommendations for Engineering Dynamics Instruction………………………169
  Recommendations for Engineering Dynamics Instructional Design …………..169
  Recommendations for Using Measuring Instrument to Assess Learning Outcome171
REFERENCES .................................................................................................................. 173
APPENDICES .................................................................................................................. 188
Appendix A: Systematic review procedure for CSA literatures in Engineering Mechanics Domain ........................................................................................................... 189
Appendix B: Study Characteristics of CSA literatures in Engineering Mechanics Domain ........................................................................................................................ 191
Appendix C: Summary of Literature Review ........................................................................ 195
Appendix D: Internet enabled PCs - Penetration .................................................................... 197
Appendix E: Examples of Actionscript 3.0 Code to animate the crank and slider mechanism of Module .................................................................................................................. 199
Appendix F: IRB Approval .................................................................................................. 209
Appendix G: Survey Questions ............................................................................................ 213
Appendix H: Coding Table .................................................................................................. 218
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1. Contents and Related Chapters of 10 CSA Modules for Rigid Body Dynamics</td>
<td>39</td>
</tr>
<tr>
<td>3.2. An Example of the Development Timeline for CSA Module 13</td>
<td>42</td>
</tr>
<tr>
<td>3.3. Storyboard of Module 13 Production</td>
<td>44</td>
</tr>
<tr>
<td>3.4. Outline of Research Design</td>
<td>47</td>
</tr>
<tr>
<td>3.5. Number of CU and PS Questions in the Bonus Homework</td>
<td>54</td>
</tr>
<tr>
<td>3.6. Reliability Test</td>
<td>54</td>
</tr>
<tr>
<td>3.7. Calculation of the Average Student and Course Average Learning Gains</td>
<td>57</td>
</tr>
<tr>
<td>3.8. Summary of Participants by Learning Condition</td>
<td>60</td>
</tr>
<tr>
<td>3.9. Student Demographics</td>
<td>60</td>
</tr>
<tr>
<td>3.10. Sample of a Polling Table with Two Items</td>
<td>71</td>
</tr>
<tr>
<td>3.11. Sample of Coders’ Responses and Polling Results</td>
<td>72</td>
</tr>
<tr>
<td>3.12. One of the Four Possible Coding Results Between Coders A and B</td>
<td>73</td>
</tr>
<tr>
<td>3.13. Summarized Intercoder Reliability Processing of Semi-structured Interview Data</td>
<td>74</td>
</tr>
<tr>
<td>4.1. Number of Students Attending Pretest and Posttest in Two Groups</td>
<td>79</td>
</tr>
<tr>
<td>4.2. Descriptive Statistics Results of Pretest, Posttest, and Learning Gains Scores</td>
<td>82</td>
</tr>
<tr>
<td>4.3. Mann-Whitney U Test Result on Pretest and Posttest Scores Differences</td>
<td>85</td>
</tr>
<tr>
<td>4.4. Wilcoxon Signed Rank Test Result for Pretest and Posttest Scores Differences</td>
<td>87</td>
</tr>
<tr>
<td>4.5. Mann-Whitney U Test Results on Learning Gain Difference of Two Groups</td>
<td>88</td>
</tr>
<tr>
<td>4.6. Descriptive Statistics of all Bonus Homework Scores for Two Groups</td>
<td>90</td>
</tr>
<tr>
<td>4.7. Mann-Whitney U Test Results on Learning Gain Differences for 10 CSA Modules</td>
<td>91</td>
</tr>
<tr>
<td>4.8. Correlations Between Pretest, Pretest to Posttest Gain, and Learning Gain</td>
<td>97</td>
</tr>
<tr>
<td>4.10. Mann-Whitney U Test for CU and PS Learning Gain of the Two Groups</td>
<td>101</td>
</tr>
<tr>
<td>4.11. Wilcoxon Signed Rank Test Results for the Conceptual Understanding and Procedural Skills Learning Gain Differences</td>
<td>102</td>
</tr>
<tr>
<td>4.12. Correlations Between Pretest and Learning Gain of LPS and HPS for Two Groups</td>
<td>107</td>
</tr>
<tr>
<td>4.15. Mann-Whitney U Test Result Comparing LPS and HPS in Two Learning Conditions</td>
<td>111</td>
</tr>
</tbody>
</table>
4.16. Correlations Between Pretest and Learning Gain of LPS and HPS for Two Groups

4.17. Mann-Whitney U Ranks on Correct Answer Rate Differences for BH 13

4.18. Mann-Whitney U Test Results on Correct Answer Rate Differences for BH 13

4.19. Summary of Main Findings from Pretest and Posttest Analysis

5.1. Survey Results of Accessibility and Functionality of CSA Modules

5.2. Survey Results of Students’ Motivation, Confidence, and Learning Activities

5.3. Correlations Between Students’ Confidence, Motivation, and Learning Gains

5.4. Survey Results on the Quality of the Technical Dynamics Problems for CSA Modules

5.5. Survey Results of Student Learning Outcomes Associated with CSA Modules

5.6. Summary of Findings from Survey and Interviews Data Analysis
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1. Relative motion analysis of general planar motion</td>
<td>17</td>
</tr>
<tr>
<td>2.2. Three types of cognitive load</td>
<td>24</td>
</tr>
<tr>
<td>3.1. Crank and slider problem in CSA Module 13</td>
<td>40</td>
</tr>
<tr>
<td>3.2. A conceptual understanding question in bonus homework 20</td>
<td>51</td>
</tr>
<tr>
<td>3.3. A conceptual understanding question in bonus homework 22</td>
<td>51</td>
</tr>
<tr>
<td>3.4. Example assessment questions for bonus homework 19</td>
<td>53</td>
</tr>
<tr>
<td>3.5. The administrations of pretest and posttest for two groups</td>
<td>61</td>
</tr>
<tr>
<td>4.1. Histograms of pretest, posttest, and learning gain scores of two groups</td>
<td>81</td>
</tr>
<tr>
<td>4.2. Mean pretest and posttest scores of two groups</td>
<td>85</td>
</tr>
<tr>
<td>4.3. Mean and median learning gains of two groups</td>
<td>88</td>
</tr>
<tr>
<td>4.4. Median learning gains for different areas of rigid body dynamics knowledge</td>
<td>91</td>
</tr>
<tr>
<td>4.5. The increasing trend in mean learning gain of the intervention group</td>
<td>92</td>
</tr>
<tr>
<td>4.6. Scatter plot of &lt;Gain&gt; versus &lt;Pre&gt; for different bonus-homework</td>
<td>93</td>
</tr>
<tr>
<td>4.7. Regression lines between pretest and learning gains, and between pretest and pretest to posttests</td>
<td>98</td>
</tr>
<tr>
<td>4.8. Three types of learning gains between two groups</td>
<td>100</td>
</tr>
<tr>
<td>4.9. Relationship between Group-Type of knowledge and Mean Learning gain</td>
<td>103</td>
</tr>
<tr>
<td>4.10. Scatter plots of &lt;Gain&gt; versus &lt;Pre&gt; for CU and PS of two groups</td>
<td>105</td>
</tr>
<tr>
<td>4.11. Scatter plots of CU learning gain versus PS learning gain for two groups</td>
<td>108</td>
</tr>
<tr>
<td>4.12. Group-Performance versus Mean learning gain of LPS and HPS</td>
<td>112</td>
</tr>
<tr>
<td>4.13. Scatter plots of &lt;Gain&gt; versus &lt;Pre&gt; for low and high performing students</td>
<td>115</td>
</tr>
<tr>
<td>4.14. Learning gains of the intervention group on bonus homework 13, 14, and 15</td>
<td>117</td>
</tr>
<tr>
<td>4.15. Correct answer rates of two groups on bonus homework 13</td>
<td>118</td>
</tr>
<tr>
<td>4.16. Correct answer rates of two groups on bonus homework 14</td>
<td>121</td>
</tr>
<tr>
<td>4.17. Correct answer rates of two groups on bonus homework 15</td>
<td>121</td>
</tr>
<tr>
<td>4.18. Learning gain histograms of three bonus homework of the intervention group</td>
<td>122</td>
</tr>
<tr>
<td>4.19. Improving trend in posttest score of 10 bonus homework assignments</td>
<td>123</td>
</tr>
<tr>
<td>4.20. A screenshot of the solution page in CSA module 13</td>
<td>128</td>
</tr>
<tr>
<td>5.1. Interview data analysis result: code distribution</td>
<td>152</td>
</tr>
<tr>
<td>5.2. Interview data analysis result: students’ interests and concerns</td>
<td>153</td>
</tr>
<tr>
<td>5.3. A slider and crank mechanism in CSA Module 14</td>
<td>158</td>
</tr>
<tr>
<td>6.1. Learning gain lines in the pretest versus posttest scores chart</td>
<td>172</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

Background of the Study

Engineering Dynamics Course in Engineering Education

Engineering Dynamics (ED) is a foundation course in many engineering disciplines, such as mechanical engineering, aerospace engineering, civil engineering, biological engineering, and materials science and engineering. For many engineering programs, the ED knowledge is offered to students as a stand-alone ED course. For others, it is offered jointly with the Engineering Statics knowledge as an Engineering Mechanics (EM) course. The ED course is built upon the foundation and framework of mathematics and physics and requires students to have strong abstract thinking and reasoning skills. Rigid body dynamics (RBD) is the second part of ED that investigates kinematics and kinetics of rigid bodies in motion (the first part of ED is particle dynamics). Engineering students constantly struggle with RBD knowledge that requires them to visualize abstract objects in motions (Flori, Koen, & Oglesby, 1996; Mazzei, 2003). In traditional lectures, instructors use words, static pictures, and even gestures to describe abstract concepts and time-dependent motions. However, this method of instruction is not always effective because depending on the individuals’ prior knowledge
and experiences in the domain, the concepts students acquire from lectures may not be aligned to what the instructor intends.

In learning RBD, students are required to have both conceptual understanding and procedural skills to solve problems. Engineering instructors are increasingly concerned with methods that facilitate the acquisitions of these two types of knowledge. The term “conceptual understanding,” sometimes mentioned as conceptual knowledge in research literature (Montfort, Brown, & Pollock, 2009; Taraban, Anderson, DeFinis, Brown, Weigold, & Sharma, 2007), is considered as “knowing what” in instruction (Leppavirta, Kettunen, & Sihvola, 2010). Montfort et al. (2009) defined conceptual understanding as “the beliefs and framework used to acquire new knowledge or perform new applications of old knowledge in that topic.” The term “procedural skills” has many equivalent terms in research literature, including computational ability (Montfort et al., 2009), algorithmic performance (Haapasalo, 2003), and procedural knowledge (Taraban et al., 2007). According to Haapasalo (2003), procedural skills “denote dynamic and successful utilization of particular rules, algorithms or procedures within relevant representation forms.” Procedural skills are also considered as “knowing how” in instruction (Leppavirta et al., 2010). In engineering dynamics instruction, conceptual understanding is one’s mastery of the true meaning and implications of dynamics concepts and principles, and procedural skills are the ability to apply one’s conceptual understanding to set up mathematical equations to generate a numerical solution to a dynamics problem (Fang & Guo, 2013).

Some researchers believed that conceptual understanding and procedural skills are developed in an iterative fashion: the development of this type of knowledge leads to the
development of the other type of knowledge and vice versa (Rittle-Johnson, Siegler, & Alibali, 2001). Others noted that students’ conceptual understandings are usually lagging behind their procedural skills, i.e., students may still solve correctly engineering problems while they do not fully understand the concepts and principles implied in those problems (McCarthy & Goldfinch, 2010; Montfort et al., 2009). Engineering educators have proved that students’ conceptual understandings can be improved significantly with visual aids (Abulencia, Vigeant, & Silverstain, 2012; Savander-Ranne & Kolari, 2003), while their procedural skills can be acquired effectively through learning with worked examples (Calfee & Stahovich, 2011; Rossow, 2005). As the majority of engineering students are visual learners (Felder & Brent, 2005), visual aids coupled with a step-by-step presentation of worked examples are important teaching tools in helping students understand RBD concepts and develop problem-solving skills.

**Computer Simulation and Animation as Teaching Aids in Engineering Education**

Advances in computer technology provide engineering educators a wide range of visual aids including computer simulation and animation (CSA) to enhance student visualization and understanding of scientific concepts and phenomena (Michau, Gentil, & Barrault, 2001). Interactive animation and simulation are computer programs that usually accept user inputs to control the pace and the scientific calculation of animation via computer graphical user interfaces (GUIs). The acts of navigating through a step-by-step CSA module with navigation buttons serve as triggers of other events and help learners explore the solution of a worked example, perform calculations with particular values, or control animations with selected parameters. As engineering mechanics (EM) courses use
a lot of mathematical concepts, the interaction between users and CSA modules through step-by-step design proves very helpful in deriving equations and synchronizing them with animated contents. CSA programs have been used by engineering educators to teach many engineering courses: Materials science and engineering (Mohler, 2001), soil mechanics (Budhu, 2001), manufacturing engineering (Ong & Mannan, 2003), control engineering (Michau et al., 2001), engineering dynamics (Flori et al., 1996), and engineering mechanics (Deliktas, 2011).

According to Mayer and Chandler (2001), learners’ interaction with animation and their control over the flow of instructional information allow them to acquire knowledge faster. The navigation buttons in CSA modules enable a gradual presentation of information to learners so that new information can be presented in a step-by-step procedure. For the CSA module used in a soil mechanics course at the University of Arizona, Budhu (2001) segmented his Mohr’s circle lesson into steps and outlined them in an interactive animation module to enhance student learning. Under the constructivist view, interactive CSA programs are learning environments that “provide students with opportunities to construct conceptual understandings and abilities in activities of problem solving and reasoning” (Greeno, Collin, & Resnik, 1996, p. 29).

Some researchers suggested that animation is not always beneficial over static graphics for instruction (Betrancourt, 2005; Mayer & Chandler, 2001; Paas & van Merriënboer, 1994) unless the animation developers adopt instructional design strategies to reduce cognitive load on learners. Hegarty and Kriz (2008) considered that animation can be a useful and important tool for teaching if it is treated as a component of a larger learning situation. This comment seems very close to the current trend of using CSA
modules in engineering mechanics instruction. The trend was extracted from a systematic review of literature in the engineering mechanics domain. According to this systematic review, 92% of CSA programs being used in engineering mechanics instruction were designed and developed as teaching aids rather than substitutions of traditional lectures. Systematic review and a summary of its results are discussed in detail in Chapter 2 of this dissertation research.

**Worked Examples in Engineering Education**

Worked examples (or known as worked problems) have been used by engineering educators as an instructional strategy to teach students how to solve problems. According to Clark, Nguyen, and Sweller (2005, p. 190), “a worked example is a step-by-step demonstration of how to perform a task or how to solve a problem.” The use of worked examples is one of the principles for effective instructional design because “people learn better from practice when worked examples are presented before to-be-solved problems” (Mayer, 2011, p. 72). In a study investigating the replacement of practice with worked examples in solving algebra problems, Sweller and Copper (1985) showed that learners not only completed the lesson and test problems significantly faster, but also made fewer errors. Worked examples have been found to be more effective in teaching engineering problem-solving skills than the traditional approach that requires extensive problem-solving practices (Calfee & Stahovich, 2011; Rossrow, 2005). Darabi, Nelson, Meeker, Liang, and Boulware (2010) studied the use of computer-simulated chemical plants to develop diagnostic problem solving skill within chemical engineering students and found
that students who used the worked examples strategy made greater progression than those who used other problem-solving strategies.

In the worked example research domain, theories and concepts from cognitive and educational psychology such as cognitive load theory and working memory (WM) have been used to provide insights why worked examples are effective for the acquisition of problem-solving skills. By using worked examples and employing proper multimedia design strategies to reduce extraneous cognitive load, CSA programs can be effective teaching aids to improve student learning in engineering education.

**Statement of the Problem**

Despite the fact that engineering dynamics plays a foundational role in engineering education, the use of interactive CSA modules as parts of teaching and learning activities in ED course has not been explored adequately. Several studies reported the applications of interactive CSA modules in learning dynamics (Cornwell, 2000; Flori et al., 2002; Stanley, 2008, 2009), statics (Hubing et al., 2002; Sidhu, Ramesh, & Selvanathan, 2005), and both dynamics and statics (Deliktas, 2011). The reported benefits of these CSA modules for students vary among different studies. In most studies, students reported that CSA modules and programs enhanced their understandings of course materials and improved their visualization skills (Aziz, Esche, & Chassapis, 2007; Deliktas, 2011; Fang, 2012; Flori et al., 1996; Hall et al., 2002; Stanley, 2008, 2009). However, in other studies, students expressed dissatisfaction with many features of CSA modules (Fong, 2008) or considered learning with CSA modules
to take too much time with respect to the benefits (Flori et al., 2002). The true benefits of CSA modules in learning ED remain controversial because these studies lacked adequate assessments and rigorous experimental designs requiring a control group (or a comparison group), pretests and posttests, or random assignment of participants. Thus, ED instructors and students do not have sufficiently reliable information to make use of CSA as parts of teaching and learning activities. More research is needed to determine the relationship between the use of CSA modules in learning ED and student’s performance. In this dissertation research, a mixed method experimental design is used to examine the effects of using interactive CSA modules on student learning of RBD.

**Purpose of This Study**

The primary purpose of this two-phase, concurrent mixed method experimental study was to determine to what extent the students studying RBD with traditional instruction and interactive CSA modules have higher learning gains than the students studying RBD with traditional instruction only. In the first phase of the project, 10 interactive CSA modules that cover typical concepts and problem-solving skills in RBD were developed by a research team including the advisor, two PhD students, and an undergraduate student. In the second phase, the developed CSA modules were used as an intervention in a nonequivalent control group experiment to assess the effects of the modules on students’ learning gains of conceptual understanding and procedural skills. Data from the experiment consisting of pretest and posttest scores, student surveys, and semi-structured interviews was collected and analyzed to provide a better understanding
of students’ learning gains of RBD as well as their experiences with and attitudes towards CSA modules.

**Significance of This Study**

The results of this study will help engineering educators, instructional multimedia developers, and curriculum designers plan research agenda, revise curriculum, and design instructional strategies to provide students with necessary skills to succeed in engineering dynamics. The techniques for developing an interactive CSA module discussed in this study can help other lecturers tailor their worked problems and develop interactive CSA modules for their classrooms. The CSA modules can be used as visual aids for teaching ED and as demonstrations for complex abstracts and motions in traditional lectures.

**Research Questions**

This mixed method study will address the following two questions:

1. To what extent do students in the intervention group who used interactive CSA modules along with traditional lectures improve learning in RBD, as compared to students in the comparison group who used traditional lectures only?

2. What are students’ attitudes towards and experiences with the interactive CSA modules?

The independent variable is the type of learning condition to which the students were assigned. Thus, the independent variable has two conditions, “with interactive CSA modules” and “without interactive CSA modules.” The dependent variable is the learning gains as measured by pretest and posttest scores.
Definitions

Canvas: An online learning management system where students and lecturers can do the administration and course event management of education courses such as delivering course content, delivering and submitting homework, scheduling, tracking, documenting, and reporting. Canvas has been adopted at Utah State University as a teaching aid for a variety of courses.

Cognitive load theory: An instructional theory based on the knowledge of human cognitive architecture that specifically addresses the limitations of working memory (Sweller, 2005, p. 28).

Computer simulation: The process of using mathematical models to simulate real-world physical processes and phenomena on a computer without a need to have real-world physical models.

Computer animation: The dynamic presentation of graphics, texts, and colors that are put in sequential frames to obtain certain visual effects.

Learning gain (or average learning gain) $g$: Learning gain for a course is the ratio of the actual average gain $G$ to the maximum possible average gain $G_{\text{max}}$:

$$ g = \frac{\% (G)}{\% (G_{\text{max}})} = \frac{\% (S_{\text{post}}) - \% (S_{\text{pre}})}{\% 100 - \% (S_{\text{pre}})} $$

where $S_{\text{post}}$ and $S_{\text{pre}}$ are the post-score and pre-score (Hake, 1998).

The details of learning gain are discussed in the section “Measuring Instrument” in Chapter 3.
Problem-solving skill: This study focuses on problem-solving skills of well-defined problems in engineering dynamics, which is the skill to find a numerical answer to a problem as seen in most undergraduate engineering textbooks.

Worked example: A worked example is “a step-by-step demonstration of how to perform a task or how to solve a problem” (Clark et al., 2005).

Assumption of This Study

Because pre-post tests were implemented as students’ bonus homework assignments, and learning gains were calculated for each individual student, it is assumed that each student in either intervention or comparison groups worked independently on assessment questions in pre-post tests, and no group efforts among students were involved.

Limitations of This Study

The present study had several limitations described as follows:

1. Quasi-experimental research design: Because the study was conducted without random assignment of students to learning conditions, the two groups of students in the experiment could be nonequivalent at the beginning of the experiment. Preexisting differences between groups, other confounding or unique factors might affect the results of the study to a certain extent. Therefore, the study’s results can only be generalized to undergraduate students in similar engineering disciplines and settings.

2. The use of extra credit: Students were offered extra credits toward the homework portion of the course grade after they accomplished each task (pretest, posttest, and survey). The pretest and posttest scores might not truly reflect the students’
efforts and skills during the experiment because students may participate the study just for extra credits. Likewise, the students’ answers for the surveys might not truly reflect their experiences with the CSA.

3. Time on task: CSA module usage was not collected due to the researcher of this study do not have administrative rights to the Canvas website to set up tracking software and examine how the CSA modules were actually utilized. In addition, because most students completed all assessments individually at home, tracking time on tasks of each CSA usage is impossible.

**Logic Structure of This Study**

The remaining portions of this dissertation are organized as follows. Chapter 2 provides an overview of previous research on the uses of computer simulation and animation in engineering education. It also introduces the systematic review of literature from the engineering mechanics domain to synthesize the best available research findings on the instructional design and development of engineering mechanics. Chapter 3 discusses the research methodology used in this dissertation. Chapter 4 focuses on the results and analyses of pretest and posttest scores of all 10 CSA modules. Chapter 5 focuses on the results and analyses of survey and semi-structured interviews data. Conclusions and implications are discussed in Chapter 6.
CHAPTER 2
REVIEW OF LITERATURE

The main purpose of this chapter is to review previous studies on the use of interactive CSA modules in teaching and learning of engineering dynamics. The first part of this review of the literature uses the traditional narrative approach to explore how conceptual understanding and procedural skills are acquired and how interactive multimedia learning environments impact these acquisitions. The second part of this chapter uses the systematic review approach to synthesize prior work, determine the trends of using CSA modules in engineering mechanics instruction, and identify techniques and strategies to develop and implement CSA modules in this study.

What Are Computer Simulation and Animation?

Although the use of CSA in learning engineering mechanics has been studied for years, there has been no explicit definition of “computer simulation” or “computer animation” from these studies. Definitions of these two terms are also inconsistent among authors doing research in different engineering fields. In chemical engineering education, Larive (2008) defined animation as a form of cartoon used to help one visualize a difficult concept, and simulation as a program that accepts inputs and simulates experimentations via computer calculations. Plass, Homer, and Hayward (2009) considered animation as a dynamic visualization that displays the process of change over
time, and simulation as an interactive dynamic visualization which permits learners to manipulate the presentation of information. The view of computer animation as a series of frames put in sequence is reflected in the following definition by Betrancourt and Tversky (2000): “Computer animation refers to any application that generates a series of frames, so that each frame appears as an alteration of the previous one, and in which the sequence of frames is determined either by the designer or the user” (p. 313). According to this definition, if the frames contain texts, pictures, and graphics in different sizes, shapes, positions, and colors, computer animation can consist of text animation, color animation, graphic animation, or a combination of these animations.

Simulation and animation are two separate steps in commercial multi-physics, multi-body simulation software packages such as ANSYS, COMSOL, and MSC Adams. Simulation and animation do not necessarily take place at the same time or on the same computer, as in the case of simulation using server cluster technology. In many cases, the outputs from simulation are fed directly into animation as if both steps take place simultaneously.

In this study, computer animation is defined as the dynamic presentation of graphics, texts, and colors that are put in sequential frames to obtain certain visual effects; computer simulation is considered as the process of using mathematical models to simulate real-world physical processes and phenomena on a computer without a need to have real-world physical models.
Computer Simulation and Animation in the Development of Conceptual Understanding

The acquisition of conceptual understanding and procedural skills is the core instructional activity in all fields of engineering education. Conceptual knowledge is critical to the development of competence in engineering students and in practicing professionals (Streveler, Litzinger, Miller, & Steif, 2008). Many principles and motions in RBD have been considered the most difficult concepts in ED course. According to Streveler et al. (2008), some concepts are more difficult to learn because they are not directly observable such as force, moment, and strain. Other concepts are difficult because they are built upon the complex motions that students have not learned from high school physics or observed from their daily life. In many cases, students bring into classes many misconceptions or incomplete conceptual knowledge. Most of the misconceptions students possess while learning ED courses are about RBD concepts (Gray, Evans, Cornwell, Costanzo, & Self, 2005).

Research has proven that visual aids like CSA can help students improve conceptual understandings (Abulencia et al., 2012; Cornwell, 2000; Mohler, 2001; Stanley, 2008). The use of CSA in engineering mechanics instruction can be classified into three types: CSA for abstract concepts, CSA for time dependent and complex motions, and CSA for spatially dependent concepts. These three types of concepts are described in the following sections.
Computer Simulation and Animation for Abstract Concepts and Complex Motions

Visual aids like pictures, videos, and animation help students understand abstract concepts better than textbooks. Abulencia et al. (2012) developed instructional videos to teach thermodynamics concepts and found that this visual teaching tool increased conceptual understanding of undergraduate engineering students for thermodynamics. Savander-Ranne and Kolari (2003) reported case studies in which computer graphics and animation were utilized to explain abstract concepts in textile and materials engineering. In this field of engineering, students are frequently required to work with subjects’ representations at the macroscopic, microscopic, and symbolic levels. Visualizing the connections between these representations helped students create “mental visual images and make visual interpretations of what concepts actually mean” (p. 190).

Cornwell (2000) found that a dynamic simulation program, called Working Model, helped students visualize the complex motion of an object. He argued that the simulation program was beneficial for students by helping them to observe the complex motion of rigid body systems and to figure out abstract entities such as velocity and acceleration. For example, with animation on a computer screen, students can clearly observe how vectors or acceleration variables change in magnitude and direction. CSA modules provide students with visual support, so students can develop mental models to understand the behavior of a complex physical system in the real world (Chan & Black, 2006). As Greeno et al. (1996) pointed out, “these simulations allow students to learn important knowledge and skills in contexts that they could never participate in naturally, to see features that are invisible in real environments (e.g., the center of mass, the insides
of pipes), to control variables that are not possible to control in the real world, and to see these in action, unlike static text figures” (p. 31).

**Computer Simulation and Animation for Time-dependent Motions**

External and dynamic visualizations in CSA modules are very important for students who have difficulty in generating such visualizations on their own brains (Hoffler, 2010; Larkin & Simon, 1987). Animations offer potential advantages over static graphics by explicitly depicting dynamic changes over time and space rather than requiring the learner to infer those changes in their minds. For example, students frequently have difficulty in understanding the general planar motion of a rigid body from static pictures depicted in most textbooks. The general planar motion can be described as a combination of translation and rotation at the same time. In a traditional instructional material such as a textbook, the general planar motion of the bar AB in Figure 2.1 is divided into two phases and depicted by two static illustration figures, one for the initial phase and one for the final position. First, the entire bar AB translates so that A, called the “base point,” moves to the final position, and point B then moves to B'. Then the bar AB rotates about A so that B' undergoes a relative displacement and moves to its final position B in the second part of the figure. However, in reality, the bar AB neither translates and then rotates, nor, alternatively, rotates and then translates as described in the textbook. It rotates and translates simultaneously. Animation offers potential advantages over static graphics by explicitly depicting dynamic changes of the bar’s positions over time, rather than requiring the learner to mentally figure out those changes.
Figure 2.1. Relative motion analysis of general planar motion.

Animation helps learners visualize not only the complex motion of a system, but also the relationships among component parts of the system. For example, in a study investigating the use of an engineering software in teaching and learning engineering dynamics, Flori et al. (1996) used animation to illustrate the motion of a typical four-bar mechanism. Learners can observe the general planar motion and have better a understanding about the instantaneous center concept with the help of animated velocity vectors of the mechanism. Animation can represent the relationships between variables more explicitly than a mathematical equation. For example, in Stanley’s (2008) study, students interacted with an animated learning module showing a motorcycle traveling along a defined path with a constant tangential acceleration. Students were able to manipulate the motion of the motorcycle by plugging in their own inputs and observe how the outputs and animations changed. In the assessment, the students were asked,
“Why does the acceleration vector change direction and magnitude as it moves along the trajectory?” Mathematically, the motorcycle’s normal acceleration is proportional to its velocity and inversely proportional to the radius of the trajectory curve. By studying the mathematic equations alone, not many students could figure out the answer for this question. However, with the computer animation program, 85% of the students answered correctly (Stanley, 2008).

**Computer Simulation and Animation for Spatially Dependent Concepts**

Spatially dependent concepts deal with systems and motions in three-dimensional (3D) world. In mechanical and civil engineering education, the need to understand the behavior of structures under load and forces plays an important role in structural analysis courses. Some analyses such as the propagation of stresses and strains of a structural member or deformations from different angles up to failure were better understood if the structures were represented in 3D rather than in two dimensional (2D) images.

Young, Ellobody, and Hu (2011) employed a 3D finite-element simulation approach in the instruction of the structural analysis courses at the University of Hong Kong and the Hong Kong University of Science and Technology and found that the simulation enhanced their student’s understanding of the courses. The 3D simulation allowed the students to see the stress distribution and the propagation of stress and strain within the steel plate under loading, things that cannot be seen with 2D images. The findings of their four-year study on the cohort of more than 380 civil engineering students strongly suggested that 3D simulations of structures can be used as a powerful and effective teaching aid in structural analysis courses.
In engineering mechanics instruction, 3D structures problems are usually drawn in the textbook at fixed viewing points. However, with the aids of interactive CSA modules, the 3D computer graphics of the same structures can be rendered in different viewing points via learner’s manipulation with the mouse or touchpad. For example, a study at Valparaiso University (Hagenberger, Johnson, & Will, 2006) investigated how students identify forces in a 3D system illustrated on different media formats. Students in two Mechanics-Statics classes were presented with the same structure but drawn in two media formats. In the first class, students learned the structure from its illustration drawn on paper. Students in the second class interacted with the same structure generated by a computer where students could manipulate input devices to observe the structure from infinite viewing angles. The ambiguity was that the direction of applied force F appears to be parallel to the x-axis and x-y plane in the paper version. While students in paper group struggled with the ambiguity of force F’s direction (25.9% correct answers for F’s direction), students in computer group easily identified the correct direction of force F (95.8% correct answer).

**Implications for This Study**

Engineering dynamics is a spatially rich course and many of rigid bodies’ complex motions and concepts can be more easily understood with the visual aids of CSA. The CSA modules developed in this study use different visual representations (diagrams, static graphics, and animation) to depict different RBD concepts and motions. The CSA modules address misconceptions students frequently have while learning ED as identified in the Dynamics Concept Inventory – a pool of assessment questions in
engineering mechanics instruction (Gray et al., 2005). For example, an explicit dynamic visualization of an object under general planar motion can help students acquire this concept better than a static picture. Students do not have to infer in their minds the changes of the object at different positions and times and can dedicate their mental resources to other learning activities. Other ED abstract concepts such as force, velocity, and acceleration will be represented in graphics (vectors) showing their quantities (vectors’ magnitude) and qualities (vectors’ directions).

Cognitive Load Theory

The advances of cognitive science have offered educational researchers many concepts and theories to rationalize how people learn. Working memory (WM) concept and cognitive load theory (CLT) have been used to shed light on how people process information while learning and provide implications onto how to improve instructional practices. For example, CLT has been used to rationalize the acquisition of problem solving skills of engineering statics course (Rossow, 2005), Excel lesson (Clark et al., 2005), and algebra problems (Sweller & Cooper, 1985). Some authors also used CLT to study the effectiveness of multimedia learning and provide guidance for instructional design and multimedia development (Mayer, 2005).

The CLT considers human cognition as a natural information-processing system with WM as the “buffer storage” and long-term memory (LTM) as the “central storage.” Working memory has limited capacity and duration when learners handle new, unfamiliar information from the outside world. It is the place where temporary information is stored and an executive system processes information. Meanwhile, LTM appears to be
unlimited and plays a role as a central executive for WM. The goal of instruction is to acquire organized knowledge called “schemas” and stored them in LTM. Sweller (2005) defined schemas as “cognitive constructs that allow multiple element of information to be categorized as a single element” (p. 21). He noted that learning takes place when these elements are organized, combined into schemas, and held in LTM. Therefore, the goal of instruction is the acquisition of schemas in LTM; the more schemas in a certain domain stored in one’s LTM, the more skillful he or she will be in that domain.

Schemas are constructed consciously through learners’ experience with things and events taking place around them. Once a schema in a certain knowledge domain has been constructed, it can be processed automatically without learners’ consciousness though practice. For example, after children know how to recognize letters of alphabet and combine them into words and phrases, further learning permits them to read without consciously paying attention about individual letters or their combination rules. If schemas are not available, as in the case of novice problem solvers when dealing with a new problem, there is no alternative central executive to call upon. Instead of spending time to search for and construct a solution schema for that type of problem, novice problem solvers can accept knowledge provided by others (such as instructors or expert problem solvers) as a central executive. This explains why novice solvers acquire problem solving skills faster when learning with worked examples than learning with extensive practices (Sweller, 2005).
Cognitive Load Theory and Worked Examples

Engineering educators have used worked examples as an instructional strategy to teach students how to solve problems. For examples, instructors walk through worked examples in class before assigning homework in the same topics to their students; textbooks contain substantial worked examples to introduce expert’s solutions for learners to study. Worked examples are also used in instructional animation. As engineering courses use a lot of mathematical concepts, the step-by-step design in instructional animation modules proves very helpful in presenting the process of deriving equations and synchronizing them with animated contents.

Mayer (2011) believed that the use of worked examples is one of the most effective principles for instructional design because “people learn better from practice when worked examples are presented before to-be-solved problems” (p. 72). Sweller (2005) demonstrated that when learners studying worked examples with a provided solution to a problem, they learned more than learners who were required to solve the equivalence problem. In a series of experiments investigating the use of worked examples in solving algebra transformation problems, Cooper and Sweller (1987) noted that learning with worked examples facilitates the development of schema acquisition and rule automation. They also found that students who were trained with worked examples performed better on similar and transfer problems than those who were trained with conventional problems.

Learning with worked examples is better than doing extensively problem-solving practice in the acquisition of problem-solving skills because the latter requires learners more mental work through a process called “means-end analysis.” Heyworth (1999)
considered this process as a form of backward reasoning because learners solve problems by (1) identifying the goal statement, (2) finding the differences between the goal and the current information, (3) finding an operation, (4) attempting to carry out this operation to reduce this difference, and then (5) repeating (2), (3) and (4) until the solution is found.

As Rossow (2005) described, this process imposes a heavy extraneous cognitive load on learners as they continuously search for “ways to reduce differences between the goal state (knowing the answer), sub goals (intermediate steps that will lead to the goal state), and the data given in the original problem statement” (p. 3). Worked examples provide learners with a clear solution so they can devote limited working memory capacity to construct schema of the analogy while solving similar problems and eliminate the need to search for the best solution approach as in case of problem solving practice (Clark et al., 2005).

**Implications for This Study**

In this study, worked examples are used in the CSA modules to help learners decrease extraneous cognitive processing. The worked examples in CSA modules and corresponding bonus homework assignments (i.e. pretest and posttest questions) are closely related. Therefore, by learning how problems were solved in CSA modules, students may acquire problem-solving skills and be able to solve bonus homework assignments. The step-by-step format of worked examples can be implemented in CSA modules by utilizing different multimedia techniques such as segmenting problems into sub-steps and linking all of them by navigation buttons and scrollbars.
Cognitive Load Theory and Instructional Animation

The CLT offered some suggestions to make CSA modules and programs more effective. According to this theory, the human cognitive system processes three types of cognitive load (Figure 2.2): (1) intrinsic load, which refers to the intrinsic nature of the learning material; (2) extraneous load, which refers to the presentation of the learning material; and (3) germane load, which refers to the working memory resources to acquire information.

![Figure 2.2. Three types of cognitive load.](image)

The three types of cognitive load are additive, and an instructional design is considered effective when the total cognitive load is within the working memory limit of a learner (Hasler, Kersten, & Sweller, 2007). Because the intrinsic load cannot be altered, reducing extraneous load (and therefore, increasing germane load) can make instructional animation more effective. Ayres, Kalyuga, Marcus, and Sweller (2005) proposed a set of strategies to reduce extraneous load of multimedia such as combining statics and animation, giving the learner control over the animation pace, and segmenting animation into parts. Alternatively, other strategies to increase the germane load of multimedia such
as increasing interactivity were also suggested. Interactivity makes instructional animation more effective because it may stimulate learners to exert more mental effort in learning.

The navigation and control buttons in CSA modules enable a gradual presentation of information to learners so that new information can be presented in a step-by-step procedure. They are also used to help learners explore the derivation of an equation, perform calculations with inputs from the learner, or draw graphs with selected parameters. Mohr’s circle lesson in Budhu’s (2001) interactive animation module is an example. Budhu segmented his lesson into steps to enhance student learning. Mohr’s circle is used in engineering mechanics and other engineering disciplines to determine the stress state of a body subjected to loads. Students can provide the module with different inputs and witness the changes of corresponding outcomes until they master the module.

Many studies of CSA usage in engineering education reported that the interactions increase student’s motivation and enjoyment of learning. Interactive CSA modules provide interactive instructions similar to those in a traditional classroom, but focus more on the individual students’ needs. The interaction enabled by interactive CSA engages students in the learning process, and the student also becomes self-motivated in the discovery of new knowledge (Oreta, 1999). The student can interact with course materials and progress at his/her own pace to study the contents of course materials. Many CSA programs for engineering education are displayable on popular web browsers, making the access to these learning modules easier and faster. Students can interact with course materials remotely from any location and progress at their own pace to study the contents of course materials (Ong & Mannan, 2003).
Implications for This Study

This study adopted strategies suggested by Ayres et al. (2005) to reduce extraneous load of multimedia in the design and development of CSA modules. Specifically, the CSA modules use both verbal and non-verbal representations (diagram, static, and dynamic graphics) to display step-by-step solutions of worked examples. They also can give users a certain degree of control over animation and a full degree of control over the module’s contents by offering navigational and control functions such as stop, play, moving forward and backward, and sliding scrollbars. In this dissertation, some CSA modules working with complex concepts provide learners with scaffolding features such as hints, brief explanations, or short quizzes to increase learner interaction with the modules. The abstract concepts such as force and velocity were depicted by vectors and students can provide input and manipulate control buttons to witness the changes of these vectors magnitudes and directions along with animations.

Current Trends of CSA Usage in Engineering Mechanics Instruction

The current trends of CSA usage in engineering mechanics instruction are extracted from the systematic review of research studies in this domain. The systematic review is an approach of reviewing literature that has been used extensively in research domains such as medicine, psychology, and education for a long time. It is now being used by engineering education researchers to synthesize prior work and identify important new directions for research (Borrego, Foster, & Froyd, 2014). Systematic reviews call for “transparent, methodical, and reproducible procedures” (p. 46) of literature selection and trend extraction from selected studies. The procedure of searching
and the criteria for selecting literatures for systematic review of CSA in engineering mechanics are introduced in Appendix A. Twelve studies, including the pilot study for this project (Fang, 2012), discussing the applications of CSA in learning EM were identified and analyzed to provide understandings about the current trend of using CSA in EM instruction. In the pilot study, a set of CSA modules were developed for both particle and rigid body dynamics. Engineering undergraduate students in multiple semesters were involved in the assessment of the developed CSA modules. The representative results reported in the paper by Fang (2012) shows that students achieved high learning gains from the CSA modules, and that more than half of the students surveyed had positive experiences with the CSA modules.

A summary of study characteristics of these twelve papers is provided at the end of this literature review section and their details are introduced in Appendices B and C. The following session provides insights on how interactive CSA modules were developed and assessed by engineering mechanics educators as well as the facts about the common study characteristics of their investigations. Both the summary and the insights from the CSA developers are based on Ha and Fang’s (2013) study with up-to-date materials.

**CSA Development and Assessment**

**Authoring tools and development software package.** Developers use a variety of computer software to create CSA modules, from open source to commercial software. Freeware and open source software, such as some versions of C++, HTML editors, DirectX, and OpenGL, were used by several researchers to develop CSA modules and programs. As CSA modules for engineering education usually contain a mixture of text,
graphics, animation, and even video and audio data, the use of authoring tools in CSA development became more popular. Authoring tool is defined as any software or collection of software components that helps developers write multimedia applications (World Wide Web Consortium, 2015). Authoring tools have also been used to write the web, from What-You-See-Is-What-You-Get HTML editors to development kits like Adobe Flash CS or Java SE.

Some engineering educators have used commercially available software packages in teaching ED courses. These commercial software packages are multi-physics or multi-body solvers, such as MSC Adams which can simulate many scientific and engineering problems in a variety of engineering fields. The CSA modules developed from these software packages require proprietary compatible software on users’ computers to play animation. These commercial software packages are powerful, and instructors do not need to spend financial and human resources to develop CSA modules. Their students have opportunities to learn high-end simulation packages that they will use in senior level courses and in professional careers (Mazzei, 2003). However, because the commercial software packages are comprehensive and require users to have full knowledge about the domain and take time to learn, their applications in introductory engineering courses like ED or EM are considered an excessive use. The initial and annual software license fees of these proprietary software packages are also expensive and unaffordable for many institutions.

The accessibility of interactive CSA modules from the client side is an important construct for any animation developer. An approach to addressing the issues of proprietary software and accessibility at the same time is to use web browser plug-ins
such as Java applet, Shockwave, and Flash players. These players and plug-ins are free, pre-installed, and constantly updated in the most popular web browsers, such as Internet Explorer, Firefox, Chrome, and Safari. This means that CSA modules written for these plug-ins would be viewable by all visitors at anytime and from anywhere (Ong & Mannan, 2003). This is also the main approach that most engineering educators have used in recent years.

**Mathematic equations presentation.** Problem-solving skills still play a central role in many engineering courses. CSA modules are expected to have interactive features that promote the acquisition of students’ problem-solving skills, including the mathematical equation derivation. According to Enelund and Larsson (2006), explicit mathematic equations, along with animated contents, helped students gain self-confidence in using CSA modules and understand the mathematic principles behind CSA modules. Mathematical expressions, user inputs, and interactivities helped students understand the mathematic principles following CSA, instead of, as Enelund and Larsson (2006) stated, “running black box simulations with ready-made programs” (p. 330).

As engineering mechanics courses use a lot of mathematic concepts, the presentation of mathematic equations is a crucial part of a CSA module. Some CSA modules show final equations as parts of learning modules. Other CSA modules utilize the interactive functionality of navigation buttons to show step by step the deriving process of mathematical equations along with animated graphics. For example, in the case of structural analysis, Sidhu, Singh, and Narainasamy (2004) used different animation techniques (changing colors, alpha values, and arrows’ directions and
magnitudes) to show students various steps involved in analyzing the equations of equilibrium for forces and moments acting on a structure’s components.

**Experimental design.** Engineering mechanics educators used different experimental designs to assess their developed CSA modules such as One-Shot Case Study, Static Group Comparison design, and One-Group Pretest-Posttest design. The classification of experimental designs in educational research discussed in this dissertation is based on the work by Gall, Gall, and Borg (2007).

In One-Shot Case Study design, the learning with CSA modules (i.e., experimental treatment) was administered to a single group of students (or groups of students who were also treated as a single group because they all received the same treatment). Then a posttest and a questionnaire survey were administered to measure the effects of CSA modules and programs.

In Static Group Comparison design, only students in the experimental group worked with the CSA module; while students in the control group did not. Posttests were implemented in both groups to measure the effectiveness of CSA modules. In One-Group Pretest-Posttest design, no control group was involved, and pretests and posttests were administered to a single group of students.

The problems with the above-described experimental designs are the lack of a control group, pretest, or the random assignment of participants to treatment conditions. Gall et al. (2007) noted that experiments with random assignment “are highly recommended by most educators because they provide strong assurance that observed effects are caused by experimental treatment and not by extraneous variables,” (p. 380). As for One-Shot Case Study design, Gall et al. (2007) found that it had “low internal validity” and “yields
meaningless findings” (p. 402). Hoffler and Leutner (2007) noted that possible extraneous variables, such as prior knowledge, spatial skills, motivation, and learners’ time spent on tasks could also affect student learning outcomes with CSA modules.

**Summarized Study Characteristics of CSA Literature in Engineering Mechanics**

Following is a summary of ten study characteristics among twelve published studies on the development and assessments of CSA modules in engineering mechanics. These characteristics include: (1) sample sizes; (2) area of study; (3) CSA usage in engineering mechanics instruction; (4) worked examples usage in CSA module; (5) authoring tools and development software packages; (6) mathematic equation presentation; (7) experimental design; (8) data collection methods; (9) commonly reported student learning outcomes; and (10) performance assessments. The details of these study characteristics are introduced in Appendices B and C.

**1. Sample sizes**

Of the 12 studies reviewed, 1 study (8.3%, \( n = 12 \)) had sample sizes of fewer than 50, 5 (41.7%) had sample sizes from 51 to 100, and 3 (25%) had sample sizes over 100. In addition, three studies (25%) reported “students taking the courses/sections” instead of specific numbers. Therefore, a half of these studies were conducted with sample size less than 100 student participants. The researchers typically assigned student participants from the same class or section at the time of conducting their research study.
2. **Area of study**

Most of the reviewed studies investigated the use of CSA modules and programs in learning dynamics (75%, \( n = 12 \)). Two studies reported the use of CSA modules and programs in learning statics (16.7%), and one study for engineering mechanics (8.3%).

3. **CSA usage in engineering mechanics instruction**

CSA modules are different in the ways they are designed and utilized in instruction. CSA modules can be one of the eight most effective principles designed to be substitution of traditional lectures and used as stand-alone courses. They can also be developed to become components of larger learning situation such as visual aids and demonstrations for traditional lectures. Of twelve selected studies, eleven reported that their CSA modules were designed as teaching aids for traditional instruction (92%) and only one study claimed that their CSA modules were suitable as stand-alone course (8%).

4. **Worked examples usage in CSA modules**

Over half of selected studies (58%, \( n = 12 \)) used worked examples in their CSA modules as strategy to improve problem solving skills. The rest of studies (42%) did not use worked examples or did not show step by step solutions of worked examples in their CSA modules.

5. **Authoring tools and development software packages**

Of the twelve studies examined in the literature review, only three researchers used commercial simulation packages in teaching their courses, accounting for 25% (\( n = 12 \)) of the studies. Seventy-five percent of the studies used authoring software such as Adobe Flash (25%), Macromedia flash - now acquired by Adobe (Adobe, 2005) (38%),
or a combination of partially-free or free software, such as C++, Java, VRML, and HTML (17% of all cases), to develop CSA modules and programs.

It was found that this 75% of CSA programs made use of the availability of plug-in software that was pre-installed (and constantly updated) in most popular web browsers and provided wide accessibility to students. For CSA modules developed with commercial simulation packages, it was found that they required some sorts of proprietary programs on students’ computers to display CSA, making the access more costly. Recently, the trend of using free web browser plug-ins to display CSA modules has been increasing. According to a recent survey from Adobe in the United States and several countries, Flash player and Java plug-in, the two free web browser plug-ins, are available in 99% and 73% of Internet-enabled PCs, respectively (Appendix D; Adobe, 2012).

6. **Mathematic equation step presentation**

Of the twelve articles examined, nine studies (75%) showed mathematic equation steps, along with animated graphics, in their CSA modules and programs. The other three studies (25%) just showed animations or animations with inputs and outputs. The former group may be used as standalone learning units, while the latter group may be used to assist student learning along with students’ own notes or other learning materials.

7. **Experimental design**

Most of the studies (8 of 12 cases, or 67%) employed One-Shot Case Study design. Two studies (17%) dealt with Static Group Comparison design, and another two (17%) used One-Group Pretest-Posttest design. As analyzed above, these experimental
designs lack random assignment of participants to conditions and have low internal validity.

8. Data collection methods

The methods used for data collection in the 12 studies included questionnaires (100%, n = 12), content analysis of students’ comments (2 studies, 17%), and scores of performance tests (quizzes or homework) (5 studies, 42%).

9. Commonly reported student learning outcomes

Nearly all published studies reported that CSA modules enhanced student learning (92%, n = 12) and student visualization skills (83%, n = 12). Seven studies (58%) claimed that CSA modules increased student enjoyment, while three studies (25%) reported that CSA modules motivated students to learn. In one study, students showed strong dissatisfaction after using a CSA module. Students disagreed or strongly disagreed that the module helped them learn and visualize the concepts involved (Fong, 2008). In another study, CSA modules were considered beneficial but with the exchange of increased times for students to learn (Flori et al., 2002). It was concluded that poorly-designed GUI and interactive functions might have been the main causes making the modules ineffective.

10. Performance assessments

Of the 12 studies examined, 2 studies used learning gain to compare the pretest and posttest changes (17% of all cases), 1 study used average scores and percentages of grade A as measures of performance test (8%), and 2 studies did not provide information on how they processed the performance test scores (17%). The rest of studies did not employ any performance test on their students (67%).
Implications for This Study

In this study, CSA modules use worked examples to guide students how to derive mathematic equations needed to solve RBD problems. Adobe Flash CS 5.5 is a series of software suites of graphic design, video editing, and web development applications (Adobe Flash, n.d.). It was used to develop CSA modules because the output files of Adobe Flash CS 5.5 can be played with Adobe Flash Player as standalone or plug-in application. In addition, because Flash player is installed in most web browsers, CSA modules produced with Adobe Flash CS 5.5 can be accessed at anytime and from anywhere. This study utilized a form of quasi-experimental design, the nonequivalent control group experiment, to measure and compare pretest-posttest changes of student’s scores between comparison and intervention groups. Although a quasi-experiment design lacks random assignment, it yields useful knowledge if researchers designed experiments carefully (Gall et al., 2007). Data from student surveys and semi-structured interviews were also collected to get a better understanding of student’s experiences with and attitudes towards the developed CSA modules.

General Conclusions of Literature Review

This chapter has presented the literature review and analysis of interactive CSA modules and programs employed in engineering mechanics education. The results show that CSA modules can enhance students’ visualization skills, improve their understanding of learning materials, and arouse their interest in learning. Many published studies reported that CSA helped students visualize complex phenomena in engineering
mechanics, and explicitly showed the relationships among various components of a complex system over time and space.

The uses of computer visual aids to improve student’ conceptual understanding and worked examples to develop students’ problem-solving skills are evidenced from literature. Theories of cognitive processes of learning such as Cognitive Load Theory and working memory concept have been employed to explain the pedagogical aspects of interactive CSAs and offer suggestions to make CSA modules more effective. Some technical aspects involved in the development of interactive CSA modules have also been discussed in this chapter. The implications of the current literature are useful to the design of experiments and the implementation of CSA modules developed in this study.
CHAPTER 3
RESEARCH METHODOLOGY

This study has two phases: development and assessment. In the first phase, the efforts were focused on the design and development of a total of 10 interactive CSA modules for rigid body dynamics. Based on the analyses of interactive computer simulation and animation software from the literature review in the previous chapter, new custom modules were designed and developed to suit the purposes of this study. The design and development of CSA modules are described in detail in this chapter.

In the second phase, the CSA modules were used as an intervention instrument in a nonequivalent control group experiment, a form of quasi-experimental design, to assess the effects of the developed CSA modules on students’ learning gains. Surveys and semi-interviews were also conducted at the end of experiments to find out students’ experiences with and attitudes towards the modules. As the study involves strands of quantitative and qualitative methods at the same time, the research design in the second phase is best described as a concurrent mixed method. The section on “Concurrent Mixed Method” in this chapter will discuss this method in greater detail.

Design and Development of CSA Modules for Rigid Body Dynamics

In the development phase, 10 CSA modules that tie to the most important RBD knowledge from chapter 16 to chapter 19 in the Engineering Mechanics-Dynamics book
by Hibberler (2010) were developed. The modules cover some of the most important concepts and problem-solving skills that students need to have in learning RBD (Gray et al., 2005). The contents and related chapters of these 10 CAS modules, from Module 13 to Module 22, were outlined in Table 3.1. Because the first twelve modules (from Module 1 to Module 12) cover Particle Dynamics knowledge, they were not discussed in this dissertation.

The development work of 10 CSA modules involved three main tasks: (1) the design of 10 worked examples (which are 10 technical problems addressed in 10 CSA modules), (2) the design of computer graphics user interfaces of ten CSA modules, and (3) write and debug computer codes for the ten CSA modules. The faculty advisor of this author, Dr. Ning Fang, is responsible for tasks 1 and 2. This author is primarily responsible for task 3. Another graduate student and an undergraduate student also helped in task 3 for 4 of the 10 CSA modules.

Implications of literature review about technical and pedagogical constructs of CSA were combined with the research team’s experiences gained from teaching and tutoring Engineering Dynamics determined the detailed framework for these ten CSA modules. Common practices, trends of authoring software and multimedia development, and the pilot CSA project (Fang, 2011) were considered during the development. The development of CSA modules was best described in Work Plans that outlined the research team’s goals and processes to accomplish these goals. Each of ten modules has its own Work Plan and the section below introduces the details of one of them (Work Plan Module 13) as a representative example.
Table 3.1.
Contents and Related Chapters of 10 CSA Modules for Rigid Body Dynamics

<table>
<thead>
<tr>
<th>Module</th>
<th>Module Title</th>
<th>Related Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Rigid body Kinematics: Vector analysis of velocity for relative motion</td>
<td>Chapter 16: Planar Kinematics of a Rigid Body</td>
</tr>
<tr>
<td>14</td>
<td>Rigid body Kinematics: Instantaneous center of zero velocity</td>
<td>Chapter 16: Planar Kinematics of a Rigid Body</td>
</tr>
<tr>
<td>15</td>
<td>Rigid body Kinetics: Rotational Motion</td>
<td>Chapter 17: Planar Kinetics of a Rigid Body: Force and Acceleration</td>
</tr>
<tr>
<td>16</td>
<td>Rigid body Kinetics: General planar motion</td>
<td>Chapter 17: Planar Kinetics of a Rigid Body: Force and Acceleration</td>
</tr>
<tr>
<td>22</td>
<td>Rigid body Kinetics: Impulse and Momentum II</td>
<td>Chapter 19: Planar Kinetics of a Rigid Body: Impulse and Momentum</td>
</tr>
</tbody>
</table>

An Example of Work Plan for Module 13

Learning outcome and target audience of CSA Module 13. After learning this module, students are able to use vector analysis method to calculate velocities of two particles in a rigid body that undergoes a general plane motion. The target audience of the module is engineering dynamics students who are typically in their junior or sophomore years of mechanical engineering, civil engineering, and aerospace engineering among many other engineering fields.
**Analysis and design of CSA Module 13.** CSA Module 13 discusses the concept of one of the most complex motions in RBD - the general plane motion - and the use of relative motion analysis method to determine the velocities of components in a crank and slider mechanism as shown in Figure 3.1. This mechanism is mainly used to convert rotary motion to a reciprocating motion or vice versa.

![Crank and slider problem in CSA Module 13](image)

*Figure 3.1. Crank and slider problem in CSA Module 13*

The mechanism consists of two links, OA and AB, and a sliding block B. Link OA is pinned at Origin O, and link AB connects link OA and sliding block B. Link OA has only rotational motion, sliding block B has only translational motion, and link OA has general plane motion. Link OA’s angular position is labeled $\theta$, and link AB’s angular position is labeled $\psi$. The angular velocity of link OA is given as $\omega_{OA}$. In this CSA module, the concept of general plane motion of the crank and slider system is illustrated by the animation, and worked problem of relative motion analysis is presented under
step-by-step format. The students are asked to find the velocity of block B, called $v_B$, given the length of the two links, the angular velocity $\omega_{OA}$, and an initial angular position $\theta$.

**The objectives of CSA Module 13 development.**

a. Clearly outline the physics of the crank and slider mechanism;
b. Create an introductory computer graphic that helps the student visualize the mechanism and the geometrical relationship among its components;
c. Introduce a worked problem in step-by-step format that help students derive a mathematical equation to determine velocities of the mechanism’s components;
d. Allow students to change input variable $\theta$ by manipulating the scrollbar. The scrollbar values and variable $\theta$ must be consistent while students navigate from page to page; and
e. Create the animation that shows the motion of mechanism. Students can control the motion by manipulating the scrollbar.

**Finished products and timeline.** The deliverables for this module development are:

a. A main resource *.fla* file that is editable and compilable;
b. An animation application *.swf* file that can be played on Adobe Flash player version 10 or earlier;
c. Relevant Actionscript *.as* files that the main resource file will call during the compiling process;
d. Copies of the graphics of the components;

e. The storyboard; and

f. This work plan document.

As coding is a time-consuming process, a timeline is necessary for any software development project. The purposes of the timeline are to outline approximate dates when certain project’s portion will be done and to determine what the deliverables are. The timeline for CSA Module 13 is outlined in Table 3.2 and some examples of Actionscript 3.0 code for CSA Module 13 are introduced in Appendix E.

Table 3.2
An Example of the Development Timeline for CSA Module 13

<table>
<thead>
<tr>
<th>Date (2012)</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 23rd</td>
<td>Work Plan 1 - Initial</td>
</tr>
<tr>
<td>Feb 20th</td>
<td>Work Plan 2 – All but storyboard</td>
</tr>
<tr>
<td>Feb 28th</td>
<td>Finish interface and graphic design, start coding with Actionscript 3.0 to control mechanism</td>
</tr>
<tr>
<td>March 13th</td>
<td>Finish coding for control, start coding with Actionscript 3.0 for calculations, draw velocity vectors. Preliminary assessment’s results and feedbacks from the advisor and research team on the module are documented.</td>
</tr>
<tr>
<td>April 13th</td>
<td>Work Plan 3 – With storyboard</td>
</tr>
<tr>
<td>April 20th</td>
<td>Begin project documentation</td>
</tr>
<tr>
<td>April 30th</td>
<td>Project files and final documentation submitted to the advisor</td>
</tr>
</tbody>
</table>

**Storyboard.** Storyboard is a series of screenshots that outline the sequence of scenes and descriptions of each scene. Its purposes are: (1) to help manage the timing of development; (2) to portray a basic idea of how the contents and GUI features are designed and positioned in the stage board of each scene during the module production;
and (3) to illustrate to the rest of the development team how the final product is seen. The storyboard for Module 13 has six scenes: three of them are for the introduction of the module’s problem and its learning outcome; one shows the animation; and two show figures and step-by-step calculations of the velocities. Details of the storyboard for CSA Module 13 are introduced in the Table 3.3.

**Concurrent Mixed Method Research Design**

The assessment phase followed right after the development phase described above. In this assessment phase, a concurrent mixed method (Creswell, 2009) which involves with the concurrent collection of quantitative and qualitative data was employed in this study. By using concurrently quantitative and qualitative methods, the researchers can “gain broader perspectives as a result of using the different methods as opposed to using the predominant method alone” (Creswell, 2009, p. 214). Within the quantitative- qualitative continuum, the quantitative study was given higher priority in relation to the qualitative study. This approach is symbolized as (QUAN/qual) and called “concurrent embedded strategy” by Creswell (2009, p. 210) or “quantitative dominant” by Johnson, Onwuegbuzie, and Turner (2007). While the assessment of students’ learning gain of this study relied heavily on the pretest and posttest quantitative data, other particular aspects of the study such as students’ attitudes towards and experiences with CSA modules were best captured by qualitative data. Table 3.4 outlines each of the research questions pursued and data collection method applied.
Table 3.3
Storyboard of Module 13 Production

**Scenes and Descriptions**

**Scene 1:** The first scene has title of the module in the center, the USU logo, the main principal investigator’s name, and his contact in the middle bottom. Every slide of the module has the navigation menu button located in the bottom with following basic functions: Previous, Next, and Close. The “Previous” button is grayed out to alert students that they are at the very first slide of the multi-slide module.

**Scene 2:** This scene introduces the learning objectives of the module.
Scene 3: This scene introduces a crank and slider mechanism problem which is typically solved by applying vector analysis. A horizontal scrollbar permits students control the angle of the driving bar (OA) and angular position, θ, from 60° to 90° relative to the vertical line through point O. The mechanism is animated at the same time.

<table>
<thead>
<tr>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Given:</strong></td>
</tr>
<tr>
<td>• Length of link OA ( l_{OA} = 0.2 \text{ m} )</td>
</tr>
<tr>
<td>• Length of link AB ( l_{AB} = 0.4 \text{ m} )</td>
</tr>
<tr>
<td>• Initially link OA and AB are on the same line (8 = 80°) and the angular velocity of link OA ( \omega_{OA} = 3 \text{ rad/s} )</td>
</tr>
<tr>
<td>• Rotating angle of link OA ( \theta = 71.0^\circ )</td>
</tr>
</tbody>
</table>

| Find: |
| • Velocity of block B \( V_B \) |

Scene 4: This scene introduces the first two steps of the worked problem. It begins by choosing a coordinate system and illustrating the geometrical relationship of mechanism’s components. The scrollbar permits students to change direction of bar OA either clockwise or counterclockwise, and hence change variable θ. The animation (on the right) helps students visualize how the directions and magnitudes of \( V_A \) and \( V_B \) change along with their inputs.
Scene 5: This scene provides Step 2 of the solution with math equations, inputs, and outputs. Students can change the inputs of the problem by dragging the horizontal scrollbar to observe how the outputs change with their inputs. The vertical scrollbar permits students to view the solution content which is out of the viewable area of the stage.

Scene 6: This scene introduces Step 3 of the solution. The values in the highlight fields vary depending on the inputs on the scrollbar. These values include the inputs, the intermediate calculation results, and the outputs. The “Next” button is grayed out to alert students that they are reaching the very last slide of the multi-slide module.
Table 3.4  
Outline of Research Design

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Research Analyses and Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To what extent do students in the intervention group who use interactive CSA modules along with traditional lectures improve learning in RBD, as compared with students in the comparison group who use traditional lectures only?</td>
<td>Quantitative method for the pretest and posttest scores of bonus homework 13-22 in the intervention and comparison groups.</td>
</tr>
<tr>
<td>2. What are students’ attitudes towards and experiences with the interactive CSA modules?</td>
<td>Quantitative method for student survey data and qualitative method for semi-structured interview data of students in the intervention group.</td>
</tr>
</tbody>
</table>

Quantitative Method

This study utilizes a nonequivalent control group design, an approach of quasi-experimental design. The nonequivalent control group design includes a pre-posttest design with both a treatment group and a control group, and students are not randomly assigned to these two groups. In the real-world teaching environment, the random assignment of students to two different learning conditions is difficult to implement. In addition, random assignment of students to different learning conditions may interfere with regular teaching activities. Therefore, intact groups of students from two course sections were used. According to Gall et al. (2007), although quasi-experiments lack random assignment, they yield useful knowledge if researchers design experiments carefully.

Because the experiment group received treatment or intervention during the study, this group of students is sometimes called the intervention group. Some authors
suggested the term “comparison group” to indicate the non-treatment group to acknowledge the fact that this design is not a randomized experiment (May, 2012). Therefore, the phrases “intervention group,” “nonequivalent comparison group design,” and “comparison group” are used in this study, instead of the phrases “experimental group,” “nonequivalent control group design” and “control group.” All students taking Engineering Dynamics course in Fall of 2012 served as the comparison group, and all students taking Engineering Dynamics course in Fall of 2013 at USU served as the intervention group. The same instructor, Dr. Ning Fang, taught the course in both semesters.

This experimental design has threats to the internal and external validities that need to be addressed and controlled. According to Campbell and Stanley (1963), key threats to internal validity were identified as history, maturation, testing, instrumentation, regression, selection, mortality, and the interaction of these threats; the key threat to external validity is the interaction of testing and intervention. Several steps have been taken to control these threats in this study as described below.

First, the students in each group did not know which learning condition the group would have; therefore, possible self-selection was eliminated as a threat. Second, the regression toward the mean was eliminated because the formation of all groups was not based on students’ test scores. Third, according to Campbell and Stanley (1963), by administering pretests in both comparison and intervention groups, many threats are controlled except the interaction of threats. For example, the preexisting differences between comparison and intervention groups can be eliminated by comparing pretest and posttest changes across two groups. In addition, the interval time between the pretest and
posttest was not very long and the experiment conditions were almost identical for all groups; therefore, the threats of history, maturation, instrumentation, and mortality were also removed. According to D’Agostino (2005), depending on knowledge domain, an interval of one week or one month between pretest and posttest is ideal to avoid remembering and practice effects that could affect the validity of an experiment. Because the average interval time between pretest and posttest in this study was 11.2 days, the threats of remembering and practice test effects were eliminated.

The threat of interaction between selection and maturation (i.e., the rates of improvement without intervention are different from the intervention and comparison groups) on the internal validity can be controlled by assuming the rates of change without the intervention for comparison and intervention groups were similar. Furthermore, Campbell and Stanley (1963) mentioned the interaction between pretest and intervention as a source of invalidity that can threaten the generalizability of quasi-experimental studies. According to their concern, the pretest would sensitize students to the intervention yet to come and pretesting does not take place in any real educational settings.

In addition to the nonequivalent control group design as the main quantitative inquiry, this study also uses students survey as a tool to provide numeric description of trends, attitudes, and experiences of the intervention group of students after they used the CSA modules. The survey was carried out online via Canvas. Details of the survey tool used in this study are discussed in the “Survey” section below.
Qualitative Method

The purposes of qualitative analysis of this mixed method design are to supplement the quantitative data and to aid in the interpretation of quantitative data. Data from the open-ended survey questions and semi-structured interviews was collected after students finished all posttests and analyzed to have a better understanding about the students’ experiences and attitudes towards the modules.

Intervention Instrument

The study used 10 CSA modules developed during its first phase as the intervention to examine the effectiveness of interactive CSA and worked problems on students in the intervention group. These CSA modules were embedded in the Canvas environment, where students had the options to run modules directly within the Canvas environment or download the modules to the computers and open the modules in separate windows. The 10 CSA modules address different areas of RBD knowledge (Table 3.1 before) and provide students with key concepts and sample problems that were solved by experts in the EM domain.

Assessment Instrument

The pre-posttest assessment instrument consisted of 58 multiple-choice questions and was divided into 10 bonus homework assignments. This assessment instrument was designed to assess students’ knowledge on both conceptual understanding (CU) and procedural skills (PS). The CU questions assessed the student’s understanding about a principle in engineering dynamics such as the Principle of Conservation of Energy
(Figure 3.2) or a Free Body Diagram (FBD) (Figure 3.3). The PS questions assessed a student’s problem-solving skills by requiring them to produce a correct numerical answer.

Figure 3.2. A conceptual understanding question in bonus homework 20.

Figure 3.3. A conceptual understanding question in bonus homework 22.
An example of assessment questions in bonus homework 19 was introduced in Figure 3.4. This assessment had three CU and three PS questions assessing student’s understanding and problem-solving skills on the Conservation of Energy. The example CU and PS questions are listed in the Table 3.5. The whole instrument was developed based on the similar assessment instrument in the pilot study in 2011 (Fang, 2011), the research group’s teaching experiences in this domain, and the dynamics concepts inventories (DCI) (Gray et al., 2005). DCI is a pool of questions assessing important but difficult concepts in engineering mechanics instruction. Some concepts addressed by the bonus homework were direct references to the DCI.

The coefficient of reliability Cronbach’s alpha of this assessment instrument was obtained during the main study. In general, the reliability of the whole instrument is good ($\alpha = 0.96$); the reliabilities for individual area of concepts ranged from 0.70 for the vector analysis of relative motion velocity to 0.94 for the Work and Energy (Table 3.6). While the required levels of reliability differed depending on the nature and purpose of the scale, a minimum level of 0.7 was recommended by Nunnally (1978). The Cronbach’s alphas in the Table 3.6 proved that the bonus homework was reliable and can be used as an assessment instrument on RBD knowledge of students in this study.
A yo-yo is released from rest. The string unwinds but does not slip as the solid cylinder drops a distance of $h$ (in meters), as shown in the following figure. The solid cylinder has the mass $m$ (in kg) and the radius $r$ (in meters). The mass moment of inertia of the solid cylinder around its mass center is $(1/2)m\,r^2$. Ignore the mass of string. Let $V_0$ be the speed of the mass center of the solid cylinder after it has dropped a distance of $h$.

**Example CU question 1**
As the mass $m$ of the solid cylinder increases (while keeping both the radius $r$ of the solid cylinder and the distance $h$ constant),

- A) $V_0$ increases
- B) $V_0$ decreases
- C) $V_0$ does not change
- D) More information is needed to determine if and how $V_0$ changes

**Example CU question 2**
As the radius $r$ of the solid cylinder increases (while keeping both the mass $m$ of the solid cylinder constant and the distance $h$ constant),

- A) $V_0$ increases
- B) $V_0$ decreases
- C) $V_0$ does not change
- D) More information is needed to determine if and how $V_0$ changes

**Example PS question**
In the case of $m = 0.70$ kg and $r = 0.18$ meters, the speed $V_0$ of the mass center of the solid cylinder after it has dropped a distance of $h = 0.5$ meters is:

- A) 1.98 m/s
- B) 2.29 m/s
- C) 2.56 m/s
- D) 2.80 m/s

**Figure 3.4.** Example assessment questions for bonus homework 19.
### Table 3.5

**Number of CU and PS Questions in the Bonus Homework**

<table>
<thead>
<tr>
<th>Area of knowledge (Bonus homework)</th>
<th>Total Number of Questions</th>
<th>Number of CU Questions</th>
<th>Number of PS Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planar Kinematics of a Rigid Body: Vector analysis of velocity for relative motion (BH 13, 14)</td>
<td>10</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Force and Acceleration (BH 15, 16)</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Work and Energy (BH 17, 18)</td>
<td>14</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Conservation of Energy (BH 19, 20)</td>
<td>11</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Impulse and Momentum (BH 21, 22)</td>
<td>11</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Overall test instrument (10 homework)</td>
<td>58</td>
<td>22</td>
<td>36</td>
</tr>
</tbody>
</table>

*Notes. CU = conceptual understanding; PS = Procedural skills, BH = bonus homework*

### Table 3.6

**Reliability Test**

<table>
<thead>
<tr>
<th>Area of knowledge (Bonus homework)</th>
<th>Cronbach's Alpha</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planar Kinematics of a Rigid Body: Vector analysis of velocity for relative motion (BH 13, 14)</td>
<td>0.70</td>
<td>10</td>
<td>4.88</td>
<td>5.99</td>
<td>2.45</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Force and Acceleration (BH 15, 16)</td>
<td>0.86</td>
<td>12</td>
<td>7.69</td>
<td>12.86</td>
<td>3.59</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Work and Energy (BH 17, 18)</td>
<td>0.94</td>
<td>14</td>
<td>9.88</td>
<td>22.08</td>
<td>4.70</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Conservation of Energy (BH 19-20)</td>
<td>0.90</td>
<td>11</td>
<td>7.62</td>
<td>12.83</td>
<td>3.58</td>
</tr>
<tr>
<td>Planar Kinetics of a Rigid Body: Impulse and Momentum (BH 21-22)</td>
<td>0.91</td>
<td>11</td>
<td>7.72</td>
<td>13.43</td>
<td>3.66</td>
</tr>
<tr>
<td>Overall Test Instrument (10 homework)</td>
<td>0.96</td>
<td>58</td>
<td>41.66</td>
<td>207.90</td>
<td>14.42</td>
</tr>
</tbody>
</table>
Measuring Instrument

This study adopted a widely-employed measuring instrument of learning gains from the physics education community (Hake, 1998). This instrument was also adopted by many researchers in engineering education (Fang, 2010; Papadopoulos & Roman, 2010; Steif & Dollar, 2009). The calculation of learning gain depends on the pretest and posttest scores. The following learning gain terms were used in the literature (Hake, 1998, 2002) depending on how the pretest and posttest scores are utilized.

The Single-student Learning Gain $g$

The single-student learning gain is defined as the gain divided by the maximum possible gain, often called the learning gain $g$ (Hake, 1998):

$$g = \frac{\text{Gain}}{\text{Gain}_{\text{max}}} = \frac{\text{Post} - \text{Pre}}{100 - \text{Pre}}$$

where $g$: single-student learning gain

Gain: The gain score (improvement) from pretest to posttest

Post: Posttest scores of bonus homework in percentage

Pre: Pretest scores of bonus homework in percentage

The Average Student Learning Gain $g$-ave

The average student learning gain $g$-ave is calculated as the average of all single-student learning gains as follows:
where 

\[ g \text{-ave} = \frac{1}{n} \left( \frac{P_{o1} - P_{e1}}{100 - P_{e1}} + \frac{P_{o2} - P_{e2}}{100 - P_{e2}} + \ldots + \frac{P_{on} - P_{en}}{100 - P_{en}} \right) \]

\[ = \frac{1}{n} \sum_{i=1}^{n} \frac{P_{oi} - P_{ei}}{100 - P_{ei}} \]  

[3.2]

where \( n \): the total number of students involved

**The Course Average Learning Gain \(<g>\)**

Learning gain calculated by equation [3.1] can also be used for the whole class to measure the change in a class of students and is called the course-average learning gain (Hake, 2002; Suppapittayaporn, Emarat, & Arayathanitkul, 2010). Unlike the single-student learning gain, the calculation of the course-average learning gain does not require the matched pairs of pretest and posttest for each student attending that course. That means the number of student attending the pretest and posttest can be any number and only the average scores of these students are used in the calculation. The symbol of the course-average learning gain is \(<g>\) and was also defined by Hake (2002):

\[ <g> = \frac{<Post> - <Pre>}{100 - <Pre>} \]  

[3.3]

\[ <g> = \frac{\sum_{j=1}^{n} P_{oj} - \sum_{i=1}^{m} P_{ei}}{n - \sum_{i=1}^{m} P_{ei}} \]  

[3.4]

where:

\(<Pre>\): the average class pretest scores in percentage

\(<Post>\): the average class posttest scores in percentage

\( m, n \): the numbers of students attending pretest and posttest
Table 3.7 below illustrates how different learning gain terms are computed from scores of an imagined simple class of four students in two scenarios. In case I, only three out of four students attend both pretest and posttest, resulting in g-ave = 0.176 and <g> = 0.200. In case II, three students attend the pretest and four attend the posttest, resulting in the same g-ave = 0.176 but smaller <g> = 0.099.

Student A has a potential 40% points to reach maximum score of the test (100%). However, he/she actually has 30% points out of that 40%. Thus, the single-student learning gain g of this student is 0.75 (or 30/40 = 75%) of the possible percentage points he/she could have gained from the pretest to the posttest.

Student B has a potential 45% points to reach maximum score of the test (100%). However, he/she actually lost an extra of 25% points beyond that 45%. Thus, the single-student learning gain g of this student is -0.556 (or -25/45 = -55.6%) of the possible percentage points he/she could have gained from the pretest to the posttest.

Table 3.7  
**Calculation of the Average Student and Course Average Learning Gains**

<table>
<thead>
<tr>
<th>Case I</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Case II</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>Pre</td>
<td>Post</td>
<td>Gain</td>
<td>g</td>
<td></td>
<td>Student</td>
<td>Pre</td>
<td>Post</td>
<td>Gain</td>
<td>g</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>60.00</td>
<td>90.00</td>
<td>30.00</td>
<td>0.750</td>
<td></td>
<td>A</td>
<td>60.00</td>
<td>90.00</td>
<td>30.00</td>
<td>0.750</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>55.00</td>
<td>30.00</td>
<td>-25.00</td>
<td>-0.556</td>
<td></td>
<td>B</td>
<td>55.00</td>
<td>30.00</td>
<td>-25.00</td>
<td>-0.556</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>10.00</td>
<td>40.00</td>
<td>30.00</td>
<td>0.333</td>
<td></td>
<td>C</td>
<td>10.00</td>
<td>40.00</td>
<td>30.00</td>
<td>0.333</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>41.67</td>
<td>53.33</td>
<td>11.67</td>
<td>0.176</td>
<td></td>
<td>D</td>
<td>-</td>
<td>30.00</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g-ave=</td>
<td>0.176</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>41.67</td>
<td>47.50</td>
<td>5.83</td>
<td>0.176</td>
<td>0.176</td>
</tr>
<tr>
<td>&lt;g&gt;=</td>
<td>0.200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;g&gt;=</td>
<td>0.099</td>
<td></td>
<td></td>
<td></td>
<td>0.099</td>
</tr>
</tbody>
</table>
In the following paragraph are some remarks about this measuring instrument suggested by Hake (1998) and widely accepted in the physics education community:

1. If student has perfect posttest score of 100%, she or he will have a learning gain of 1, regardless of his or her pretest score except when pretest score is at 100%. On the contrary, if a student has perfect pretest score of 100%, his or her single-student learning gain \( g \) cannot be determined \( (g = \infty) \) and recorded, regardless of his or her posttest scores.

2. Student must attend both the pretest and posttest to have their single-student learning gain \( g \) calculated. Therefore, the number of pretest and posttest scores should match. However, for the course-average learning gain \( <g> \), pretest and posttest can differ in the number of attending students.

3. Since the learning gain scores are not always approximated by normal distributions and the analysis can be based on nonparametric statistics, the median of learning gain is a more appropriate way of characterizing the results. In most of the literature, the \( g \) and \( <g> \) are used to imply the means. However, some authors (Harlow, Harrison, & Meyertholen, 2014) also report them using the medians, \( g \) median and \( <g> \) median.

4. As a reference from physics instruction, a learning gain less than 0.3 was considered as “low”, from 0.3 up to 0.7 as “medium”, and from 0.7 up as “high” (Hake, 1998). Hake (2002) noted that these criteria were case-specific. To date, there has been no similar benchmark available for engineering mechanics instruction.
Participants and Procedure

Participants

Before data collection, an approval for research on computer simulation and animation in engineering dynamics was obtained from the Institutional Review Board (IRB) at Utah State University. After the researcher of this study successfully defended his dissertation proposal, a subsequent IRB approval that listed this study as the dissertation research for this researcher was also obtained (see Appendix F). A convenient sample consisting of 161 students from two semesters of the ENGR 2030 engineering dynamics course was selected to provide data necessary for the study. The courses were taught by the same instructor. All student participants signed on the informed consent forms.

The distribution of the participants by the learning conditions, whether comparison or intervention groups, is outlined in Table 3.8. Most of participants were undergraduate students who were in their sophomore years in the College of Engineering at Utah State University. The demographics of student population for each semester are showed on Table 3.9. Of the 161 students, 88.82% were male \( n = 143 \) and 11.18% were female \( n = 18 \); 57.14% majored in Mechanical and Aerospace engineering \( n = 92 \) and 21.74% majored in civil and environmental engineering \( n = 35 \). Students majoring in other disciplines make up 21.11% in the total number of students in the study \( n = 34 \).
Table 3.8  
Summary of Participants by Learning Condition

<table>
<thead>
<tr>
<th>Learning Condition</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison Group – Fall 2012</td>
<td>74</td>
</tr>
<tr>
<td>Intervention Group – Fall 2013</td>
<td>87</td>
</tr>
</tbody>
</table>

Table 3.9  
Student Demographics

<table>
<thead>
<tr>
<th></th>
<th>Comparison group, Fall 2012</th>
<th>Intervention group, Fall 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>N_F</td>
</tr>
<tr>
<td>Biological Engineering</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Civil &amp; Environmental Engineering</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>General Engineering</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Mechanical &amp; Aerospace Engineering</td>
<td>39</td>
<td>1</td>
</tr>
<tr>
<td>Technology &amp; Engineering Education</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other &amp; Undeclared Major</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>74</td>
<td>9</td>
</tr>
</tbody>
</table>

Note. N_F = Number of female student; N_M = Number of male student.

Procedure

For each 15-week-long course section, the first half (week 1 to week 8) was dedicated for particle dynamics and the second half (week 9 to week 15) was for rigid body dynamics instruction. During the second half of the semesters, the students in both groups received regular instruction as usual, but only the intervention group students
have access to the CSA modules in a sequential order so that the topics discussed in the modules and in the class instruction matched together.

The pretest and posttest were administered to students in two instructional groups in the form of bonus homework assignments before and after the introduction of each topic (Figure 3.5). The average pre-to-posttest time intervals in this study were 11.1 days for the comparison group and 11.3 days for the intervention group (minimum 5 days and maximum 17 days). The pre-to-posttest time intervals for the HW17, 18, 19, 20, and 21 were longer than these for the rest of HW because the regular second midterm exams and Thanksgiving holidays taken place during this time.

![Table](image)

*Figure 3.5. The administrations of pretest and posttest for two groups. Notes: BH = bonus homework, O = indicates pretest or posttests, X and subscripted number indicate the CSA intervention and CSA module number.*
Students received extra grades for bonus homework in return for their participations. In this research, the same bonus homework assignment was used for the pretests and posttests. No lectures or other homework covered the same materials discussed in CSA modules prior to the pretests and posttests. Students were not allowed to get helps from the tutors nor from the teaching assistants on the same CSA materials. All instructions were taken place at the same classroom and meeting time, and taught by the same instructor but in different semesters. The students in the Fall 2012 section used the 12th edition *Engineering mechanics-dynamics* book by Hibbeler (2010) while the students in the Fall 2013 section used the 13th edition book also by the same author and publisher. No significant difference is found in the learning topics covered in the two editions.

The students in the intervention group took the surveys on Canvas (an online learning management system) by the end of the semester. The semi-structured interviews took place on the USU campus with selected individuals from the intervention group after they had finished the last module’s posttest but before the survey was launched on Canvas. E-mail was the primary method of contact to recruit participants for the semi-structured interviews from the pool of the intervention group’s students. There were 10 students from the intervention group accepting to participate in the interviews. Students were offered $15 bookstore gift cards to compensate for their time spent on the interviews. Extra homework credits were provided to student participants for completing the online survey.
**Data Collection**

Data was collected from students who agreed to participate in the study and signed the letter of informed consent approved by the USU Institutional Review Board. This research study assessed students’ learning gain by collecting pretest and posttest scores of the bonus homework assignments. The study also performed assessments with student surveys and semi-structured individual interviews to explore students' attitudes towards and experiences with the CSA modules. Assessment results can show how the interactive CSA modules affect student learning and the areas of engineering dynamics where students succeed most with the developed CSA modules.

**Pretests and Posttests**

Since conceptual understanding and procedural skills play the important roles in many engineering courses, CSA modules for ED have elements that help the acquisitions of ED concepts and problem-solving skills. In this study, conceptual understanding is defined as a student’s mastery of the true meaning and implications of dynamics concepts and principles; procedural skills are defined as a student’s skills to apply his/her conceptual understanding to set up mathematical equations to generate a numerical solution to a dynamics problem (Fang & Guo, 2013).

Pretest and posttest scores of bonus homework assignments were collected before and after students learned with each CSA module. Bonus homework was designed with the contents that related to the conceptual understandings and procedural skills addressed in the corresponding CSA modules. The pretest and posttest scores on bonus homework were used to assess students’ learning gains. Like other regular homework, students had
the same window of time to work on their bonus homework assignments and submit the answers on Canvas before the due dates. Most bonus homework had five questions that covered both conceptual understanding and procedural skills. All questions, regardless of conceptual or procedural type, had multiple choice formats. Students were assumed to work on their own calculations to have final quantitative solution and pick the best answer from multiple choice responses.

Survey

The main purpose of the survey was to assess students’ experiences with and attitudes towards the CSA modules. Therefore, the comparison group students were not included in the survey. The survey data was collected online through Canvas. The survey instrument was designed by the research team based on the frameworks of similar surveys from engineering education literature (Fang, 2012; Hall et al., 2002, Hall, Philpot, Hubing, Flori, & Yellamraju, 2004) and team members’ experiences of teaching ED. The research team consisted of the researcher of this study, another PhD student, and the researcher’s advisor Dr. Ning Fang. The survey contained 26 questions and was organized in 6 themes: (a) accessibility and functionality of CSA modules, (b) motivation and confidence of student learning, (c) interactivity, (d) quality of technical dynamics problems of CSA modules, (e) student learning outcomes associated with CSA modules, and (f) other comments. The survey questions are presented in Appendix G.

Some items in the survey were designed as open-ended and thought-provoking questions where students could type in their comments. For example, students were invited to provide comments on how they compare the way they learn from modules and
from the textbook examples. Several items used the Likert scale for the response options on the survey. For example, in the “Accessibility and Functionality of CSA modules” section, one question asked students whether the modules are easy to navigate and a five-point Likert response was offered with options ranging from “Very easy” to “Very difficult.” Two other questions in the “Motivation and Confidence of Student Learning” section asked students to indicate their agreement with statements about whether the modules increase their confidence and motivation for learning engineering dynamics. Response options for these questions ranged from “Highly agree” to “Highly disagree.”

Other items had multiple-choice format with multiple answers allowed or combined multiple choice response with open ended fields. For example, one question in the “Quality of the Technical Dynamics Problems of CSA Modules” section asked students to pick what technical dynamics problems designed in the modules they like most and explain why they chose so. Students were able to choose from one to 10 modules in the list and type in their comments in the open space provided immediately below the list.

As the survey instrument is a mix of questions in several types (Likert scale questions, open-ended questions, multiple-choice questions with multiple answers allowed, combined multiple choice response with open ended fields), the coefficient of reliability (Cronbach’s alpha) of the whole instrument cannot be determined. However, based on 322 responses on seven Likert-style questions of the survey during the main study (questions 6, 9, 10, 15, 18, 20, and 22), this subset of the survey instrument has a Cronbach's alpha of 0.82.
Semi-structured Interviews

The semi-structured interviews were conducted with 10 students in the intervention group. There were 19 interview questions probing students’ thoughts in six themes as identified in the student survey above. Compared to the survey, the semi-structured interviews might more deeply probe students’ thoughts and learning experiences with the modules. The interviews were approximately 25 to 40 minutes long. All interviews were recorded by an electronic audio recorder. Note taking was also performed by the researcher of this study during and at the end of each interview to record non-verbal information and general comments about the interviews.

Data Analysis

The purpose of data analysis was to investigate the effects of computer simulation and animation on the learning gain of students in learning engineering dynamics. Learning gain (Hake, 1998) is the popular measuring instrument in physics instruction to assess student learning and has been widely adopted by many educators in various fields. As the learning outcome in this engineering field consists of two types of knowledge, conceptual understanding and procedural skills, the assessment particularly measures the learning gains of students’ conceptual understanding and procedural skills.

Pretest and Posttest Data Analysis

The learning gains on conceptual understandings (CU), procedural skills (PS), and overall learning (CU and PS) were used to compare student learning of RBD in two learning conditions. Learning gain is established on the difference between the pre- and
posttest scores of bonus homework assignments and calculated based on Hake’s (1998) formula. As the pretest, posttest, and learning gain scores were not normally distributed, the Wilcoxon Signed Rank test and Mann-Whitney U test were used to assess the differences in the mean ranks between groups. The Wilcoxon Signed Rank test is a nonparametric alternative method to the paired Student's t test, and Mann-Whitney U test is often considered the nonparametric alternative to the independent t test. These tests do not rely on normal distribution of the data (Corder & Foreman, 2009; Pallant, 2007). All quantitative data in the study was analyzed using a combination of SPSS 19.0 software and R language.

In addition to the statistically significant nonparametric results, this study also analyzes and reports the effect sizes of the differences between groups’ means. As parametric effect sizes such as Cohen’s $d$ and Hedges’ $g$ are distorted by non-normality and heterogeneity of variances, the uses of nonparametric effect sizes such as Cliff’s $d$ and Vargha and Delaney’s $A$ for nonparametric statistic analyses were supported by many researchers (Hess & Kromrey, 2004; Leech & Onwuegbuzie, 2002; Macbeth, Razumiejczyk, & Ledesma, 2011). This study uses the nonparametric effect size Cliff’s $d$. The calculation of the effect size Cliff’s $d$ was carried out by using package “Effsize” by Torchiano (2014) inside the R environment.

**Semi-structured Interviews Data Analysis**

**Steps of coding and analyzing interviews data.** The audio files of semi-structured interviews were transcribed and analyzed to determine what types of outcomes were mentioned by students. Following the coding procedure suggested by Gall et al.
(2007) and the advice from Campbell, Quincy, Osserman, and Perdesen (2013), the researcher of this study and another doctoral student carried out the following steps to code and analyze the transcripts.

1. **Preparation:** One researcher read all the transcripts and developed a set of six main categories of outcomes mentioned by students. The categories included (a) technical design, (b) instructional design, (c) usage pattern, (d) suggested usage, (e) suggested revision, and (f) benefits. The other researcher also read all the transcripts and made some revisions on the subcategories but kept the main categories intact based on her analysis. After that, both researchers agreed on the first version of coding table. It had 73 codes classified into 6 categories.

2. **Testing:** Both researchers coded a sample of short transcript independently and achieved a very good agreement rate (over 80%).

3. **Recruiting coders:** Two undergraduate students who had taken high school physics and college engineering dynamics courses were recruited as coders. They initially had very little experience with instructional software or animated learning materials. They were offered training on coding work and instructed how to use the coding table before actually coded independently all transcripts. As the result of the first coding attempt, the two coders generated 946 codes and the agreement rate was only 25.4%.

The following paragraphs describe the calculation of intercoder reliability: Intercoder agreement was calculated to quantify the extent to which two or more independent coders agree on the coding of the same content. In literature, researchers use a variety of methods to calculate intercoder reliability of coding work, which includes simple calculation of agreements percentage among coders (Garrison, Cleveland-Innes,
Koole, & Kappelman, 2006; Miles and Huberman, 1994) and Krippendorff’s alpha coefficient (Campbell et al., 2013). The use of Krippendorff’s alpha coefficient to determine intercoder reliability involves more complicated statistical calculation and is based on the assumptions that all codes have equal probability of being used and that all coders have the same qualifications (Campbell et al., 2013). Because the code and coders of this study did not meet these assumptions of Krippendorff’s alpha coefficient, this study used a formula [3.5] introduced by Miles and Huberman (1994) to calculate the level of intercoder reliability for a coding work.

\[
\text{reliability} = \frac{\text{number of agreements}}{\text{total number of agreements} + \text{disagreements}}
\]  

[3.5]

4. Revision of coding table: The efforts to improve intercoder reliability were carried out based on Campbell et al.’s (2013) strategy by dropping and merging unreliable codes to reduce the number of codes that coders need to remember, clarifying coding definitions, and modifying codes. The detail of the final version of coding table is introduced in Appendix H. The table had 51 codes reduced from 73 as in the original coding table. It was categorized in four main areas (reduced from six) at the first level, including (1) the technical design, (2) the instructional design, (3) the user patterns, and (4) the benefits of CSA. Most of the codes in the coding table are self-explanatory and few of them need special notes to guide the coders. According to Miles and Huberman (1994), the level of details of a coding scheme depends on how fine the coding should be.
All codes in the coding table were developed with three deep levels and few were developed at a fourth deep level.

5. *Reconcile and negotiation:* After revising the coding table, the two coders were requested to recode all transcripts based on the new version of coding table. The agreement rate right after the recoding work done was improved (around 48%) but still below the required agreement rate level of 80%. The coders were then convened in face-to-face meetings to reconcile their code disagreements. The negotiations were long and tedious processes. The description of the transcripts negotiation by Garrison et al. (2006) was very close to what the researcher of this study faced: “The transcript negotiation process was a very slow, arduous task requiring each coder to advocate for his/her codes.”

After the first negotiation, the agreement rate was improved insignificantly (from 48% to 60%) and still below the required agreement rate. This low agreement rate also triggered a second round of negotiation as stated in the next section.

6. *Virtual negotiation by polling:* Before the second attempt of negotiation started, coders were requested to recode on some of the total 10 transcripts. At the time the second negotiation planned to be implemented, the two coders entered the new academic semester and had conflicting schedules. Facing the challenges about the lengthy negotiation meetings waiting ahead and the unsolved conflicting schedules, the researcher of this study was forced to be innovative. Virtual negotiation by polling was the answer for this situation. As this method of negotiation had not been discussed in any literature before, the following example is used as a replacement of the description of virtual negotiation.
Example of code polling. After the first attempt at negotiation and before the poll, the two coders had two different codes for the same chunk of interview in transcript 6. This chunk of transcript started from minutes 01:24 and ended on 1:27. The two coders disagreed on two codes which were 3-4.1 supported by Coder A and 3-4.4 supported by Coder B. Consequently, it was counted as two disagreements for this chunk of transcript. These two codes were then put in a polling table (Table 3.10).

Next, each coder was given the polling table with two codes and a choice column with two sub-choices, “Yes” to agree with or “No” to reject the suggested code. It was assumed that at this point of coding process, no new codes would be introduced. The poll-able codes were the codes suggested by the coders.

Table 3.10
Sample of a Polling Table with Two Items

<table>
<thead>
<tr>
<th>Time Point in the Transcript</th>
<th>Poll-able Items</th>
<th>Put Letter &quot;X&quot; in Corresponding Cell to Indicate Your Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>01’:24”</td>
<td>1) 3-4.1 (Y) vs. none (N)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>2) 3-4.4 (Y) vs. none (N)</td>
<td>No</td>
</tr>
</tbody>
</table>

Finally, after getting the replies from the two coders, the researcher combined the polling results and produced the final codes for that chunk of interview as well as updated the agreement rate for the whole transcript (Table 3.11).
Table 3.11
Sample of Coders’ Responses and Polling Results

<table>
<thead>
<tr>
<th>Poll-able Items</th>
<th>Coder A’s Poll Result</th>
<th>Coder B’s Poll Result</th>
<th>Final Code(s)</th>
<th>Final Number of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>1) 3-4.1 (Y) vs. none (N)</td>
<td>x</td>
<td>x</td>
<td>3-4.1</td>
<td>1</td>
</tr>
<tr>
<td>2) 3-4.4 (Y) vs. none (N)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this case, Coder A insisted on his code and supported the Coder B’s code as well, while Coder B withdrew his code and supported the Coder A’s code. As the final conclusion, the two coders agreed on two things: a) adding code 3-4.1 in the pool of commonly agreed codes for the selected chunk of interview; and b) dropping code 3-4.4 as a potential code for that chunk of interview.

Theoretically, with two negotiable codes and two choices for each code, each coder has four (2 x 2) options to poll. In total, there were 16 ways (4 x 4) for the two coders to poll. Table 3.12 analyzed one of the four possible coding results, in which Coder A insisted on his code (3-4.1) and supported the Coder B’s code (3-4.4), while Coder B had full four options.

Table 3.13 summarizes the whole process of assessing the intercoder reliability of semi-interview data. There were 543 final, usable codes generated from the 10 transcripts. From this pool of codes, the mean number of times that each outcome category was mentioned and the percentage of times students mentioned it were analyzed and graphed.
Table 3.12
One of the Four Possible Coding Results between Coders A and B

<table>
<thead>
<tr>
<th>Polling Items &amp; Scenarios</th>
<th>Coder A</th>
<th>Coder B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3-4.1 (Y) vs. none (N)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3-4.4 (Y) vs. none (N)</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Scenarios
- Coder A insisted on his code and supported Coder B’s code
- Coder B insisted on his code and rejected Coder A’s code
- Coder B with no code was supported and Coder A’s code

<table>
<thead>
<tr>
<th>Final code(s)</th>
<th>3-4.4</th>
<th>3-4.1, 3-4.4</th>
<th>none</th>
<th>3-4.1</th>
</tr>
</thead>
</table>

| Number of agreement | 1 | 2 | 0 | 1 |

Advantages and disadvantages of virtual negotiation.

1. Advantages: In comparison to face-to-face negotiation, virtual code negotiation with polling had some advantages. First, the coders did not need to convene in lengthy, face-to-face meetings. The coders actually participated in the negotiation virtually from anywhere and at anytime. Second, virtual negotiation by polling can avoid the two extremes of a face-to-face negotiation as the researcher of this study faced in the first round of negotiation. On one hand, the less knowledgeable (weaker) coder tends to easily accept the codes introduced by the more knowledgeable (stronger) one. On the other hand, the weaker coder tended to emotionally fight the stronger one on even simplest codes. Third, there is no limit on the number of coders that can participate in the negotiation. Last but not least, virtual negotiation by polling gave the coders more time to look at their coding work more carefully before giving their votes.
Table 3.13
*Summarized Intercoder Reliability Processing of Semi-structured Interview Data*

<table>
<thead>
<tr>
<th>Transcript File</th>
<th>Before Negotiation</th>
<th>After Negotiation and Before Polling</th>
<th>After Polling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N_C) Agreement (%)</td>
<td>(N_C) Agreement (%)</td>
<td>(N_F) Agreement (%)</td>
</tr>
<tr>
<td>1</td>
<td>86</td>
<td>30.2</td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td>93</td>
<td>24.7</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>29.7</td>
<td>51</td>
</tr>
<tr>
<td>4</td>
<td>111</td>
<td>27.0</td>
<td>69</td>
</tr>
<tr>
<td>5</td>
<td>65</td>
<td>26.5</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>43</td>
<td>18.6</td>
<td>31</td>
</tr>
<tr>
<td>7</td>
<td>111</td>
<td>20.7</td>
<td>76</td>
</tr>
<tr>
<td>8</td>
<td>114</td>
<td>33.3</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>112</td>
<td>25.0</td>
<td>73</td>
</tr>
<tr>
<td>10</td>
<td>137</td>
<td>18.3</td>
<td>92</td>
</tr>
<tr>
<td><strong>Total (Avg.)</strong></td>
<td>946</td>
<td>(25.4)</td>
<td>647</td>
</tr>
</tbody>
</table>

First negotiation, data reduction, revised coding table

Second negotiation (polling)

*Note. \(N_C\): Number of codes; \(N_F\): Number of final codes*

2. *Disadvantages:* Virtual negotiation had the following disadvantages as compared to the face-to-face negotiation. First, the coders were not always equally knowledgeable and experienced about the subject matters. The more knowledgeable coders would not have any chance to advocate their codes and persuade the others. Eventually, their legitimate codes could be discarded during the poll. On the contrary, the codes introduced by the weaker coders might have chances to be approved. Second,
because the researchers had to compose and collate all disagreed codes in the polling table, their work load increased with the number of disagreed codes. Third, virtual negotiation did not give the coders any chance to discuss the subtlety of students’ responses.

**Survey Data Analysis**

This study also examined students’ attitudes towards and experiences with the CSA modules based on students’ responses in the survey. Data from students’ surveys were examined to explore whether there was an interrelationship between the self-reported confidence and motivations and their acquisition of conceptual understanding and procedural skills. There were three approaches to analyze the survey data depending on the types of questions.

First, Likert scale data were coded depending on the responses, such as “highly disagree” = 1, “disagree” = 2, “neutral” = 3, “agree” = 4, “highly agree” = 5. The data was analyzed and collated into bar charts or tables to yield the central tendency, standard deviations, and the most frequent responses, as well as the distribution of responses for each category (percentages that agree or disagree, etc.).

Second, the open-ended responses in the surveys were coded and analyzed. In comparison to the coding work on the semi structured interviews data as described above, the coding work of open-ended responses was done with almost similar steps but on a much smaller scale. It was also much less strenuous and generated higher agreement rate. Two researchers in the research team consisting of the researcher of this study and another doctoral student, read all open-ended responses and developed a set of categories
of outcomes mentioned by students. Based on this set of categories, the two researchers working independently of each other had assigned codes to a sample of open-ended response chosen randomly from the survey and compared the coding results. As the agreement rate of coding this open-ended response sample between the two researchers was very high (over 90%), the coding work was deployed to all open-ended responses.

There were two reasons why the agreement rate of coding open-ended responses was high and the coding work was not strenuous. First, there are only 11 open-ended questions in the total of 26 questions of the survey. Second, as the survey was conducted by the end of the semester when students had many final tests for other courses, they might have less motivation to type in their responses for open-ended questions. Some of them left the response fields blank, while others provided very short or garble responses.

Finally, students’ responses from multiple choice questions were tabulated for different variables in the data to show their frequencies and percent distributions.
CHAPTER 4
RESULTS AND ANALYSIS OF LEARNING GAINS

Introduction

This chapter reports the results of quantitative analysis to answer research question 1 proposed in Chapter 3: “To what extent do students in the intervention group who use interactive CSA modules along with traditional lectures improve learning in RBD, as compared with students in the comparison group who use traditional lectures only?” The analysis and descriptive statistics were carried out with the pretest and posttest scores of bonus homework to examine the differences in learning gains between the two learning conditions. The dependent variable of this study, the learning gain, was not collected directly from the experiment. It is calculated from the pretest and posttest scores by using the equation [3.1]. Because the learning gains of the comparison and intervention groups were not normally distributed, this study used two non-parametric statistical tests - the Wilcoxon Signed Rank test and Mann-Whitney U test - to assess the differences in the mean ranks between groups. Non-parametric effect size Cliff’s $d$ is employed to quantify the size of the difference between two groups corresponding to the use of non-parametric statistical tests. All statistical tests are based on a significance level of 0.05 unless explicitly noted otherwise. Software SPSS version 19, Microsoft Excel, and R language were used in most statistical calculations.
Exploration and Preliminary Analysis of Pretest and Posttest Scores

Matched Pretest and Posttest Scores

The calculation of single-student learning gain \( g \) requires a matched pairs of pre- and posttest scores. Because the attendance at this study is voluntary, the numbers of pretest and posttest scores for each bonus homework (BH) assignment are usually not the same. Some students attended the pretest but not the posttest and vice versa, making the calculation of their single-student learning gains impossible. Table 4.1 summarizes the numbers of students attending the pretest and posttest in two instructional groups. \( N_{\text{Pre}} \) and \( N_{\text{Post}} \) are the numbers of students attending the pretest and posttest of each module. \( N_{\text{Pre} \& \text{post}} \) is the number of students attending both pretest and posttest. \( N_{m} \) is the number of students with matched pairs of pretest and posttest scores after subtracting the number of outliers from \( N_{\text{Pre} \& \text{post}} \).

The matched sets of data were used to calculate single-student and student-average learning gains (\( g \) and \( g \)-average), while the unmatched sets of data were used in the calculation of the course-average learning gain \( \langle g \rangle \). Students whose learning gains were less than -1.5 were identified as non-serious test takers and considered outliers. There are five outliers in the comparison group and one in the intervention group, and their learning gains were removed from the data. These outliers were identified by the researcher of this study. The section “Handling Outliers” in this chapter addresses how the study handles the outliers identified by the SPSS software.
Table 4.1
Number of Students Attending Pretest and Posttest in Two Groups

<table>
<thead>
<tr>
<th></th>
<th>$N_{\text{Pre}}$</th>
<th>$N_{\text{Post}}$</th>
<th>$N_{\text{Pre} &amp; \text{Post}}$</th>
<th>Outliers</th>
<th>$N_{m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BH 13</td>
<td>67</td>
<td>66</td>
<td>63</td>
<td>2</td>
<td>61</td>
</tr>
<tr>
<td>BH 14</td>
<td>69</td>
<td>63</td>
<td>62</td>
<td>1</td>
<td>61</td>
</tr>
<tr>
<td>BH 15</td>
<td>60</td>
<td>61</td>
<td>57</td>
<td>0</td>
<td>57</td>
</tr>
<tr>
<td>BH 16</td>
<td>62</td>
<td>62</td>
<td>55</td>
<td>1</td>
<td>54</td>
</tr>
<tr>
<td>BH 17</td>
<td>63</td>
<td>61</td>
<td>56</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>BH 18</td>
<td>62</td>
<td>61</td>
<td>55</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>BH 19</td>
<td>64</td>
<td>65</td>
<td>60</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>BH 20</td>
<td>61</td>
<td>64</td>
<td>59</td>
<td>0</td>
<td>59</td>
</tr>
<tr>
<td>BH 21</td>
<td>61</td>
<td>63</td>
<td>58</td>
<td>0</td>
<td>58</td>
</tr>
<tr>
<td>BH 22</td>
<td>65</td>
<td>62</td>
<td>58</td>
<td>0</td>
<td>58</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>634</td>
<td>628</td>
<td>583</td>
<td>5</td>
<td>578</td>
</tr>
<tr>
<td><strong>Intervention Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BH 13</td>
<td>85</td>
<td>78</td>
<td>78</td>
<td>1</td>
<td>77</td>
</tr>
<tr>
<td>BH 14</td>
<td>80</td>
<td>77</td>
<td>74</td>
<td>0</td>
<td>74</td>
</tr>
<tr>
<td>BH 15</td>
<td>81</td>
<td>79</td>
<td>75</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>BH 16</td>
<td>81</td>
<td>79</td>
<td>76</td>
<td>0</td>
<td>76</td>
</tr>
<tr>
<td>BH 17</td>
<td>83</td>
<td>77</td>
<td>76</td>
<td>0</td>
<td>76</td>
</tr>
<tr>
<td>BH 18</td>
<td>82</td>
<td>75</td>
<td>75</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>BH 19</td>
<td>83</td>
<td>82</td>
<td>80</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>BH 20</td>
<td>82</td>
<td>82</td>
<td>79</td>
<td>0</td>
<td>79</td>
</tr>
<tr>
<td>BH 21</td>
<td>80</td>
<td>82</td>
<td>76</td>
<td>0</td>
<td>76</td>
</tr>
<tr>
<td>BH 22</td>
<td>83</td>
<td>80</td>
<td>79</td>
<td>0</td>
<td>79</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>820</td>
<td>791</td>
<td>768</td>
<td>1</td>
<td>767</td>
</tr>
</tbody>
</table>

*Note.* $N_{\text{Pre}}, N_{\text{Post}}$ are the numbers of students who attended the pretest and posttest of each module. $N_{\text{Pre} \& \text{Post}}$ is the number of students who attended both pretest and posttest (matched pairs). $N_{m}$ is also the number of students who attended both pretest and posttest but after subtracting the number of outliers, whose learning gains were lower than -1.5.
Normality Test

The study uses the learning gain scores as the main measuring instrument to compare the effectiveness of the two types of instructional methods. It also analyzes the pretest to posttest gains to complement the findings. The learning gain scores were not directly collected from the experiment. Instead, they were derived from the pretest and posttest scores according to the formula [3.1]. The collected data – pretest and posttest scores, the derived data, and the learning gain scores - are examined to see if they are normally distributed by using visual and numerical tests. The distributions of pretest, posttest, and learning gain scores of students in both groups are introduced in Figure 4.1. The descriptive statistics and normality test results with the Shapiro Wilk test for these data sets are presented in Table 4.2.

Upon inspection of histogram plots and the Shapiro-Wilk tests, the assumption of normality of pretest, posttest, and learning gain score was determined to be untenable. First, the histograms of pretest, posttest, and learning gain scores for both groups (Figure 4.1) do not have the bell shapes of a normal distribution. Second, most of the z scores for skewness in Table 4.2 do not fall inside the ± 2.58 range, which are the critical z scores for large sample size of 200 or more, to pass the normality assumption for a significance level of 0.05 (Corder & Foreman, 2009; Ghasemi & Zahediasl, 2012). Furthermore, according to Leech and Onwuegbuzie (2002), the z scores outside the ± 3 range imply the data departed significantly from normality. Finally, since the p-values for the Shapiro-Wilk tests are less than 0.001 for all score types (Table 4.2), the null hypothesis assuming about the normality of these data sets is also rejected at a significance level of 0.05.
Figure 4.1. Histograms of pretest, posttest, and learning gain scores of two groups. Note: Left column: the pretest, posttest, and learning gain scores for the comparison group. Right column: the pretest, posttest, and learning gain scores for the intervention group.
Table 4.2  
*Descriptive Statistics Results of Pretest, Posttest, and Learning Gains Scores*

<table>
<thead>
<tr>
<th></th>
<th>Comparison Group</th>
<th>Intervention Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Pre&gt;</td>
<td>&lt;Post&gt;</td>
</tr>
<tr>
<td>N</td>
<td>578</td>
<td>578</td>
</tr>
<tr>
<td>Mean</td>
<td>24.31</td>
<td>32.34</td>
</tr>
<tr>
<td>Std. error of the mean</td>
<td>0.71</td>
<td>1.02</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>83.25</td>
<td>100.00</td>
</tr>
<tr>
<td>Median</td>
<td>20.00</td>
<td>28.60</td>
</tr>
<tr>
<td>Percentiles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25th</td>
<td>16.65</td>
<td>16.65</td>
</tr>
<tr>
<td>50th</td>
<td>20.00</td>
<td>28.60</td>
</tr>
<tr>
<td>75th</td>
<td>33.30</td>
<td>50.00</td>
</tr>
<tr>
<td>Std. error of skewness</td>
<td>0.102</td>
<td>0.102</td>
</tr>
<tr>
<td>z</td>
<td>3.69</td>
<td>8.03</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.40</td>
<td>0.38</td>
</tr>
<tr>
<td>Std. error of kurtosis</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>z</td>
<td>-1.98</td>
<td>1.86</td>
</tr>
<tr>
<td>Shapiro-Wilk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statistic</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>df</td>
<td>578</td>
<td>578</td>
</tr>
<tr>
<td>Sig.</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Consequently, the pretest, posttest, and learning gain data sets are analyzed using nonparametric statistics due to their non-normal distributions. Specifically, the Wilcoxon Signed Rank test, a non-parametric equivalent of paired Student's t test, and Mann-Whitney U test, a non-parametric equivalent of independent t test, are used to evaluate
the differences in mean ranks of scores as these tests do not rely on normal distribution (Corder & Foreman, 2009; Pallant, 2007).

In addition to the statistically significant nonparametric results, this study also reports the effect sizes of the differences between groups’ means. As parametric effect sizes, such as Cohen’s $d$ and Hedges’ $g$, are distorted by non-normality and heterogeneity of variances, the uses of nonparametric effect sizes such as Cliff’s $d$ and Vargha and Delaney’s $A$ for nonparametric statistical analyses were supported by many researchers (Cliff, 1993; Hess & Kromrey, 2004; Leech & Onwuegbuzie, 2002; Macbeth et al., 2011). This study uses the nonparametric effect size with Cliff’s $d$. The calculation of the effect size Cliff’s $d$ was carried out by using the package “Effsize” by Torchiano (2014) inside the R environment. According to Romano, Kromrey, Coraggio, and Skowronek’s (2006) guideline, an effect size $|d| < 0.147$ is considered as negligible, $0.147 < |d| < 0.33$ as small, $0.33 < |d| < 0.474$ as medium, and $|d| > 0.474$ as large.

Preliminary Analysis with Pretest and Posttest Scores

Table 4.2 also provides the means and medians of pretest and posttest scores for the comparison group and the intervention group. As remarked in the section “Assessment Instrument” of Chapter 3, this study reports both the median and mean scores because the use of median score is more appropriate for non-parametric statistics and the use of mean score is still popular in the literature of this field. As a consequence, the dispersion of scores is quantified in inter quartiles range ($IQR$) along with the median scores. The dispersion of the mean scores, the standard deviation ($SD$), is not reported because the distributions of scores were highly skewed. Instead, this study reports the
standard error of the mean (SEM) along with the mean to quantify the precision of scores. All the median and mean scores are reported in percentage and calculated at a 95% confident interval. All statistical tests are calculated at a significance level of 0.05 or noted otherwise.

As the study employs the quasi-experimental design, the pretest scores of the comparison group and the intervention group were compared first to see whether the two groups were equivalent at the beginning of the study. The result of the Mann Whitney U test (Table 4.3) indicates no statistically significant difference in the pretest scores of bonus homework between the two groups ($U = 220550.5, N_1 = 568, N_2 = 768, \ p = 0.873$, two tailed). This confirms that the two groups were equivalent at the beginning of the study. Figure 4.2 illustrates the mean and the error bounds of the pretest and posttest scores for both groups.

For the posttest scores, the Mann-Whitney U test reveals that the mean posttest score of the intervention group ($M = 65.01 \pm 1.28$) is statistically significantly higher ($U = 109407.50, N_1 = 568, N_2 = 768, p < 0.001$, two tailed) than that of the comparison group ($M = 32.34 \pm 1.02$). This increase in the posttest scores demonstrates a positive impact of the instruction with interactive web-based CSA module in the intervention group when compared with the traditional instruction in the comparison group.

Another non-parametric statistical test, the Wilcoxon Signed Rank test, was performed to examine whether there was a statistically significant difference between pretest and posttest scores within an instructional group. The Wilcoxon Signed Rank
Table 4.3  
Mann-Whitney U Test Results for Pretest and Posttest Scores Differences

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pretest score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison Group</td>
<td>578</td>
<td>674.92</td>
<td>390106.5</td>
<td>220550.5</td>
<td>-0.16</td>
<td>0.873</td>
<td>0.01</td>
</tr>
<tr>
<td>Intervention Group</td>
<td>767</td>
<td>671.55</td>
<td>515078.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Posttest score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison Group</td>
<td>578</td>
<td>478.79</td>
<td>276738.5</td>
<td>109407.5</td>
<td>-15.98</td>
<td>0.000</td>
<td>0.51</td>
</tr>
<tr>
<td>Intervention Group</td>
<td>767</td>
<td>819.36</td>
<td>628446.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Cliff’s d = 0.01 is considered as negligible and d = 0.51 as large.*

*Figure 4.2. Mean pretest and posttest scores of two groups.*  
Note: The standard error of the mean was calculated at 95% of confident interval.
test is equivalent to the paired t test in parametric statistics. The result in Table 4.4 shows statistically significant difference between the mean posttest scores \((M = 32.34 \pm 1.02)\) and the mean pretest scores \((M = 24.31 \pm 0.71)\) of the comparison group \((W = 26691, n = 578, p < 0.001, \text{ two tailed})\). Similarly, the difference between the mean posttest scores \((M = 65.01 \pm 1.28)\) and the mean pretest scores \((M = 24.36 \pm 0.68)\) of the intervention group also reaches statistical significance \((W = 13351, N = 767, p < 0.001, \text{ two tailed})\). In addition, the sums of the positive ranks are larger than the sums of the negative ranks in both cases \((\Sigma R_+ = 55930 \text{ versus } \Sigma R_- = 26691 \text{ for the comparison group; } \Sigma R_+ = 214799 \text{ versus } \Sigma R_- = 13351 \text{ for the intervention group})\), demonstrating the positive impact of the two instructional methods.

That means learning with traditional instruction and learning with traditional instruction plus CSA modules helped students improve their scores of bonus homework from pretest to posttest. However, because the effect size of the difference in the mean test scores of the intervention group \((d = 0.62)\) is much larger than that of the comparison group \((d = 0.17)\), the instruction with CSA modules is more effective than the traditional instruction in improving students’ posttest scores. This result provides yet another piece of evidence showing the positive impact of the instruction with interactive web-based CSA module when compared with the traditional instruction.
Table 4.4
Wilcoxon Signed Rank Test Results for Pretest and Posttest Scores Differences

<table>
<thead>
<tr>
<th>Comparison Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Ranks</td>
<td>154</td>
<td>173.32</td>
<td>26691.0</td>
<td>-6.20</td>
<td>0.000</td>
<td>0.17</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>252</td>
<td>221.94</td>
<td>55930.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ties</td>
<td>172</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>578</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intervention Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Ranks</td>
<td>100</td>
<td>133.51</td>
<td>13351.0</td>
<td>-19.89</td>
<td>0.000</td>
<td>0.62</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>575</td>
<td>373.56</td>
<td>214799.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ties</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>767</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results and Analysis with Overall Learning Gains

Figure 4.3 below illustrates the mean and the median learning gain of the two groups. The standard error of the mean and the interquartile ranges are calculated at 95% confident interval. The results of the overall learning gain assessment with the Mann-Whitney U test (Table 4.5) show that the overall mean learning gain of the intervention group students ($M = 0.51 \pm 0.02, n = 767$) is significantly higher than that of the comparison group students ($M = 0.07 \pm 0.02, n = 578$), with $U = 112143.5$, $z = -15.60$, $p < 0.001$, two tailed. That means the instruction with CSA modules is effective in improving students’ learning gains of rigid body dynamics. The Cliff’s effect size $d = 0.50$ of the mean learning gain difference is considered as large according to Romano et al. (2006).
Figure 4.3: Mean and median learning gains of two groups.  
Notes: Learning gain (left) and median learning gains (right). The standard error of the means and the inter quartile ranges were calculated at 95% confident interval.

Table 4.5  
Mann-Whitney U Test for Learning Gain of Two Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison Group</td>
<td>578</td>
<td>483.52</td>
<td>279474.5</td>
<td>112143.5</td>
<td>-15.60</td>
<td>.000</td>
<td>0.50</td>
</tr>
<tr>
<td>Intervention Group</td>
<td>767</td>
<td>815.79</td>
<td>625710.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To examine the effects of CSA modules on different knowledge areas of rigid body dynamics, a series of Mann-Whitney U tests were conducted to assess the differences of the learning gain between the two instructional groups for all bonus homework assignments. Table 4.6 reports the mean pretest, posttest, and learning gain scores, and Figure 4.4 illustrates the distributions of the medians of the learning gain for all bonus homework for both instructional groups. In each instructional group, the ten
CSA modules were grouped into subgroups according to the areas of rigid body dynamics knowledge that the CSA modules covered. The results of these Mann-Whitney U tests are summarized in Table 4.7.

In general, the CSA modules help students significantly improve their learning gain in almost all areas of rigid body dynamics knowledge except for bonus homework 13 (all p values < 0.001 and $p_{13}$ value = 0.077). Although the learning gains of bonus homework 14 and 15 of the intervention group ($g_{14} = 0.41$ and $g_{15} = 0.44$) are significantly higher than those of the comparison group, they are lower than the average performance of the whole intervention group ($g_{\text{ave-IG}} = 0.54$). Based on the analysis of the effect sizes, the CSA modules generally help students improve their learning of rigid body dynamics, but the rates of improvement vary with different areas of the course. The CSA modules help students learn most with the Impulse and Momentum ($d_{22} = 0.56$) and Work and Energy knowledge ($d_{17} = 0.53$ and $d_{18} = 0.51$). On the contrary, students learned least with the Relative Motion and Instantaneous Center knowledge ($d_{13} = 0.15$ and $d_{14} = 0.32$).

Bonus homework 13, 14, and 15 cover the knowledge of planar kinematics and kinetics of a rigid body, and altogether they play as an entry point for students moving from particle dynamics into rigid body dynamics. Compared to particle dynamics students learned in the first half of the engineering dynamics course, these homework assignments require students to have strong spatial ability skills to grasp new concepts and to be proficient in various mathematical tools to solve problems. Section “Results and Analysis with Three Most Challenging Bonus Homework” below will analyze the
learning and performances of students on these three homework assignments 13, 14, and 15 in details.

Table 4.6
Descriptive Statistics of all Bonus Homework Scores for Two Groups

<table>
<thead>
<tr>
<th>Bonus Homework</th>
<th>Comparison Group</th>
<th></th>
<th>Intervention Group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Pre&gt;</td>
<td>&lt;Post&gt;</td>
<td>&lt;Gain&gt;</td>
<td>&lt;g&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;Pre&gt;</td>
<td>&lt;Post&gt;</td>
<td>&lt;Gain&gt;</td>
<td>&lt;g&gt;</td>
</tr>
<tr>
<td>BH 13</td>
<td>25.93</td>
<td>36.85</td>
<td>10.92</td>
<td>0.15</td>
</tr>
<tr>
<td>BH 14</td>
<td>27.46</td>
<td>34.02</td>
<td>6.56</td>
<td>0.10</td>
</tr>
<tr>
<td>BH 15</td>
<td>25.12</td>
<td>24.83</td>
<td>-0.29</td>
<td>0.00</td>
</tr>
<tr>
<td>BH 16</td>
<td>26.83</td>
<td>32.99</td>
<td>6.17</td>
<td>0.08</td>
</tr>
<tr>
<td>BH 17</td>
<td>25.48</td>
<td>33.80</td>
<td>8.32</td>
<td>0.11</td>
</tr>
<tr>
<td>BH 18</td>
<td>22.62</td>
<td>29.64</td>
<td>7.02</td>
<td>0.09</td>
</tr>
<tr>
<td>BH 19</td>
<td>23.31</td>
<td>36.91</td>
<td>13.60</td>
<td>0.17</td>
</tr>
<tr>
<td>BH 20</td>
<td>24.75</td>
<td>41.36</td>
<td>16.61</td>
<td>0.22</td>
</tr>
<tr>
<td>BH 21</td>
<td>19.52</td>
<td>28.13</td>
<td>8.61</td>
<td>0.11</td>
</tr>
<tr>
<td>BH 22</td>
<td>22.07</td>
<td>24.14</td>
<td>2.07</td>
<td>0.03</td>
</tr>
<tr>
<td>Avg.</td>
<td>24.31</td>
<td>32.27</td>
<td>7.96</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24.36</td>
</tr>
</tbody>
</table>

The knowledge in these three homework assignments is critically important for the learning of the rest of rigid body dynamics course. Once students have basic conceptual understanding and procedural skills addressed in these assignments, their performances increases (Figure 4.5). While the learning gain of the intervention group increases gradually from bonus homework 13 ($g_{BH-13} = 0.27$) towards bonus homework 22 ($g_{BH-22} = 0.63$) at the end of the experiment, the learning gain of the comparison group fluctuates around the average learning gain of that group ($g_{CGmin} = 0, g_{CGmax} = 0.221$).
Figure 4.4. Median learning gains for different areas of rigid body dynamics knowledge.

Table 4.7

Results of Mann-Whitney U Tests on Learning Gain Differences for Ten CSA Modules.

<table>
<thead>
<tr>
<th>Bonus HW</th>
<th>Comparison Group</th>
<th>Intervention Group</th>
<th>Mann-Whitney U</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size, d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean Rank</td>
<td>Sum of Ranks</td>
<td>N</td>
<td>Mean Rank</td>
</tr>
<tr>
<td>BH 13</td>
<td>61</td>
<td>62.78</td>
<td>3829.5</td>
<td>77</td>
<td>74.82</td>
</tr>
<tr>
<td>BH 14</td>
<td>61</td>
<td>54.43</td>
<td>3320.0</td>
<td>74</td>
<td>79.19</td>
</tr>
<tr>
<td>BH 15</td>
<td>57</td>
<td>47.93</td>
<td>2732.0</td>
<td>75</td>
<td>80.61</td>
</tr>
<tr>
<td>BH 16</td>
<td>54</td>
<td>44.96</td>
<td>2428.0</td>
<td>76</td>
<td>80.09</td>
</tr>
<tr>
<td>BH 17</td>
<td>55</td>
<td>42.53</td>
<td>2339.0</td>
<td>76</td>
<td>82.99</td>
</tr>
<tr>
<td>BH 18</td>
<td>55</td>
<td>43.38</td>
<td>2386.0</td>
<td>75</td>
<td>81.72</td>
</tr>
<tr>
<td>BH 19</td>
<td>60</td>
<td>50.32</td>
<td>3019.0</td>
<td>80</td>
<td>85.64</td>
</tr>
<tr>
<td>BH 20</td>
<td>59</td>
<td>51.81</td>
<td>3056.5</td>
<td>79</td>
<td>82.72</td>
</tr>
<tr>
<td>BH 21</td>
<td>58</td>
<td>46.88</td>
<td>2719.0</td>
<td>76</td>
<td>83.24</td>
</tr>
<tr>
<td>BH 22</td>
<td>58</td>
<td>43.50</td>
<td>2523.0</td>
<td>79</td>
<td>87.72</td>
</tr>
</tbody>
</table>
Figure 4.5. The increasing trend in mean learning gain of the intervention group.

Figure 4.6 illustrates the relationships among the pretest scores, the pretest to posttest gains, and the learning gains. It is the scatter plot of $<\text{Gain}>$ versus $<\text{Pre}>$ for the comparison group (circles) and intervention group (squares). The learning gains are represented by the lines with negative or positive slopes starting from the point (100, 0). The slope of a learning gain line is determined by the ratio $<\text{Gain}>/ (100 - <\text{Pre}>)$ and the y-intercept of the learning gain is the value of learning gain it represented. This type of chart was first introduced by Hake (1998, 2002) to visualize the relationships among the pretest score (horizontal axis), the gain score from pre-to posttest (vertical axis), and the learning gain (slant line) of a student or a course. It is more informative than the above learning gain figures (Figures 4.3 and 4.4) in terms of the dispersion of three test scores (the pretests, gains, and learning gains) and the relationships among them.
From Figure 4.6, the following remarks are observed:

1) The distributions of the comparison group’s scores (circles) and the intervention group’s scores (squares) are converged around the average pretest score of two groups (24.3%) on the \(<\text{Pre}\>\) axis, reflecting the fact that there was no significant difference in the prior-knowledge (as measured by the mean pretest scores) of students in both groups (Table 4.3).

2) The average learning gain for the intervention group (\(<g>_{\text{IG-ave}} = 0.54\)) is higher than that of the comparison group (\(<g>_{\text{CG-ave}} = 0.11\)). According to the Mann-
Whitney U test’s result presented in Table 4.5, this difference reaches statistical significance ($p < 0.001$). This demonstrates the effectiveness of the CSA modules in improving student learning. As a reference from the physics education, Hake (1998) defined a learning gain of less than 0.3 as small, within the range [0.3, 0.7] as medium, and equal to or greater than 0.7 as large.

3) The distribution of the intervention group’s scores (squares) is scattered within a wide range along the <Gain> axis, with the pretest to posttest gains and the learning gains of BH 13 and 14 being the lowest. The distribution of the comparison group’s scores (circles) is also scattered along the <Gain> axis but within a narrower range. This proves that: a) the CSA modules improved student learning of different areas of rigid body dynamics knowledge at different rates; and b) even with the help of the CSA modules, students in the intervention group still struggle with the knowledge of Relative Motion and Instantaneous Center addressed in BH 13 and 14. This also reflects the high difficulty level of the learning materials in this chapter for many students.

4) The same learning gain (slant lines) can be obtained by different combinations of gains and pretest scores, such as squares 17, 18, and 21 or circles 14, 16, 18, and 21. This means students with different prior knowledge could have the same learning gain.

**Handling Outliers**

Besides the six outliers that were removed earlier in the preliminary inspection of data, the SPSS software reported several outliers in the box plots of the comparison group
and intervention group. To determine whether these outliers influence the results of the Mann-Whitney U tests on the learning gain, these tests were conducted twice, with and without outliers. Results were nearly identical in both cases for the p-values and mean learning gains. Both analyses concluded that there is a statistically significant difference between the mean learning gains of intervention group and comparison group students. Both p-values were far below a significance level of 0.05 (p < 0.001 in both cases). There are two reasons to keep the outliers identified by SPSS in the data. First, a verification of these data points revealed that they were legitimate, as no error occurred during the processes of handling and processing of these numbers. In the context of the study, a learning gain of -1 or +1 is possible. Learning gain of +1 can be obtained by any combination of difference between pre and posttest scores, with the posttest score of 100%. In the contrary, learning gain of -1 can be obtained by a variety of combinations of pretest and posttest scores, with the pretest scores from 50% and up. Second, as confirmed in the literature (Parke, 2012; Utts & Heckard, 2011), it can be expected to see a few outliers in skewed data with a large sample size and their presence probably would not seriously impact the results.

**Correlations between Pretest, Pre-posttest Gain, and Learning Gain**

Table 4.8 reports Spearman’s correlation coefficients between students’ pretest scores and pretest to posttest gain, as well as between the pretest score and the learning gain in both learning conditions. Spearman’s correlation test was chosen over Pearson’s test because the former is suitable for the non-normality of this study’s data. As a rule of thumb for interpreting the correlation coefficient offered by Hinkle, Wiersma, and Jurs
(2003), a correlation less than 0.3 was considered as negligible, from 0.3 to 0.5 as low, from 0.5 to 0.7 as moderate, and greater than 0.7 as high. Spearman’s correlation tests reveal that there are negative correlations between students’ pretest scores and their learning gains in both instructional groups. This means there are the associations between low pretest scores and high learning gains, and the strength of this association for the comparison group (effect size of 0.213) is stronger than that for the intervention group (effect size of 0.033). Therefore, a high learning gain score of the comparison group is likely the result of a low pretest score rather than the effect of the instruction. On the contrary, a high learning gain score of the intervention group is likely the effect of the CSA modules rather than the result of the low pretest score.

There are also the associations between pretest scores and the pretest to posttest gains and the strengths of these associations are almost the same for both instructional groups. Figure 4.7 illustrates scatter plots of pretest scores versus learning gains and pretest scores versus pretest to posttest gains for two groups to visualize the correlations in Table 4.8. From these plots, it can be observed that students who have low pretest scores tend to have higher pretest to posttest gains and learning gains than those who have high pretest scores.
### Table 4.8

*Correlations between Pretest, Pretest to Posttest Gain, and Learning Gain*

<table>
<thead>
<tr>
<th></th>
<th>Comparison Group</th>
<th>Intervention Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;Pre&gt;</td>
<td>&lt;Gain&gt;</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>1.000</td>
<td>-0.505*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>578</td>
<td>578</td>
</tr>
<tr>
<td>Effect size ($\rho^2$)</td>
<td>0.255</td>
<td>0.988*</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>-0.505*</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>578</td>
<td>578</td>
</tr>
<tr>
<td>Effect size ($\rho^2$)</td>
<td>0.255</td>
<td>0.976</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>-0.462*</td>
<td>0.988*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>578</td>
<td>578</td>
</tr>
<tr>
<td>Effect size ($\rho^2$)</td>
<td>0.213</td>
<td>0.976</td>
</tr>
</tbody>
</table>

*Note.* *.$^* Correlation is significant at the 0.01 level (2-tailed).
Figure 4.7. Regression lines between pretest and learning gains, and between pretest and pretest to posttest gains.
Note: Pretest scores versus learning gains (top row) and pretest scores versus gain scores (bottom row) in two instructional groups.
Results and Analysis with Conceptual Understanding (CU) and Procedural Skills (PS) Learning Gains

Learning Gains of Conceptual Understanding and Procedural Skills

To evaluate the effectiveness of the CSA modules on the acquisitions of students’ CU and PS, the average student learning gains (or g-ave) in the CU and PS scores between the two groups were examined. Comparisons between groups of students were performed using Mann-Whitney tests due to the skewness of learning gain distributions. Table 4.9 provides descriptive statistics and Figure 4.8 illustrates the means of CU and PS learning gains for both groups.

Table 4.9
Descriptive Statistics of Learning Gain on Conceptual Understanding and Procedural Skills of Two Groups

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SEM</th>
<th>Min.</th>
<th>Max.</th>
<th>Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25th</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Median)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75th</td>
</tr>
<tr>
<td><strong>Comparison Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU Learning gain</td>
<td>540</td>
<td>0.16</td>
<td>0.02</td>
<td>-1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>PS Learning gain</td>
<td>560</td>
<td>0.05</td>
<td>0.05</td>
<td>-1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

| **Intervention Group** |    |      |     |      |      |              |
| CU Learning gain       | 744| 0.55 | 0.02| -1.00| 1.00 | 0.00         |
| PS Learning gain       | 748| 0.51 | 0.02| -1.00| 1.00 | 0.00         |

*Note. CU = conceptual understanding; PS = procedural skills*
The results of the CU and PS learning gain assessments with the Mann-Whitney U test are reported in Table 4.10. The intervention group students have higher mean learning gains on both types of knowledge when compared to these of the comparison group students ($M = 0.55 \pm 0.02$ versus $M = 0.16 \pm 0.02$ for CU; and $M = 0.51 \pm 0.02$ versus $M = 0.05 \pm 0.05$ for PS). The Mann-Whitney U test shows these differences to be statistically significant: $U = 118892.0$, $z = -13.21$, $p < 0.001$ (2 tailed), effect size $d = 0.41$ (for CU) and $U = 110735.50$, $z = -14.96$, $p < 0.001$ (2 tailed), effect size $d = 0.47$ (for PS).

This means the CSA modules are effective in improving students’ CU and PS learning gains of rigid body dynamics and the improvements of these types of knowledge were almost at the medium effect size. The CSA modules help students improve their PS
better than they do for the CU, evidenced by the fact that the effect side of the PS learning gain ($d_{PS} = 0.47$) was higher than that of the CU learning gain ($d_{CU} = 0.41$).

Table 4.10
*Mann-Whitney U Test for CU and PS Learning Gain of Two Groups*

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CU learning gain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison group</td>
<td>540</td>
<td>490.67</td>
<td>264962.0</td>
<td>118892.0</td>
<td>-13.21</td>
<td>.000</td>
<td>0.41</td>
</tr>
<tr>
<td>Intervention group</td>
<td>744</td>
<td>752.70</td>
<td>560008.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PS learning gain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison group</td>
<td>560</td>
<td>478.24</td>
<td>267815.5</td>
<td>110735.5</td>
<td>-14.96</td>
<td>.000</td>
<td>0.47</td>
</tr>
<tr>
<td>Intervention group</td>
<td>748</td>
<td>786.46</td>
<td>588270.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* CU = conceptual understanding; PS = procedural skills

The Wilcoxon Signed Rank tests were conducted to assess how students in each group perform on one type of knowledge when compared to the other type of knowledge (Table 4.11). It is found that the difference between the mean CU learning gain ($M = 0.16 \pm 0.02$) and the mean PS learning gain ($M = 0.05 \pm 0.05$) of the comparison group students is statistically significant ($W = 24099.5$, $n = 522$, $p < 0.001$, two tailed). On the contrary, the difference between the mean CU learning gain ($M = 0.55 \pm 0.02$) and the mean PS learning gain ($M = 0.51 \pm 0.02$) of the intervention group students is not significant ($W = 30114.5$, $n = 725$, $p = 0.086$, two tailed). The sums of positive ranks are higher the sums of negative ranks in both cases ($\Sigma R_+ = 201.96$ versus $\Sigma R_- = 254.48$ for the comparison group, and $\Sigma R_+ = 193.96$ versus $\Sigma R_- = 172.08$ for the intervention group),
demonstrating that students in both groups have mean CU learning gains higher than the
mean PS learning gains. Although the difference between the mean CU and PS
knowledge in the comparison group is significant, the effect size (0.1) is negligible
according to the classification of Cliff’s effect size by Romano et al. (2006).

Table 4.11
Wilcoxon Signed Rank Test Results for the Conceptual Understanding and Procedural
Skills Learning Gain Differences

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU Learning gain – PS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning gain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>156</td>
<td>154.48</td>
<td>24099.50</td>
<td>-4.41</td>
<td>.000</td>
<td>0.10</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>206</td>
<td>201.96</td>
<td>41603.50</td>
<td></td>
<td>0.086</td>
<td>0.03</td>
</tr>
<tr>
<td>Ties</td>
<td>160</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>522</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intervention Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU Learning gain – PS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning gain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>175</td>
<td>172.08</td>
<td>30114.5</td>
<td>-1.72</td>
<td>0.086</td>
<td>0.03</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>191</td>
<td>193.96</td>
<td>37046.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ties</td>
<td>359</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>725</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. CU = conceptual understanding; PS = procedural skills*

Figure 4.9 compares the improvements of both types of knowledge in both
instructional groups. Based on the above analyses with the Mann-Whitney U and
Wilcoxon Signed Ranks tests, the following remarks are interpreted from this figure.
First, regardless of the types of instruction, students have higher CU learning gains (significantly for the comparison group, but insignificantly for the intervention group) than their PS learning gains. Second, the CSA modules help students in the intervention group improve significantly both CU and PS knowledge when compared to those of students in the comparison group (Table 4.10). Third, when comparing the performance of each type of knowledge between two instructional groups, the rate of improvement of PS knowledge is higher than that of the CU knowledge. This is evidenced by two facts: a) the effect size of the difference in the PS learning gain ($d = 0.49$) is higher than the effect size of the difference in the CU learning gain ($d = 41$), and b) the difference between these two types of knowledge is not statistically significant for the intervention group.
Figure 4.10 is the scatter plots of <Gain> versus <Pre> for both types of knowledge in the comparison group (circles) and intervention group (squares). The following remarks are withdrawn from the plots:

1. The average prior knowledge of students on CU and PS knowledge (as measured by CU and PS pretest scores of bonus homework) are equivalent for both instructional groups as evidenced by the convergences of circles and squares around the average CU pretest score of 22.5% (top plot) and the average PS pretest score of 24.7% (bottom plot).

2. The students’ CU scores of both groups are highly scattered in three criteria: pretest (<Pre> axis), pretest to posttest gain (<Gain> axis), and learning gain (slant lines <g>). On the pretest score criterion, the CU scores of both groups vary from 0% to 38%, confirming that students’ prior CU knowledge is not consistent among different areas of rigid body dynamics. In both groups, students had lowest prior CU knowledge on BH 14 (Instantaneous Center of general planar motion) and 18 (Impulse and Momentum). On the learning gain criterion, the intervention group has a higher mean CU learning gain than the comparison group, indicating the effectiveness of the CSA modules in improving students’ conceptual understanding.

Even with the help of the CSA modules, students still struggle with the CU and PS of general planar motion addressed in BH 13. This was evidenced by the facts that the pretest to posttest gain and learning gain of BH 13 in the intervention
Figure 4.10. Scatter plots of <Gain> versus <Pre> for CU and PS of two groups. Notes: conceptual understanding (CU, top) and procedural skills (PS, bottom) of two groups.
group on both types of knowledge are very low in comparison with to the averages of the group (20.33% vs. 40.57%, and 0.27 vs. 0.54, respectively).

3. The distribution of CU learning gains for the intervention group is much less dispersed than that for the comparison group, indicating that the CSA modules are rather equally effective in improving learning gains of most CU knowledge areas. The low CU learning gains of BH 13, 14, and 15 will be discussed in details in the session “Results and Analysis of Three Most Challenging Bonus Homework.”

4. In contrast with the scattered CU scores, the students’ PS scores scatter within narrower ranges in three criteria: pretest, pre- to posttest gain, and learning gain. On the pretest criterion, the concentrated PS pretest scores on the <Pre>axis means that the prior PS knowledge is relatively consistent among students (Figure 4.10). On the learning gain criterion, although the average learning gains of the PS knowledge are lower than those of the CU knowledge, the students’ performance on PS are very consistent in both groups. This is evidenced by the high concentration of individual module learning gains around the group average learning gain (slant lines $g_{IG-ave} = 0.52$ and $g_{CG-ave} = 0.09$).

5. Students in the intervention group had the lowest PS learning gains on BH 13 and 14. Along with remark #4 above, this could indicate that both CU and PS knowledge addressed in BH13, and possibly BH 14 and 15, were difficult to many students. The intrinsic cognitive load of this learning material might occupy a large chunk of students’ limited working memory capacity, leaving little room for CSA intervention to make any perceived improvement.
Correlation between Conceptual Understanding and Procedural Skills Knowledge

Table 4.12 reports Spearman’s correlation coefficients between CU and PS learning gain in both learning conditions. As a rule of thumb for interpreting the correlation coefficient offered by Hinkle et al. (2003), a correlation less than 0.3 is considered as negligible, from 0.3 to 0.5 as low, from 0.5 to 0.7 as moderate, and greater than 0.7 as high. Spearman’s correlation tests reveal that there is negligible positive correlation between students’ CU and PS in the comparison group. For the intervention group, the correlation between CU and PS learning gain reaches statistical significance at the medium size ($r_{IG} = 0.575$, $p < 0.001$, two tailed).

Table 4.12
Correlations between Pretest and Learning Gain of LPS and HPS for Two Groups

<table>
<thead>
<tr>
<th>Spearman’s rho</th>
<th>Comparison Group</th>
<th>Intervention Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CU &lt;g&gt;</td>
<td>PS &lt;g&gt;</td>
</tr>
<tr>
<td>Correlation coefficient (rho)</td>
<td>1.000</td>
<td>.188*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>N</td>
<td>540</td>
<td>522</td>
</tr>
<tr>
<td>Effect size (rho^2)</td>
<td>0.035</td>
<td>.331</td>
</tr>
<tr>
<td>Correlation coefficient (rho)</td>
<td>.188*</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>N</td>
<td>522</td>
<td>560</td>
</tr>
<tr>
<td>Effect size (rho^2)</td>
<td>0.035</td>
<td>.331</td>
</tr>
</tbody>
</table>

Note. * Correlation is significant at the 0.01 level (2-tailed). CU = Conceptual understanding; PS = procedural skills.
Figure 4.11 visualizes these correlations. There is a medium association between these two types of knowledge after students interacted with the CSA modules. This means that CSA modules increases the interplay between CU and PS. In other words, with the help of CSA, the development of one type of knowledge facilitates the acquisition of the other, and vice versa. For example, an understanding of the concept of instantaneous center of zero velocity helps students calculate the unknown linear velocities of points on a rigid body.

![Figure 4.11](image)

*Figure 4.11. Scatter plots of CU learning gain versus PS learning gain for two groups. Note: a) Comparison group, b) Intervention group*

**Results and Analysis with Low and High Performance Students**

The learning condition is the primary independent variable of this study. However, analyses were also conducted with the low and high performing students
(measured by their pretest scores) in order to determine whether the CSA modules are effective for students of all prior knowledge levels or just for students of particular prior knowledge. As confirmed by the results of the Mann-Whitney U tests in Table 4.3 above, the two groups were equivalent at the beginning of the study in terms of students’ average pretest scores. However, within each group, students could be split into two groups, low and high performing, based on their pretest scores. The low performing students (LPS) are students whose pretest scores were less than or equal 24.35%, and the high performing student (HPS) are students whose pretest scores were greater than 24.35%. The value of 24.35% is obtained by taking the average pretest scores of both groups. The descriptive statistics of learning gain for the LPS and HPS in two groups are presented in Table 4.13. The Mann-Whitney U tests were conducted to determine the difference in the mean learning gain between the two learning conditions for students at two performance levels (Table 4.14).

Table 4.13
Descriptive Statistics of Learning Gain of LPS and HPS

<table>
<thead>
<tr>
<th>Group-Performance</th>
<th>N</th>
<th>Mean (SEM)</th>
<th>Median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison Group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low performing students</td>
<td>340</td>
<td>0.21 (±0.02)</td>
<td>0.20 (16.7-43.0)</td>
</tr>
<tr>
<td>High performing students</td>
<td>238</td>
<td>-0.13 (±0.03)</td>
<td>0.00 (16.7-50.0)</td>
</tr>
<tr>
<td><strong>Intervention Group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low performing students</td>
<td>399</td>
<td>0.60 (±0.02)</td>
<td>0.75 (0.0-16.7)</td>
</tr>
<tr>
<td>High performing students</td>
<td>368</td>
<td>0.41 (±0.03)</td>
<td>0.63 (33.3-50.0)</td>
</tr>
</tbody>
</table>
Table 4.14
Mann-Whitney U Test Result Comparing Two Learning Conditions for LPS and HPS

<table>
<thead>
<tr>
<th>Performance - Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low performing students</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison Group</td>
<td>340</td>
<td>265.9</td>
<td>90397.5</td>
<td>32427.5</td>
<td>-12.30</td>
<td>.000</td>
<td>0.52</td>
</tr>
<tr>
<td>Intervention Group</td>
<td>399</td>
<td>458.7</td>
<td>183032.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High performing students</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison Group</td>
<td>238</td>
<td>209.0</td>
<td>49747.5</td>
<td>21306.5</td>
<td>-10.73</td>
<td>.000</td>
<td>0.51</td>
</tr>
<tr>
<td>Intervention Group</td>
<td>368</td>
<td>364.6</td>
<td>134173.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The LPS of the intervention group has a significantly higher mean learning gain \((M = 0.60 \pm 0.02, n = 340, \text{ Mean rank} = 458.7)\) than the LPS of the comparison group \((M = 0.21 \pm 0.02, n = 399, \text{ Mean rank} = 265.9)\), with \(U = 32437.5, z = -12.3, p < 0.001, \text{ two tailed}\). Similarly, the HPS of the intervention group also has significantly higher mean learning gain \((M = 0.41 \pm 0.03, n = 238, \text{ Mean rank} = 364.6)\) than the HPS of the comparison group \((M = -0.13 \pm 0.03, n = 368, \text{ Mean rank} = 209)\), with \(U = 21306.5, z = -10.73, p < 0.001, \text{ two tailed}\). This confirms that the CSA intervention help both the LPS and HPS increase their learning gains. The effect sizes for the differences in the mean learning gains in the two cases are medium and almost equal to each other \((d = 0.52 \text{ for the LPS and } d = 0.51 \text{ for the HPS})\).

Within the same learning conditions, the LPS has significantly higher mean learning gain than the HPS (Table 4.15). For the comparison group, the mean learning gain of the LPS \((M = 0.21 \pm 0.02, n = 340, \text{ Mean Rank} = 346.8)\) is significantly higher than that of the HPS \((M = -0.13 \pm 0.03, n = 238, \text{ Mean Rank} = 209)\), with \(U = 20976.5, z = \)
–9.99, and \( p < 0.001 \), two tailed. The LPS in the intervention group also has a significantly higher mean learning gain (\( M = 0.60 \pm 0.02, n = 399, \text{Mean Rank} = 459 \)) than the HPS in the same group (\( M = 0.41 \pm 0.03, n = 368, \text{Mean Rank} = 351 \)), with \( U = 61276.0 \), \( z = -3.97 \), and \( p < 0.001 \), two tailed.

Table 4.15
*Mann-Whitney U Test Result Comparing LPS and HPS in Two Learning Conditions*

<table>
<thead>
<tr>
<th>Group - Performance</th>
<th>( N )</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney ( U )</th>
<th>( z )</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low performing students</td>
<td>340</td>
<td>346.8</td>
<td>117913.5</td>
<td>20976.5</td>
<td>-9.99</td>
<td>0.000</td>
<td>0.48</td>
</tr>
<tr>
<td>High performing students</td>
<td>238</td>
<td>209.0</td>
<td>49417.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intervention Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low performing students</td>
<td>399</td>
<td>458.7</td>
<td>165356.0</td>
<td>61276.0</td>
<td>-3.97</td>
<td>0.000</td>
<td>0.17</td>
</tr>
<tr>
<td>High performing students</td>
<td>368</td>
<td>351.0</td>
<td>129172.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although the LPS has a significantly higher mean learning gain than the HPS in both instructional groups, the effect sizes of the difference between two means are not the same for the two groups. While the effect size of the mean difference between LPS and HPS in the comparison group is medium (\( d = 0.48 \), the effect size for this difference in the intervention group is small (\( d = 0.17 \)). It can be interpreted that within the intervention group, the CSA modules improve learning gain of the HPS better than they do for the LPS. Therefore, the HPS in the intervention group could gain more benefits from the CSA modules than the LPS could and this gain could help the HPS narrow the gap in the mean learning gain between them and the LPS. Specifically, the difference in
the mean learning gain between LPS and HPS was 0.34 (= 0.21 – (-0.13)) in the comparison group but reduces to 0.19 (= 0.60 – 0.41) in the intervention group, or a reduction of 44.12% (= (0.34-0.19)/0.34) (Figure 4.12).

![Graph showing Group-Performance versus Mean learning gain of LPS and HPS.](image)

Figure 4.12. Group-Performance versus Mean learning gain of LPS and HPS. Note: * denotes the differences reached statistical significance at the level of 0.05.

To investigate why the LPS has higher learning gain than the HPS in both learning conditions, nonparametric correlation tests between the pretest scores and learning gains of the LPS and HPS in two groups were further conducted. Because the main difference between the LPS and HPS is their pretest scores, a nonparametric Spearman’s rank correlation was conducted to find any association between the students’ pretest scores and their learning gains.

The result of this correlation test (Table 4.16) found that there are significant negative correlations between student’s pretest scores and the learning gains of LPS ($r_s =$
-0.21) and HPS ($r_s = -0.35$) in the comparison group. Similarly, there is significant negative correlation between student’s pretest scores and the learning gains of the LPS ($r_s = -0.17$) in the intervention group. There is no correlation between the pretest scores and the learning gains of the HPS students in the intervention group. The negative correlation can be interpreted that a low pretest score is associated with a high learning gain. All these facts mean the improved learning gains of the LPS and HPS in the comparison group and the LPS in the intervention group are explained partly by the variations of their pretest scores. Only the improved learning gain of the HPS in the intervention group is not associated with pretest scores that would suggest the effectiveness of the CSA modules on this group.

### Table 4.16

*Correlations between Pretest and Learning Gain of LPS and HPS for Two Groups*

<table>
<thead>
<tr>
<th>Spearman's rho</th>
<th>Comparison Group</th>
<th>Intervention Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LPS &lt;g&gt;</td>
<td>HPS &lt;g&gt;</td>
</tr>
<tr>
<td>Correlation coefficient (rho)</td>
<td>-0.209**</td>
<td>-0.345**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>340</td>
<td>238</td>
</tr>
<tr>
<td>Effect size (rho²)</td>
<td>0.04</td>
<td>0.12</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

Figure 4.13 presents the scatter plots of <Gain> versus <Pre> of the LPS (circles) and HPS (squares) in the comparison group (bottom) and intervention group (top). The following remarks are derived from the plots:
1. The average prior knowledge of LPS is equivalent for both instructional groups as evidenced by the convergences of circles around the average LPS pretest scores of 11% (top plot, intervention group) and 12% (bottom plot, comparison group). Similarly, the average prior knowledge of HPS is also equivalent for both instructional groups as evidenced by the convergences of squares around the average HPS pretest scores of 41% (top plot, intervention group) and 42% (bottom plot, comparison group).

2. In alignment with the above findings (Table 4.15, Figure 4.12), the LPS has higher learning gain and pretest to posttest gain than the HPS, regardless of types of instruction. It is possible that, with the same performance in the posttest scores, low performing students have more room to grow than high performing students.

3. The learning gain of students in both performance levels increased. The distributions of circles and squares were scattered along the <Gain> axis, demonstrating that the improvement rate varied depending on the area of rigid body dynamics knowledge. For the HPS, they continued to struggle with the knowledge of general planar motion addressed in BH 14 and 15. For LPS, they also had lowest learning gain scores on BH 13, 14, and 15. CSA modules help both LPS and HPS learn most on Work and Energy (BH 17 and 18) and Impulse and Momentum (BH 21 and 22).
Figure 4.13. Scatter plots of <Gain> versus <Pre> for low and high performing students. Notes: Top = intervention group; Bottom = comparison group; LPS = low performing student; HPS = High performing student; Slant lines are learning gains.
4. The difference between the average learning gains of LPS and HPS in the comparison group is narrowed down in the intervention group. This demonstrates the CSA modules might have more effect on the learning of HPS than that of the LPS. For example, the gain of 0.54 in learning gain of the HPS (from -0.14 to 0.4) is higher than the gain of 0.38 in learning gain of the LPS (from 0.21 to 0.59).

Results and Analysis with Three Most Challenging Bonus Homework

This session analyzes in detail student learning for the most challenging CSA modules, which correspond to BH 13, 14, and 15 and offers explanations as to why student performances of these three bonus homework assignments are lower than those of the rest of bonus homework assignments. Figure 4.14 presents the learning gains of students in both groups for BH 13, 14, and 15. The learning gains of intervention group students on these three modules are greater than those of the comparison group students. However, these learning gains are significantly lower than the average learning gain ($g_{ave}$ = 0.55) and the learning gains of other bonus homework (from 0.55 to 0.63) in the intervention group (Table 4.6 above).

Bonus homework 13 and 14 cover the knowledge of planar kinematics of a rigid body and require students to have proper problem-solving skills, such as the vector analysis method, to determine the velocity of relative motion and general planar motion. Bonus homework 15 addresses the knowledge of planar kinetics of a rigid body and required students to have solid problem-solving skills to determine force and acceleration of a rigid body. Bonus homework assignments 13, 14, and 15 were designed on the frameworks of the corresponding CSA modules 13, 14, and 15. The intervention group
students were expected to learn the concepts and problem-solving techniques addressed in the corresponding CSA modules and apply their newly acquired knowledge and skills to the bonus homework assignments.

**Figure 4.14.** Learning gains of the intervention group on bonus homework 13, 14, and 15. Note: BH = bonus homework

**Results and Analysis of Bonus Homework 13**

Figure 4.15 presents the student performance of both groups on the individual questions of BH 13. Relative to the comparison group in general, the intervention group did very well on the two conceptual understanding questions, but failed on three of four procedural skills questions. The correct answer rate for question 6 of the intervention group is far below that of the comparison group. Although the intervention group students have an average correct answer rate higher than the comparison group students
on six questions of the HW13 (45% versus 37%), their performance was inconsistent between the conceptual understanding and procedural skills.

Figure 4.15. Correct answer rates of two groups on bonus homework 13. Note: sample size of comparison group \( n = 61 \); sample size of intervention group \( n = 77 \). Symbol * denotes the mean differences between the two groups reach statistical significance at \( p < 0.05 \), two tailed.

The result of the Mann-Whitney \( U \) test on the differences of correct answer rates for BH 13 between two groups (Table 4.17 and 4.18) reveal that the correct answer rates of the intervention group on question 2 (\( M = 75\% , n = 77 \)) is statistically significantly higher than that of the comparison group students (\( M = 36\% , n = 61 \)) with \( U = 1426.5 , z = -4.62 \), and \( p < 0.001 \), two tailed. For procedural skills questions, the intervention group students only performed better than the comparison group students on question 3 and
### Table 4.17
**Mann-Whitney U Ranks on Correct Answer Rate Differences for BH 13**

<table>
<thead>
<tr>
<th>Question and learning conditions</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Comparison group</td>
<td>61</td>
<td>65.54</td>
<td>3998.0</td>
</tr>
<tr>
<td>Q1 Intervention group</td>
<td>77</td>
<td>72.64</td>
<td>5593.0</td>
</tr>
<tr>
<td>Q2 Comparison group</td>
<td>61</td>
<td>54.39</td>
<td>3317.5</td>
</tr>
<tr>
<td>Q2 Intervention group</td>
<td>77</td>
<td>81.47</td>
<td>6273.5</td>
</tr>
<tr>
<td>Q3 Comparison group</td>
<td>61</td>
<td>57.10</td>
<td>3483.0</td>
</tr>
<tr>
<td>Q3 Intervention group</td>
<td>77</td>
<td>79.32</td>
<td>6108.0</td>
</tr>
<tr>
<td>Q4 Comparison group</td>
<td>61</td>
<td>69.78</td>
<td>4256.5</td>
</tr>
<tr>
<td>Q4 Intervention group</td>
<td>77</td>
<td>69.28</td>
<td>5334.5</td>
</tr>
<tr>
<td>Q5 Comparison group</td>
<td>61</td>
<td>72.49</td>
<td>4422.0</td>
</tr>
<tr>
<td>Q5 Intervention group</td>
<td>77</td>
<td>67.13</td>
<td>5169.0</td>
</tr>
<tr>
<td>Q6 Comparison group</td>
<td>61</td>
<td>78.41</td>
<td>4783.0</td>
</tr>
<tr>
<td>Q6 Intervention group</td>
<td>77</td>
<td>62.44</td>
<td>4808.0</td>
</tr>
</tbody>
</table>

### Table 4.18
**Mann-Whitney U Test Results on Correct Answer Rate Differences for BH 13**

<table>
<thead>
<tr>
<th>Questions</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>z</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>61</td>
<td>65.54</td>
<td>3998.0</td>
<td>77</td>
<td>72.64</td>
<td>5593.0</td>
<td>2107.0</td>
<td>-1.20</td>
<td>0.23</td>
</tr>
<tr>
<td>Q2</td>
<td>61</td>
<td>54.39</td>
<td>3317.5</td>
<td>77</td>
<td>81.47</td>
<td>6273.5</td>
<td>1426.5</td>
<td>-4.62</td>
<td>0.00</td>
</tr>
<tr>
<td>Q3</td>
<td>61</td>
<td>57.10</td>
<td>3483.0</td>
<td>77</td>
<td>79.32</td>
<td>6108.0</td>
<td>1592.0</td>
<td>-3.77</td>
<td>0.00</td>
</tr>
<tr>
<td>Q4</td>
<td>61</td>
<td>69.78</td>
<td>4256.5</td>
<td>77</td>
<td>69.28</td>
<td>5334.5</td>
<td>2331.5</td>
<td>-0.09</td>
<td>0.93</td>
</tr>
<tr>
<td>Q5</td>
<td>61</td>
<td>72.49</td>
<td>4422.0</td>
<td>77</td>
<td>67.13</td>
<td>5169.0</td>
<td>2166.0</td>
<td>-1.02</td>
<td>0.31</td>
</tr>
<tr>
<td>Q6</td>
<td>61</td>
<td>78.41</td>
<td>4783.0</td>
<td>77</td>
<td>62.44</td>
<td>4808.0</td>
<td>1805.0</td>
<td>-2.94</td>
<td>0.00</td>
</tr>
</tbody>
</table>
worse on questions 4, 5, and 6. Most notably, the result of the Mann-Whitney $U$ test on question 6 also reveals that the performance of the intervention group is statistically significant lower than that of the comparison group ($U = 1805, z = -2.94, \text{ and } p < 0.001$, two tailed). This means that CSA module 13 improves students’ learning of conceptual understanding but does not have the expected positive impact on students’ procedural skills learning.

**Results and Analysis of Bonus Homework 14 and 15**

The analysis of correct answer rates for BH 14 and 15 reveals that the intervention group performance on both conceptual understanding and procedural skills gradually improved from BH 14 to 15. For example, in term of correct answer rate, three of four responses of BH 14 and all six responses for BH 15 of the intervention group are significantly higher than those of the comparison group (Figures 4.16 and 4.17). That means the performance of intervention group students is gradually increasing from BH 13 to BH 14 and BH 15, initiating an improving trend in learning of the intervention group. This improving trend in learning can be clearly identified from the chart of mean learning gain (Figure 4.5 above), the histograms of learning gains on the three bonus homework of the intervention group (Figure 4.18), and the chart of posttest scores for 10 bonus homework assignments (Figure 4.19). The improving trend in learning of the intervention group has two key characteristics:

1) The performance of students in the intervention group improve gradually from BH 13 to BH 14, to BH 15, and to the last bonus homework BH 22; and

2) Bonus homework 13 plays a pivotal role in this trend of learning.
Figure 4.16. Correct answer rates of two groups on bonus homework 14. Notes: comparison group sample size $n = 61$ versus intervention group sample size $n = 74$. Symbol * denotes the mean differences between the two groups reach statistical significance at $p < 0.05$, two tailed.

Figure 4.17. Correct answer rates of two groups on bonus homework 15. Notes: comparison group sample size $n = 57$ versus intervention group sample size $n = 75$. CU = conceptual understanding, PS = procedural skills; Symbol * denotes the mean differences between the two groups reaches statistical significance at $p < 0.05$, two tailed.
Figure 4.18. Learning gain histograms of three bonus homework of the intervention group. Notes: a) BH 13, b) BH 14, and c) BH 15.
Figure 4.19. Improving trend in posttest score of 10 bonus homework assignments
Notes: Intervention group = squares, comparison group = circles. The error bounds are estimated at 95% confident interval.

In summary, this section analyzes the performances of the intervention group on BH 13, 14, and 15, as they have the lowest learning gains compared to the rest of bonus homework. The analysis results of three bonus homework reveal that the intervention group’s performances, in terms of learning gain and the correct answer rates, are gradually increased from BH13 to BH15 and to the last assignment BH22. The analysis also offers the explanation for the low performances on some procedural skills questions in BH13. The improvement in the learning of the intervention group on the above three homework assignments established the improving trend in learning, ranging from BH13 up to BH22. On this improving trend, the conceptual understanding and procedural skills addressed in the BH13 both play pivotal roles in acquiring new knowledge and applying
it for the rest of rigid body dynamics course. In the transition from particle dynamics to rigid body dynamics, there are many new abstract concepts and problem-solving skills that engineering dynamics students need to acquire. Students also need to have strong spatial abilities and good competency in mathematics to support their learning of rigid body dynamics.

**Discussions**

It has been found that, with the help of CSA modules, the intervention group students have mean overall learning gain statistically significantly higher than that of the comparison group students. The effect size for this difference is 0.49. This finding is consistent with previous studies confirming that CSA modules improved student learning (Dollar & Steif, 2008; Fang, 2012; Flori et al., 1996). In addition, the intervention group students also have mean conceptual understanding and procedural skill learning gains statistically significantly higher than these of the comparison group students. The effect sizes for these differences are 0.41 and 0.47, respectively.

The effect sizes of this study show that the CSA modules are effective instructional intervention as compared to all other instructional interventions and animations. First, the effect sizes of mean differences in this study are higher than the average effect size of 0.4 for all instructional interventions reported by Hattie (2009) from over 800 meta-analyses. Second, the effect sizes in this study are also higher than the average effect size of 0.37 for all instructional animations reported by Hoffler and Leutner (2007) from 26 studies.
The findings in this chapter have identified the improving trend in learning gain of the intervention group after learning with the CSA modules, and the knowledge addressed in BH 13, 14, and 1 plays a critical role in the improving trend of rigid body dynamics knowledge. College student learning engineering dynamics course usually start with particle dynamics and their prior knowledge from high school physics, such as velocity, acceleration, forces, momentum, and work and energy, would suffice to help them succeed in the first half of the ED course. Compared to the particle dynamics knowledge students learned in the first part of the ED course, the rigid body dynamics introduces to students complex new concepts as well as approaches to solve problems. As analyzed in the text below, learning rigid body dynamics requires students to have strong spatial ability skills to handle complex new learning materials and to master the combined use of mathematics tools to solve problems.

In particle dynamics, all objects are considered as having no shapes and volumes. Regardless of how big or how long the objects are, a rocket, a car, and a stone are conventionally assumed to be a single particle and all kinematics and kinetic characteristics are applied to that particle. On the contrary, rigid body dynamics is considered as a particular system of particles which has volume and shape like any object in the real world. By having shape and size, a rigid body can undergo both translational and rotational motions while a particle can undergo only translational motion. This concept is very important knowledge in the learning of rigid body dynamics, as many other concepts for the rest of rigid body dynamics course rely on this understanding. For example, rigid bodies have both translational and rotational kinetic energy, and both translational and rotational angular momentum.
Spatial Abilities for Conceptual Understanding of Rigid Body Dynamics

In a study on 203 college students learning the force concept inventory (FCI) in physics education, Hake (2002) presented correlation analysis between students’ learning gains and their mathematics and spatial visualization test scores. He found that there were positive correlations between students’ learning gains on the FCI and their spatial visualization abilities ($r = 0.24$) and mathematics skills ($r = 0.36$). In term of the effect sizes, Hake’s (2002) finding implied that 5.8% of students’ learning gain on the physics course in his study was explained by their spatial abilities. Similarly, 13% of students’ learning gain on the physics course was explained by their mathematical competencies.

Until date, there has been no similar study in engineering dynamics and spatial ability testing was not used in this study; therefore, the correlations between students’ learning gain on rigid body dynamics and their spatial abilities and mathematics competence are unknown. However, the knowledge addressed in the FCI and in the dynamics concept inventory (DCI) for engineering mechanics education is very close. In fact, the creators of the DCI instrument for engineering mechanics instruction have adopted many questions from the FCI and 50% of 24 questions in the DCI directly cover rigid body dynamics knowledge (Gray, Evans, Cornwell, Costanzo, & Self, 2003; Gray et al., 2005). Therefore, it would be reasonable to assume that learning rigid body dynamics requires students to have good spatial abilities as well as strong mathematics skills.

The role of learners’ spatial abilities and their performances in physics learning was reported by some researchers, including Isaak and Just (1985), and Kozhevnikov, Motes, and Hegarty (2007). In Kozhevnikov and colleagues’ (2007) experiment, participants were asked to determine a hockey puck’s trajectory after it received a swift
kick in the direction perpendicular to its original trajectory. Within five possible options, the majority of low spatial performers chose a response showing the puck’s trajectory perpendicular to its original velocity. Meanwhile, the majority of high spatial performers chose a response which shows the puck’s trajectory as a combination of the initial velocity and the velocity acquired from the kick. Kozhevnikov et al. (2007) applied working memory model to explain why low spatial performers made more errors in multi-dimensional motion problems. A person’s working memory consists of the visual-spatial sketchpad that processes visual-spatial information and the phonological loop that processes verbal information. Because the visual-spatial sketchpad subsystem has limited processing capacity, it is quickly overloaded by spatially dependent learning contents. The limited capacity of visual-spatial working memory of a person reduces his or her ability to process and integrate concurrently multiple motion components into the overall motion. In the above problem with the hockey puck in motion, the high-spatial participants chose the correct answer possibly because they “took into account and correctly integrated both the horizontal and vertical motion components” (Kozhevnikov et al., 2007).

The role of spatial ability in learning general planar motion - another multi-dimensional motion - was discussed in a study conducted by Isaak and Just (1995). They argued that the lack of cognitive resources caused peoples’ errors and illusions about this motion. The general planar motion of a rigid body is best described as the combination of simultaneous translational and rotational motions. The concept of this motion was first introduced in BH 13, employed in BH 14 and 15, and discussed in other bonus homework of rigid body dynamics in various contexts.
Competency of Mathematics Tools in Solving Rigid Body Problems

Solving rigid body dynamics problems requires students to have good mathematics skills on multiple domains, including algebra, calculus, geometry, trigonometry, and vectors. Figure 4.20 is a screenshot of CSA module 13 to illustrate how the various mathematical tools were used to solve for the velocity of the slider B and the angular velocity of link AB (Figure 3.1 in Chapter 3). The knowledge of vectors, geometry, and trigonometry is important in solving the general planar motion problems in rigid body dynamics. In addition to the knowledge of vectors and geometry necessary to render the mechanism in proper scale, students are required to use a great deal of trigonometric knowledge to solve problems in Chapter 16 of the course.

**Solution**

At the initial position $\theta = 60^\circ$ (Figure 1)

\[ OC = 0.6 \times \sin(60^\circ) = 0.52 \text{m} \]  \hspace{1cm} (Eq. 1)

At any position $\theta$ (Figure 2), line BC equation:

\[ x = 0.52 \]

The equation of the circle with A as the center and AB (0.4m) as the radius:

\[ (x + 0.2 \sin 60.0)^2 + (y + 0.2 \cos 60.0)^2 = (0.4)^2 \]  \hspace{1cm} (Eq. 2)

Solve Eqs. (1) and (2) to find the coordinates of point B:

\[ B_x = -0.52 \]

\[ B_y = -\sqrt{0.16 - (-0.52 + 0.2 \sin 60.0)^2 - 0.2 \cos 60.0} = -0.30 \]

Coordinates of point A:

\[ A_x = -0.2 \sin 60.0 = -0.17 \]

\[ A_y = -0.2 \cos 60.0 = -0.10 \]

\[ \tan \psi = \frac{B_y - A_y}{B_x - A_x} = \frac{(-0.30) - (-0.10)}{(-0.52) - (-0.17)} \]

\[ \therefore \psi = \tan^{-1} 0.558 = 30.0 \text{ deg.} \]

*Figure 4.20. A screenshot of the solution page in CSA module 13.*
As for the low performance of the intervention group on the procedural skills questions in BH 13, it would be possible that CSA module 13 helped students acquire the new procedural skills but their newly acquired knowledge had not been transferred into the learning situation addressed in BH 13. The administration of the posttest BH 13 on the intervention group provided students less than 72 hours (including 48 hours of two weekend days) after learning with the CSA intervention (Figure 3.3 in Chapter 3). This time interval may not have been long enough for the intervention group students to learn the new problem-solving skills and transfer their learning to the problem-solving task of BH13. The comparison group had higher performance than the intervention group on the procedural skills questions in BH 13, possibly by chance because the performance of the former group stayed unchanged while the performance of latter group kept increasing during the study.

Another explanation for the low performance on question 6 in BH13 includes the possibility that CSA module 13 did not help students acquire new problem-solving skills. In other words, the step-by-step worked problem offered in CSA module 13 might have confused the intervention group students and prohibited them from obtaining the new skills. In reality, this possibility does happen in many fields as some research papers have pointed out. Many new multimedia interventions increased, instead of reduced, the cognitive load of the learners (Mayer & Moreno, 2002; Moreno, 2006). However, the improving trend in learning gain discussed above (Figure 4.18 and 4.19) shows that the CSA modules help students learn. Therefore, the possibility that the CSA module 13 was ineffective and had a negative impact on student performance in BH13 is eliminated.
Summary of Findings

This chapter has reported the results and discussions from data analyses of pretest, posttest, and learning gain scores to answer research question 1. Table 4.19 restates research question 1 and summarizes the key findings of this chapter. The analyses have compared the mean differences between the two instructional groups on three types of measurements: posttests, pre- to posttest gains, and learning gains. Because the distributions of all test scores are non-normal and highly skewed, two non-parametric statistics tools, Mann-Whitney U and the Wilcoxon Signed Rank Wilcoxon tests, were used to evaluate the mean differences. The analyses have also evaluated the means differences between the low and high performing students and between the conceptual understanding and procedural skills learning gains to justify the effects of CSA modules on student learning from other perspectives. The chapter has also analyzed and reported the effect sizes of all mean differences with nonparametric effect size Cliff’s d and correlations between variables with Spearman’s correlation test.
Table 4.19
Summary of Main Findings from Pretest and Posttest Analysis

<table>
<thead>
<tr>
<th>Inquiries</th>
<th>Main findings</th>
<th>Test results / Evidences</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1: To what extent do students in the intervention group who use interactive CSA modules along with traditional lectures improve learning in RBD as compared with students in the comparison group who use traditional lectures only?</td>
<td>The intervention group students have a significantly higher mean posttest score of RBD than the comparison group students.</td>
<td>Mann-Whitney U test with $U = 109407.50$, $N_1 = 568$, $N_2 = 768$, $p &lt; 0.001$, two tailed, effect size $d = 0.51$ (Table 4.3).</td>
</tr>
<tr>
<td></td>
<td>The mean pretest to posttest gain score on bonus homework of the intervention group reaches statistical significance.</td>
<td>Wilcoxon Signed Rank test with $W = 13351$, $n = 767$, $p &lt; 0.001$, two tailed, effect size $d = 0.62$ (Table 4.4).</td>
</tr>
<tr>
<td></td>
<td>The intervention group students have a significantly higher mean overall learning gain of RBD than the comparison group students.</td>
<td>Mann-Whitney U test with $U = 112143.5$, $z = -15.60$, $p &lt; 0.001$ (2 tailed), effect size $d = 0.50$ (Table 4.5).</td>
</tr>
<tr>
<td></td>
<td>The intervention group students have a significantly higher mean CU learning gain of RBD than the comparison group students.</td>
<td>Mann-Whitney U test with $U = 118892.0$, $z = -13.21$, $p &lt; 0.001$ (2 tailed), effect size $d = 0.41$ (Table 4.10).</td>
</tr>
<tr>
<td></td>
<td>The intervention group students have a significantly higher mean PS learning gain of RBD than the comparison group students.</td>
<td>Mann-Whitney U test with $U = 110735.50$, $z = -14.96$, $p &lt; 0.001$ (2 tailed), effect size $d = 0.47$ (Table 4.10).</td>
</tr>
<tr>
<td>Other inquiries</td>
<td>The intervention group students have higher mean CU and PS learning gains than the comparison group students, but the effect side of the difference in the mean PS learning gain is higher than that of the mean CU learning gain.</td>
<td>The effect side of the difference in the mean PS learning gain ($d_{PS} = 0.47$) was higher than this in the mean CU learning gain ($d_{CU} = 0.41$) (Figure 4.9, Table 4.10).</td>
</tr>
<tr>
<td>CSA modules improve PS learning gain better than CU learning gain.</td>
<td>The low performing students have a higher mean learning gain than the high performing students, regardless types of instruction, but the latter increases learning gain faster than the former with the help of CSA modules.</td>
<td>Mann-Whitney U tests with $U = 20976.5$, $z = -9.99$, and $p &lt; 0.001$ (2 tailed), effect size $d = 0.48$ (the comparison group); and $U = 61276.0$, $z = -3.97$, and $p &lt; 0.001$ (2 tailed), effect size $d = 0.17$ (the intervention group) (Table 4.14 &amp; Figure 4.15).</td>
</tr>
</tbody>
</table>
Table 4.19. (cont’d)

<table>
<thead>
<tr>
<th>Inquiries</th>
<th>Main Findings</th>
<th>Test results / Evidences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Correlations</strong></td>
<td><strong>There are significant positive correlations between students’ CU and PS knowledge in both groups, but the correlation in the comparison group is negligible while the correlation in the intervention group is moderate.</strong></td>
<td>Spearman’s correlation $r_{CG} = 0.188$, $n = 522$, $p &lt; 0.001$, two tailed versus $r_{IG} = 0.575$, $n = 725$, $p &lt; 0.001$, two tailed (Table 4.12).</td>
</tr>
<tr>
<td>Correlation between CU and PS knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Correlation between CU and PS knowledge</strong></td>
<td><strong>As compared to the comparison group, the improved conceptual understanding of students in the intervention group might better facilitate acquisition of their procedural skills and vice versa.</strong></td>
<td>Spearman’s correlation $r_{IG} = 0.575$, $p &lt; 0.001$, two tailed (Table 4.12).</td>
</tr>
</tbody>
</table>

*Note. CU = conceptual understanding, PS = procedural skills, CG = comparison group, IG = intervention group.*
CHAPTER 5

RESULTS AND ANALYSIS OF SURVEYS AND INTERVIEWS

Introduction

This chapter describes the results and analysis of survey and interview data to answer research question 2 stated in Chapter 3: “What are students’ attitudes towards and experiences with the interactive CSA modules?” At the end of the course, the intervention group students were asked to complete a questionnaire survey on the use of and their attitudes towards the CSA modules. Participation in the survey was voluntary and students got bonus credit towards their participation. There are 26 questions in the survey and they are classified into six categories. The survey results are presented in Tables 5.1 to 5.5. In these tables, “Q” is the abbreviation for “Question” and “M” for “Modules.” In addition, some question text and choices are abbreviated to make the tables concise. Details of these survey questions are presented in Appendix G.

For multiple-choice questions, regardless of single choice or multiple choices allowed, the results include the percentage of each choice over the total number of choices made by students. For Likert-scale questions, the results include the percentage of each choice, the median (Mdn), and the interquartile range (IQR). For open-ended questions, the results include the outcomes mentioned by students and categorized by a team of researchers as well as the percentage of each outcome.
In addition to the questionnaire survey, ten students from the intervention group were randomly selected for interviews to collect their detailed experiences about the CSA modules. The participation in the survey or interview was voluntary and students got bonus credit or a $15 bookstore gift card for their participation. The semi-structured interviews data recorded under audio format were transcribed and analyzed to provide more details about students’ thoughts and learning experiences with the CSA modules.

Survey Data

Accessibility and Functionality of CSA modules

The analysis in Table 5.1 reports the accessibility and functionality of the CSA modules for rigid body dynamics. As the answer of Question 1 indicated, the majority of students (63%) accessed the CSA modules from off-campus locations. The off-campus locations could be interpreted as students’ homes or dormitories because 93% of students indicated that they always or often ran the CSA modules individually while only 1.4% always used the CSA modules with their classmates (Q5).

Nearly 75% of students ($n = 71$) used the CSA modules to complete bonus homework and revisited them at later dates to review, while approximately 25% visited the CSA modules only once for the bonus homework (Q2). When asked the purpose of the revisit of the CSA modules on Canvas at later dates, 47.9% of students indicated that they used the CSA modules as reference material to review before the class exams (Q3). Question 4 asked students about time on task. For each access of the modules, some students spent less than 15 minutes (43.7%) working with the CSA modules, some spent from 15 to 30 minutes (42.3%), and very few spent more than 45 minutes (2.8%). When
asked in a multiple choice question with multiple answers allowed (Q7) about which features of the modules students liked most, the most popular replies were the mathematic equations presented in the modules (80.3%), the animations (53.5%), and the diagrams, including free-body diagrams (49.3%).

Table 5.1
Survey Results of Accessibility and Functionality of CSA Modules

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1: Where did you typically use CSA modules?</td>
<td>Multiple choices</td>
<td>63.4%</td>
</tr>
<tr>
<td></td>
<td>a) Off campus</td>
<td>5.6%</td>
</tr>
<tr>
<td></td>
<td>b) On and Off campus</td>
<td>31.0%</td>
</tr>
<tr>
<td></td>
<td>c) On campus</td>
<td>Total (n = 71) 100.0%</td>
</tr>
<tr>
<td>Q2: How often did you use these modules?</td>
<td>Multiple choices</td>
<td>25.4%</td>
</tr>
<tr>
<td></td>
<td>a) I used them only when I need to complete bonus homework, and then I did not visit them again.</td>
<td>74.6%</td>
</tr>
<tr>
<td></td>
<td>b) I used them to complete bonus homework, and also visited them again later.</td>
<td>Total (n = 71) 100.0%</td>
</tr>
<tr>
<td>Q3: Did you run these modules prior to exams in order to better prepare for exams?</td>
<td>Multiple choices</td>
<td>8.5%</td>
</tr>
<tr>
<td></td>
<td>a) Yes, I always run these modules before each exam.</td>
<td>39.4%</td>
</tr>
<tr>
<td></td>
<td>b) Yes, I sometimes run these modules before some exams.</td>
<td>52.1%</td>
</tr>
<tr>
<td></td>
<td>a) No, I did not run any module prior to any exam.</td>
<td>Total (n = 71 ) 100.0%</td>
</tr>
<tr>
<td>Q4: How long did you usually spend on a module?</td>
<td>Multiple choices</td>
<td>43.7%</td>
</tr>
<tr>
<td></td>
<td>a) Less than 15 minutes</td>
<td>42.3%</td>
</tr>
<tr>
<td></td>
<td>b) Between 15 and 30 minutes</td>
<td>11.3%</td>
</tr>
<tr>
<td></td>
<td>c) Between 30 and 45 minutes</td>
<td>2.7%</td>
</tr>
<tr>
<td></td>
<td>d) More than 45 minutes</td>
<td>Total (n = 71) 100.0%</td>
</tr>
<tr>
<td>Q5: Did you use CSA module individually or in team?</td>
<td>Multiple choices</td>
<td>73.3%</td>
</tr>
<tr>
<td></td>
<td>a) Always individually</td>
<td>19.7%</td>
</tr>
<tr>
<td></td>
<td>b) Most often individually, sometimes in team.</td>
<td>5.6%</td>
</tr>
<tr>
<td></td>
<td>c) Most often in team, sometimes individually</td>
<td>1.4%</td>
</tr>
<tr>
<td></td>
<td>d) Always in team</td>
<td>Total (n = 70) 100%</td>
</tr>
</tbody>
</table>
Table 5.1. (Cont’d)

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Q6:</strong> Are the modules easy to navigate?</td>
<td><em>Multiple choices</em></td>
<td></td>
</tr>
<tr>
<td>a) Strongly agree ( = 5)</td>
<td>11.4%</td>
<td></td>
</tr>
<tr>
<td>b) Agree ( = 4)</td>
<td>52.9%</td>
<td></td>
</tr>
<tr>
<td>c) Neutral ( = 3)</td>
<td>32.9%</td>
<td></td>
</tr>
<tr>
<td>d) Disagree ( = 2)</td>
<td>2.9%</td>
<td></td>
</tr>
<tr>
<td>e) Strongly disagree ( = 1)</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td><strong>Median (IQR) = 4 (3-4); Total (n = 70)</strong></td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>

| **Q7:** Which features of the modules do you like most? Select all that are applicable. | *Multiple choices allowed* |  |
| a) Animations | 53.5% |
| b) Figures | 49.3% |
| c) Math equations | 80.3% |
| d) Scrollbars | 9.9% |
| e) Color that highlights important items | 18.8% |
| **Total (n = 71)** |  |

| **Q8:** If you have any comments on the computer graphical user interfaces designs of the modules, please provide below. | *Category* |  |
| a) Help to learn CU knowledge better (+) | 10.3% |
| b) Good in general (+) | 13.8% |
| c) Easy to navigate and learn (+) | 10.3% |
| d) Scrollbar problems (-) | 29.3% |
| e) Screen size issues (-) | 25.9% |
| f) Other unfriendly GUI features (-) | 10.3% |
| **Total number of times mentioned (n = 58)** | 100.0% |

*Note.* (+) and (-): Positive and negative feedback

For the Likert-style question asking students whether the modules are easy to navigate (Q6, with “strongly disagree” as 1, and “strongly agree” as 5), students almost universally agreed that moving around the modules was easy (*Mdn = 4, IQR = 3-4*).

However, when compared to other features of graphical user interface, the number of comments indicating navigation as a good feature was only one third of the total positive feedback (10.3% over 34.4%, Q8). Of 65.6% negative feedback, scrollbars (29.3%) and screen sizes of modules (25.9%) accounted for the most problems. These two notable
issues were likely a result of the access method used by the students to view the CSA modules. Specifically, the Canvas program where the modules were uploaded for students’ view and access controls the window sizes of the Flash modules embedded in its environment. As a consequence, students sometimes worked with the modules on smaller windows and with extra scrollbars automatically added by the Canvas program.

**Students’ Motivation, Confidence, and Learning Activities**

Questions 9 and 10 (Table 5.2) asked students whether they agreed with the statements that the CSA modules increased their confidence (Q9) and motivation (Q10) for learning engineering dynamics. Students indicated their agreement on a five-point Likert response, ranging from “1 = strongly disagree” to “5 = strongly agree”. In question 9, most students indicated that the CSA modules increased their confidence for learning engineering dynamics \( (Mdn = 4, IQR = 3-4) \). However, students’ opinions were divided for question 10, which asked students whether the CSA modules increased their motivation to learn. 28% of students expressed strong disagreement or disagreement, but 38% indicated that they agreed or strongly agreed with statement in question 10 \( (Mdn = 3, IQR = 2-4) \). The median of 4 (= agree) and the small \( IQR \) (3-4) for question 9 indicate the high consensus among students about the positive impact of the CSA modules on their confidence in learning engineering dynamics. In contrast, with a median of 3 (= neutral) and a larger \( IQR \) (2-4), the response to question 10 might suggest that the CSA modules might have no impact on students’ motivation in learning engineering dynamics.

The analysis of students’ responses for question 11 reveals that there seems to be two main types of learners, the “active” and “passive” ones, depending on their usage
pattern of the modules. The “active” learners, which accounted for 60.3% of the respondents, were willing to face challenges by investing energy in the learning process and solving the bonus homework without help from the CSA modules first. Afterwards, they ran the modules, watched the animation, and checked with the modules to see whether their solutions (problem-solving approach and numerical results) made sense. About a third of respondents (32.8%) could be classified as “passive” learners, as they chose to run the CSA modules and watch the CSA animation before solving the bonus homework. On one hand, those learners may have had no idea about how to tackle the specific problems or the conceptual understanding addressed in the problem statements. On the other hand, they may have avoided challenges of the problem solving and chose to acquire ideas and theoretical concepts from the modules before solving the problem on their own. The “active” and “passive” learners in this study were very similar to the “learning oriented” and “performance oriented” learners, respectively, described by Dweck (as cited in Bransford, Brown, & Cocking, 2001, p. 61). The “learning oriented” learners like new challenges, and the “performance oriented” learners worried more about making mistakes than about learning. A “learning oriented” learner was more likely to stimulate higher cognitive processes and critical thinking than a “performance oriented” one.

The following are examples of the “active” learners’ responses:

“I usually gave each assignment a quick review and tried my best to solve it before looking at the module. If I was stumped or confused then I would go and open the module. I would look for patterns that were similar between the online solution and mine.
Where there were discrepancies I would try to figure out why and then work to fix them until I got the right answer. If I still remained confused, I would call a class mate."

Table 5.2
*Survey Results of Students’ Motivation, Confidence, and Learning Activities*

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q9: Do you agree with the statement: &quot;Overall, these modules increase my confidence for learning engineering dynamics&quot;?</td>
<td>Multiple choices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Strongly agree ( = 5)</td>
<td>11.8%</td>
</tr>
<tr>
<td></td>
<td>b) Agree ( = 4)</td>
<td>41.2%</td>
</tr>
<tr>
<td></td>
<td>c) Neutral ( = 3)</td>
<td>26.5%</td>
</tr>
<tr>
<td></td>
<td>d) Disagree ( = 2)</td>
<td>10.3%</td>
</tr>
<tr>
<td></td>
<td>e) Strongly disagree ( = 1)</td>
<td>10.3%</td>
</tr>
<tr>
<td></td>
<td>Median (IQR) = 4 (3,4); Total (n = 68)</td>
<td>100.0%</td>
</tr>
<tr>
<td>Q10: Do you agree with the statement: &quot;Overall, these modules increase my motivation for learning engineering dynamics&quot;?</td>
<td>Multiple choices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Strongly agree ( = 5)</td>
<td>10.3%</td>
</tr>
<tr>
<td></td>
<td>b) Agree ( = 4)</td>
<td>27.9%</td>
</tr>
<tr>
<td></td>
<td>c) Neutral ( = 3)</td>
<td>33.8%</td>
</tr>
<tr>
<td></td>
<td>d) Disagree ( = 2)</td>
<td>19.1%</td>
</tr>
<tr>
<td></td>
<td>e) Strongly disagree ( = 1)</td>
<td>8.8%</td>
</tr>
<tr>
<td></td>
<td>Median (IQR) = 3 (2,4); Total (n = 68)</td>
<td>100.0%</td>
</tr>
<tr>
<td>Q11: Please describe how you run CSA modules, i.e., describing the entire process from the beginning to the end.</td>
<td>Category</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Solve-Watch-Check (SWC)*</td>
<td>60.3%</td>
</tr>
<tr>
<td></td>
<td>b) Watch-Solve-Check (WSC)*</td>
<td>32.8%</td>
</tr>
<tr>
<td></td>
<td>c) Combinations of a) and b) (S/WC)*</td>
<td>6.9%</td>
</tr>
<tr>
<td></td>
<td>Total number of times mentioned (n = 58)</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

*Note.*

**SWC:** Students solve the bonus homework first without the CSA’s help. Then they run, watch, and interact with the modules. Finally, they check if their solutions make sense as compared to the problem-solving approach offered in the modules.

**WSC:** Students run, watch, and interact with the modules first. Then they solve the bonus homework based on the framework setup in the modules. Finally, they check if their solutions make sense as compared to the problem-solving approach offered in the modules.

**S/WC:** Students use both strategies depending on their time budgets and their understandings about the module’s problems.
“I always tried to do the bonus homework on my own, and whenever I would get stuck I would look through the module to figure out where I was unclear on. Then I would apply what was in the module to the bonus homework.”

The following are examples of the “passive” learners’ responses:

“I would go over the sample problem on my own and the animation of the sample problem to understand what was going on. Then I would look at the bonus problem and compare them and use the sample problem to solve the bonus problem.”

“I mostly used the modules as a review before the test. Just to reiterate the principles already learned and demonstrated on homework and bonus homework.”

Correlation analysis between the students’ rating on confidence and motivation and their learning gains was conducted to investigate the relationships between student's confidence, motivation and learning outcomes. The analysis was implemented by using Spearman’s correlation in SPSS (Table 5.3). Overall, there was a statistically significant positive correlation between student’s agreement levels on confidence and their learning gains ($r_s = 0.323$, $n = 46$, $p < 0.001$, two tailed). This means an increase in students’ agreement level on confidence is correlated with an increase in their overall learning gain. Similar correlation analysis was also conducted between the students’ motivation agreement levels and their learning gains, but the result did not yield a statistically significant correlation between the two variables ($r_s = 0.268$, $n = 46$, $p = 0.071$, two tailed). These results might indicate that a student’s confidence would play a certain role in improving their learning gains while their motivation would not.
Table 5.3
*Correlations between Students’ Confidence, Motivation, and Learning Gains*

<table>
<thead>
<tr>
<th></th>
<th>Learning Gain</th>
<th>Confidence</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>0.323*</td>
<td>0.268</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>-</td>
<td>0.028</td>
<td>0.071</td>
</tr>
<tr>
<td>N</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed);

Quality of the Technical Dynamics Problems Designed for CSA Modules

Table 5.4 presents the results of the survey from question 12 to question 15. These questions asked a student’s opinions about the quality of the technical dynamics problems designed for CSA modules. It seems there is no clear trend regarding students’ preference on the technical dynamics problems designed for the modules (Q12). Although Modules 13 and 20 were likely to be the most favorite technical dynamics problems in terms of the percentage of choices (14.6% and 12.1%, respectively), other modules received nearly equal percentage ($M = 10.0\% \pm 2.3\%$). This might indicate that the technical problems for all CSA modules were selected and designed consistently. There are four main reasons (Q13) that explain why students liked the specific technical dynamics problems in question 12. First, “Challenging” and “interesting” were the two most coded comments from students’ responses (29%) when they tried to explain their preference for technical
dynamics problems. The following are some students’ comments and the module(s) they liked:

Student 1 (picked Modules 13, 14, and 21) wrote:

“They were challenging problems and the modules helped me learn the concepts.”

Student 2 (liked Modules 14 and 20) wrote:

“They are more complex versions of the test problems.”

Next, visualization features such as animation and diagrams and the benefits of learning from the CSA modules were the next two most common reasons provided for why students liked specific modules. They accounted for 25.8% and 24.2% of the responses, respectively. Typical responses from students are listed below.

Student 3 (liked Module 16):

“The yo-yo problem [w]as difficult to visualize and this helped.”

“I really struggled with learning these sections in class, and the simulations clearly showed how these concepts were applied. I liked the simulations because they illustrated the changes in IC and the velocity which were a couple concepts that I had a hard time with.”

Student 4 (liked Modules 14, 15, 20, 21, and 22) indicated:

Student 5 (liked Modules 19 and 22):

“I liked them because they helped my understanding.”

Finally, the computer GUIs and step-by-step presentation of the worked problems in the CSA modules might have also been the factor that stimulated students to learn. For example, Student 6 (liked Modules 13, 14, 21, and 22) commented:
Table 5.4
Survey Results on the Quality of the Technical Dynamics Problems for CSA Modules

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Q12:</strong> Among the 10 modules for rigid-body dynamics (Modules 13-22 that cover textbook chapters 16, 17, 18, and 19), which technical dynamics problems designed for modules do you like most?</td>
<td><img src="image" alt="Multiple choices with multiple answers allowed" /></td>
<td>Min. = 7.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. = 14.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean = 10.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD = ± 2.3%</td>
</tr>
<tr>
<td><strong>Q13:</strong> Explain why you like those technical problems that you have selected in answering the above question.</td>
<td><strong>Category</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Visualization</td>
<td>25.8%</td>
</tr>
<tr>
<td></td>
<td>b) Challenging &amp; Interesting</td>
<td>29.0%</td>
</tr>
<tr>
<td></td>
<td>c) GUI and step-by-step features</td>
<td>21.0%</td>
</tr>
<tr>
<td></td>
<td>d) Learning benefits</td>
<td>24.2%</td>
</tr>
<tr>
<td>Total number of times mentioned (n = 62)</td>
<td></td>
<td>100.0%</td>
</tr>
<tr>
<td><strong>Q14:</strong> Among Modules 13-22 for rigid-body dynamics, which technical dynamics problems designed for the modules can be redesigned and improved? Why?</td>
<td><img src="image" alt="Multiple choices with open-ended fields" /></td>
<td>Min. = 0.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. = 22.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean = 10.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD = ± 8.0%</td>
</tr>
<tr>
<td><strong>Q15:</strong> Overall, what do you think of the level of technical difficulty of the dynamics problems addressed by Modules 13-22 for rigid-body dynamics?</td>
<td><strong>Multiple choices</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Very easy (= 5)</td>
<td>1.5%</td>
</tr>
<tr>
<td></td>
<td>b) Easy (= 4)</td>
<td>10.3%</td>
</tr>
<tr>
<td></td>
<td>c) Neutral (= 3)</td>
<td>26.5%</td>
</tr>
<tr>
<td></td>
<td>d) Difficult (= 2)</td>
<td>50.0%</td>
</tr>
<tr>
<td></td>
<td>e) Very difficult (= 1)</td>
<td>11.8%</td>
</tr>
<tr>
<td>Median (IQR) = 2 (2-3); Total (n = 68)</td>
<td></td>
<td>100.0%</td>
</tr>
</tbody>
</table>
“They were easy to follow and learn from. I [...] liked how you could change certain factor in the problem like mass, or radius and to see how those factors would change the outcome of the problem.”

As for the question asking students if the modules needed to be re-designed and improved, the responses were divided. While 57.1% of respondents satisfied with the modules and suggested no changes, 42.9% of them pointed out several changes on the animation and computer graphics user interfaces that should be made. Their suggestions for changes (Q14) were highest for Modules 13 and 14 and the most common reasons for change were the animation (33.3%), mathematics equation derivation (25%), and scaffolding strategies (25%). These comments were aligned with the above findings (Figures 4.5, 4.5, and 4.10) where students had lowest overall, conceptual understanding, and procedural skills learning gains on these modules. The rigid body dynamics topics discussed in these modules were relative motion and general planar motion, which are rated as the most difficult engineering dynamics concepts (Gray et al., 2005). Even with the help of animations and worked examples provided in the CSA modules, understanding and solving problems in the bonus homework 13 and 14 remained challenging tasks for some students (Q12 and Q13’s results).

Question 15 asked students’ opinions about the difficulty level of the rigid body dynamics problems in the modules and provided a five-scale Likert response, ranging from “5 = very easy” to “1 = very difficult.” Most of the respondents (61.8%) considered the modules’ dynamic problems as difficult or very difficult, while only a few of them (11.8%) rated the problems as easy or very easy. On average, the rating for difficult level
of the module’s dynamics problems was 2 (= “Difficult”, $IQ R = 2$). This result closely aligned with findings from scholarly papers in this domain (Gray et al., 2005).

**Student Learning Outcomes Associated with CSA Modules**

Questions from 16 to 26 probe students’ opinions regarding the learning outcomes and their experiences with the CSA modules. The results of these questions are presented in Table 5.5. Based on the responses to question 16, the areas of rigid body dynamics knowledge wherein students learned the most were Relative Motion (M13), the Instantaneous Center for general planar motion (M14), the Principle of Work and Energy (M18), and the Conservation of Energy (M20).

In the following excerpts, students identified the module(s) they thought they learned the most from along with their explanations:

“I feel like I learned the most from one and two (i.e. M13 and M14). They helped me calculate the IC (i.e. instantaneous center).”

“The spring ones (i.e. M18 and M20), because I don't know how to react when I see the spring ones. The modules taught me how to dissect the problem with the springs in it.”

“I learned from the modules 13, 14, 19, 21, and 22 because they were challenging but approachable. These were some of the harder concepts to grasp and viewing how the procedure is done was beneficial.”

The responses to question 17 seem contradictory to those of question 16 when Modules 13 and 14 were rated as the least learned modules. The rigid body dynamics knowledge addressed in these modules, the relative motion and general planar motion, is
intrinsically difficult and challenging (Gray et al., 2005). As analyzed in the previous chapter, the knowledge in these modules plays a pivotal role in the learning of the rest of rigid body dynamics. Students who were able to understand and solve problems in these bonus homework assignments (with or without the CSA modules’ help) might rate them as the most learned ones. In contrast, others who failed to understand the concepts and problem-solving steps (with or without the CSA modules’ help) addressed in the assignments might classify them as the least learned modules as well. Furthermore, student attitudes towards and adoption of a new instructional technology vary depending on their prior exposure to the same technology. It seems many students were more technologically savvy than others, and their demands for a new educational technology could be higher than or at least equal to similar technology or media they have experienced.

The following students’ comments demonstrated that students still struggled with the rigid body dynamics concepts in the modules even after using the CSA modules:

“The rotational and general plane motion simulations [were the least learned modules]. Because the concepts were foreign and the animations did not clarify the links between the equations and the motion.”

“13--15. I really did not like the circle equations that were brought into the module. I would have never figured that out on my own and even after meeting with the TA's I still don’t understand why it was that way.”

Responses to questions 18 through 22 provide students’ ratings and opinions regarding the impact of the CSA modules on three learning outcomes: conceptual understanding (Q18, 19), procedural skills (Q20, 21), and overall learning (Q22).
Table 5.5
Survey Results of Student Learning Outcomes Associated with CSA Modules

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
</table>
| **Q16**: Among Modules 13-22 for rigid-body dynamics, which modules did you learn the most from? | *Multiple choices with multiple answers allowed* | Min.= 0.0%  
Max.= 18.8%  
Mean = 10.0%  
SD = ± 5.8% |
| **Q17**: Among Modules 13-22 for rigid-body dynamics, which modules did you learn the least from? | *Multiple choices with multiple answers allowed* | Min.= 0.0%  
Max.= 21.3%  
Mean = 10.0%  
SD = ± 6.6% |
| **Q18**: Do you agree with the statement: "Overall, Modules 13-22 increase my conceptual understanding of rigid-body dynamics problems"? | *Multiple choices*  
a) Strongly agree ( = 5)  
b) Agree ( = 4)  
c) Neutral ( = 3)  
d) Disagree ( = 2)  
e) Strongly disagree ( = 1) | 7.2%  
52.2%  
29.0%  
4.3%  
7.2% |
| **Q19**: Please provide a few examples of how Modules 13-22 increase your conceptual understanding of rigid-body dynamics problems. | *Category*  
a) Visualization  
b) Step-by-step  
c) Navigation  
d) Interaction  
e) Unhelpful | 58.6%  
22.4%  
1.7%  
5.2%  
12.1% |

Median (IQR) = 4(3-4); Total (n = 54) 100.0%
<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q20: Do you agree with the statement: &quot;Overall, Modules 13-22 increase my procedural skills of solving rigid-body dynamics problems&quot;?</td>
<td><strong>Multiple choices</strong>&lt;br&gt;a) Strongly agree ( = 5) 7.2%&lt;br&gt;b) Agree ( = 4) 47.8%&lt;br&gt;c) Neutral ( = 3) 36.2%&lt;br&gt;d) Disagree ( = 2) 2.9%&lt;br&gt;e) Strongly disagree ( = 1) 5.8%</td>
<td>Median (IQR) = 4(3-4); Total (n = 69) 100.0%</td>
</tr>
<tr>
<td>Q21: Please provide a few examples of how these Modules 13-22 increase your procedural skills of solving rigid-body dynamics problems</td>
<td><strong>Category</strong>&lt;br&gt;a) Step-by-step 49.2%&lt;br&gt;b) Equation 14.8%&lt;br&gt;c) Diagrams 9.8%&lt;br&gt;d) Visualization 9.8%&lt;br&gt;e) Unhelpful 16.4%</td>
<td>Total number of times mentioned (n = 54) 100.0%</td>
</tr>
<tr>
<td>Q22: Do you agree with the statement: &quot;Overall, Modules 13-22 increase my learning of rigid-body dynamics&quot;?</td>
<td><strong>Multiple choices</strong>&lt;br&gt;a) Strongly agree ( = 5) 8.7%&lt;br&gt;b) Agree ( = 4) 53.6%&lt;br&gt;c) Neutral ( = 3) 30.4%&lt;br&gt;d) Disagree ( = 2) 1.4%&lt;br&gt;e) Strongly disagree ( = 1) 5.8%</td>
<td>Median (IQR) = 4(3-4); Total (n = 69) 100.0%</td>
</tr>
<tr>
<td>Q23: How do you compare the ways in which you learn from Modules 13-22 and from textbook problem examples?</td>
<td><strong>Multiple choices</strong>&lt;br&gt;a) Learning from CSA is better than from textbook 66.6%&lt;br&gt;b) Learning from CSA is not better than from textbook 13.0%&lt;br&gt;c) No differences in learning from the two media 20.4%</td>
<td>Total (n = 54 ) 100.0%</td>
</tr>
<tr>
<td>Q24: What challenges did you have in using Modules 13-22 to learn RBD?</td>
<td><strong>Category</strong>&lt;br&gt;a) CU knowledge addressed in the modules 24.1%&lt;br&gt;b) PS knowledge addressed in the modules 36.2%&lt;br&gt;c) Difficulty of the subjects 10.3%&lt;br&gt;d) Lacks of time / motivation to learn RBD from CSA 13.8%&lt;br&gt;e) Technical and instructional design issues 15.5%</td>
<td>Total number of times mentioned (n = 58 ) 100.0%</td>
</tr>
</tbody>
</table>
Table 5.5 (Cont.)

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple Choices/ Categories</th>
<th>Student Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Q25:</strong> Provide your comments on how to make the design of Modules 13-22 better. Also provide any other comments that you want us to be aware of.</td>
<td><strong>Category</strong>&lt;br&gt;a) Modules Access on Canvas&lt;br&gt;b) Animation &amp; GUI&lt;br&gt;c) Assessment &amp; Scaffolding features&lt;br&gt;d) Conceptual understanding&lt;br&gt;e) Step-by-step procedure</td>
<td>31.0%&lt;br&gt;28.6%&lt;br&gt;16.7%&lt;br&gt;14.3%&lt;br&gt;9.5%</td>
</tr>
<tr>
<td><strong>Q26:</strong> Provide your final comments on how to more effectively use computer simulation and animation in teaching and learning dynamics.</td>
<td><strong>Category</strong>&lt;br&gt;a) Used as bonus HW&lt;br&gt;b) Used as required HW&lt;br&gt;c) Used as teaching aids&lt;br&gt;d) Used for test preparation</td>
<td>58.2%&lt;br&gt;12.7%&lt;br&gt;21.8%&lt;br&gt;7.3%</td>
</tr>
</tbody>
</table>

Total number of times mentioned ($n = 42$) 100.0%

Total number of times mentioned ($n = 55$ ) 100.0%

Students’ responses seemed very consistent regarding their agreements with the ideas that the modules increased their conceptual understanding, procedural skills, and overall learning of rigid body dynamics with the median rating of 4 (“Agree”) and $IQR = (3-4)$ for all three outcomes. Nearly 60% of students’ opinions considered that visual features, such as animations and diagrams, helped students develop conceptual understanding. In contrast, the step-by-step instruction and the derivation of mathematical equations were the two most common factors (total of 64%) that helped students develop procedural skills, according to the analyses of open-ended comments in Q19 and Q21. This finding is well aligned with many studies’ results concluding that visual aids improved students’ conceptual understandings (Abulencia et al., 2012; Savander-Ranne & Kolari, 2003) and
worked examples facilitate their acquisition of procedural skills (Calfee & Stahovich, 2011; Rossow, 2005).

In the following comments, students indicated the benefits of visual features and step-by-step instruction on their learning:

“Rigid body is really hard to visualize so the simulations and examples helped a lot.”

“I learn well visually and the modules had animation and then diagrams that showed what was happening.”

“They helped me develop a step by step way to approach problems.”

“They allowed me to visualize the problems since I am a visual learner. Like the other modules, they gave me an idea on how to tackle a problem.”

“Just how they went step by step. It kept me organized and allowed me to retrace my steps if I messed up and be able to fix it easily.”

A small percentage of students’ opinions in the responses of these two questions (12.1% for Q19 and 16.4% for Q21) considered that the CSA modules neither increased their conceptual understanding nor improved their procedural skills.

When asked to compare the ways students learned from the CSA modules and from the textbook (Q23), most respondents (66.6%) indicated that learning from CSA is better than from the textbook, while there was only a few (13%) thought oppositely. Students also indicated that acquiring the conceptual understanding and procedural skills addressed in the modules was the most challenging task to them (60.3% of total choices). Along with the opinion about the general difficulty of the subjects (accounted for 10.3%, Q24), mastering the conceptual and procedural knowledge of rigid body dynamics was
the biggest challenge for students to learn (70.6% of total number of times mentioned). In other words, the conceptual understanding and procedural skills continue to be the most important knowledge for students to learn during this course. A few students also reported that they lacked time or motivation (13.8%) and the poor technical and instructional design of the modules were added challenges for them to overcome while learning rigid body dynamics from the CSA modules (15.5%).

Responses to question 26 reveals that over half of students wanted to use the modules as the bonus homework (58.2%) while the rest of them would like to use the CSA modules as teaching aides (21.8%), required homework (12.7%), or test preparation materials (7.3%). Because students got extra grades towards their course homework grades for joining the study, it is understandable that the majority of students support the use of CSA modules as bonus homework. However, a considerable percentage of students (22%) indicate that the CSA modules could be used effectively as teaching aids in regular lectures. This could be a valuable implication for instructors and instructional designers because the CSA modules can complement and enhance the learning of engineering dynamics courses in a variety of ways that other instructional method might not have.

**Semi-structured Interview Data**

Only students from the intervention group interacted with the CSA modules in this study. Ten students in this group were randomly selected for the interviews to give inputs about their experiences with and attitudes towards the CSA modules. In general, the interview questions were close to the questions that appeared in the survey. The questions were also classified in six themes as the survey questions were. However, with
the interviews, the researcher could tactically change the order of questions or include additional inquires depending on the flows of conversation. All interviews were recorded, transcribed, and coded. The average length of an interview session was 29 minutes. The coding process of the interview data analysis is summarized in Table 3.10 of Chapter 3 and the result of the coding is presented in Figure 5.1 below.

![Interviews Coding Result](image)

**Figure 5.1.** Interview data analysis result: code distribution.

There are 543 codes generated by the two coders and from ten audio transcripts. These codes are classified in four categories, including: (a) benefits of CSA modules to learning, (b) students’ responses on technical design, (c) students’ pattern of CSA modules usage, and (d) students’ responses on instructional design. Students’ responses in each of category are then broken down further into subcategories to show their interests and concerns about the CSA modules (Figure 5.2).
Technical design features and benefits of the CSA modules are the two subcategories that take the biggest chunks of interview data (201 and 170, respectively). Aligning with the findings in the quantitative survey analysis regarding the improvements of conceptual and procedural knowledge, conceptual understanding and procedural skills were the two most frequently mentioned benefits during interviews (Figure 5.2b, 57.1% and 33.5% of times, respectively). There seemed to be relationships between the benefits...
and the technical features of the CSA modules and those relationships aligned with the survey’s results. For example, whenever students mentioned their improved conceptual understanding and procedural skills, they frequently cited the two technical design features – visualization (33.8%) and step-by-step interactivity (23.4%) - that helped them increase these two types of knowledge (Figure 5.2a). These findings are well aligned with the findings from the survey data analysis (Table 5.5, Q18 and Q19 for visualization and conceptual understanding; Q20 and Q21 for procedural skills).

In the following transcript, one student let the investigator know about his learning experience on the general planar motions of a four bar linkage system (Module 13) or a Yo-yo (Module 19):

Investigator: “...Okay, so the next question I'm asking you about your motivation and confidence in working with CSA modules. Do you think the CSA modules helped you to improve your motivation and confidence in learning Engineering Dynamics?”

Student: “I do, yeah. Just because on my own I can't picture a yo-yo, or something on my- what is happening, and the book [unintelligible]. It definitely helps me.”

Investigator: “But in the book they also have some similar problems. Why do you think the CSA modules helped you?”

Student: “Oh, just because in the book, it's static. They show you an image, and I- I probably sound stupid, but I see something sitting there, and it's straightforward and imaginary, and for me it helps to at least see the
motion. There's the velocities and force applied. You can change them, move the - I like the sliders on, you know…”

Investigator: “You mean all of these controls?”

Student: “Yeah, exactly, I thought that was very helpful actually. If I could say that something was helpful, it was the sliders honestly because if you pose a problem to me, then “Is mass important?” you can slide it, “is velocity important, is acceleration important? We'll see.” That was probably the most helpful, in a straightforward manner."

In the above conversation, the student described his feelings about the advantages of the CSA modules over the textbooks in illustrating the rigid body dynamics concepts. Textbooks are undoubtedly good learning materials for students in any academic field. However, in this engineering dynamics course, the CSA modules provided students with new learning experiences that textbooks do not have: animation and interactivity.

Comparing learning from textbooks and from the CSA modules, one student put it:

“Because like um… textbook to me is dead, you know, it's not moving. It's just there, it's black and white, you know, it's there… But this is more interesting when we can see something in motion and when we are given the authority to change certain things to see the changes. So it's more interesting to me to do something like this than read the textbook. And obviously when you're more interested in something you tend to focus more attention or put more thought into the problem statements like this, so textbook- I would definitely prefer this over the textbook.”
Following the implications mentioned by Greeno et al., (1996) in which computer interactivities were used to construct an understanding of concepts, the modules were designed to allow students to manipulate the input variables and observe numerical results. Within the opinions about the positive impact of the modules’ technical design on student learning, there were 33.8% of responses relating to the animation or diagrams and 23.4% of times relating to the interactivity.

The following transcripts reveal how the animation and interactivities benefit student learning:

Investigator: … Do you think all of these modules helped you increase your conceptual understanding?

Student: Yeah.

Investigator: Why? In what way?

Student: Just the visual part of it, that I could see it, and actually watch the animation happen. ’Cause you don't get that anywhere else, like in class. You know, he can draw it on the board and sometimes, like, he can bring a ball to class and throw it up and down or put it on a string, but it was nice having that animation that was slow enough that I could follow what it was doing, but also I could actually see the motion involved.

Investigator: Ok. And how about the interaction with the animation, do you think... this feature will help you understand the problem better?

Student: Mm hmm. Yeah, I think it did. It was also nice that with the equations
you could also change these values. So, it wasn't just with animations, it was with the equations, and so it was also nice... It helped me to understand that, 'cause it was like I could change this and see not only how it affected the animation but the equation. So, see how the output changes depending on those first factors.

Investigator: Ok. So how about the umm... procedure skills? I mean, setting up a math equation for a certain problem? Do you think this CSA module helped you improve that skill?

Student: Yeah, I think that it helped. I think it just helped with everything all around. ... It helped me setting it up once again because I could see what was happening, so I knew. It helped me to better understand where the forces were and where they were coming from, and the moments and everything.

Investigator: Yeah. Uh... What did you mean everything? Did you include sketches, free body diagrams?

Student: Mm hmm and the kinetic diagrams, yeah.

One of the most informative and interesting things of the interviews could be the opportunity to observe students’ behaviors, mostly facial expressions and body gestures, synchronizing with their thought while answering the researcher’s questions about their learning experience. For example, in order to reason the motion of the slider B in the slider and crank mechanism of Module 14 (Figure 5.3), one student had to use his hands
and entire arms to mimic the motions of the short and long cranks in space. He made the following remarks with excitement:

“It was difficult for me to picture the motion along- I don't know why, but I struggled with picturing the motion of B, where it dropped, and where it went up, and also the yo-yo was pretty good. This one, which I guess was 19. It was tough for me, so just visualizing things was difficult, but it was helpful in that regard. I'm not saying I did well on them, but it helped me at least to picture them.”

Figure 5.3. A slider and crank mechanism in CSA Module 14.
Note: IC = Instantaneous center

As discussed in Chapter 4 about the role of spatial abilities in learning rigid body dynamics, the difficulty in learning general planar motion was related to the low spatial visualization ability of the learners (Isaak & Just, 1995). In their experiment, participants were asked to conjecture the possible trajectories of a dot on the rim of a wheel rolling on a horizontal plane under different slipping conditions. In RBD terms, the dot underwent
general planar motion by having simultaneously translational and rotational motions when the wheel rolled without slipping. As the authors explained, their participants failed to identify the correct trajectories of the dot because “the cognitive system sometimes does not have sufficient resources for simultaneously processing two components of the motion: its translation and its rotation about its current instant center” (Isaak & Just, 1995, p. 1391). They elaborated that the limited capacity of working memory combined with the succession of motion may force the participants to neglect one of the motions and high spatial participants were better than low spatial peers in manipulating the working memory.

The relationship between the difficulty in figuring out the general planar motion of the slider and crank mechanism and the use of body gestures to express that motion could be explained by Chu and Kita’s (2012) findings. Chu and Kita argued that the difficulty in spatial visualization processes triggers people to spontaneously produce body gestures that, in turn, facilitate spatial problem solving. Specifically, spontaneous body gestures facilitate mental rotation by linking spatial language and existing sensorimotor experience with the spatial transformation process.

Regarding students’ usage pattern of the CSA modules, the interview analysis results on the students’ average access time and their preferred knowledge areas of rigid body dynamics are well aligned with the findings from the survey and learning gain data analyses. The interviewed students spent an average of 30 minutes to work on each CSA. They struggled with knowledge addressed in the first two modules (Modules 13 and 14) and showed strong preferences for the last modules (Modules 19, 20, 21, and 22). For instructional design, although students mentioned only 25 times during the interviews
(over a total of 543 codes), their input was important. For example, because mathematics
equations presented in the CSA modules are the most important feature in learning
problem-solving skills of engineering dynamics (finding from question 7, Table 6.1),
students expected the CSA modules to have features that would facilitate their learning.
A student put his expectations about how the modules could assess student learning on
problem-solving skills as such:

“... I think it would be better if somehow- you'll have to think about this a lot-
somehow you could have the student go through a process of discovering how to
set up the equations, or have them choose the correct equation. Something like
that, something to help them- because if you just have the equations written down
then I don't have to think about how to set them up.”

Another student specified multiple-choice as the type of assessment he would like
to see in the modules as the following:

“Yeah, and so that was nice because then I had to kind of go through and choose.
And that's probably the easiest way to have us choose which equation is correct,
rather than- I know it's hard having us type in the equation. That makes it very
difficult to do the module, but I think maybe a multiple choice: "Which equation
do you think is correct?" or "How would you set this up?" maybe would be
helpful.”

One of the scaffolding features students mentioned several times was the hints or
brief instructions during the process of driving an equation. One student shared his
learning experience about the lack of explanation feature in the modules as following:
“That's a problem that the book has, too. The book usually will throw an equation down, and it doesn't explain why that equation's used, or how- because mostly being just in systems where this link affects this link, it's hard to understand the complete relationships between each one. And then also which variables are constant for the entire body, or which variables are only constant for certain links. Maybe more of those explanations, more detail on it.”

**Summary of Findings**

The results and analysis in this chapter answer research question 2. Some of the most important findings are presented in Table 5.6. Other findings and analysis include the relationship between spatial abilities and learning rigid body dynamics, the pivotal role of general planar motions in learning the rigid body dynamics, and the CSA modules usage pattern.
Table 5.6
Summary of Findings from Survey and Interviews Data Analysis

<table>
<thead>
<tr>
<th>Inquiries</th>
<th>Main Findings</th>
<th>Test results / Evidences</th>
</tr>
</thead>
</table>
| **RQ2:** What are students’ attitudes towards and experiences with the interactive CSA modules? | CSA modules increase students’ learning outcomes                              | In a five-point Likert-style response, ranging from “1 = strongly disagree” to “5 = strongly agree”:
|                                                                          | • 62.3% agreed or strongly agreed that CSA modules increased overall learning of RBD ($Mdn = 4$, $IQR = 3-4$) | • 62.3% agreed or strongly agreed that CSA modules increased overall learning of RBD ($Mdn = 4$, $IQR = 3-4$) |
|                                                                          | • 59.4% agreed or strongly agreed that CSA modules increased conceptual understanding of RBD ($Mdn = 4$, $IQR = 3-4$) | • 59.4% agreed or strongly agreed that CSA modules increased conceptual understanding of RBD ($Mdn = 4$, $IQR = 3-4$) |
|                                                                          | • 55% agreed or strongly agreed that CSA modules increased procedural skill of RBD ($Mdn = 4$, $IQR = 3-4$) | • 55% agreed or strongly agreed that CSA modules increased procedural skill of RBD ($Mdn = 4$, $IQR = 3-4$). Details are on Table 6.4. |
| **CSA modules increase students’ confidence but motivation in learning ED** | • 53% agreed or strongly agreed that CSA modules increased confidence in learning ED ($Mdn = 4$, $IQR = 3-4$). | • 53% agreed or strongly agreed that CSA modules increased confidence in learning ED ($Mdn = 4$, $IQR = 3-4$). |
|                                                                          | • 38.2% agreed or strongly agreed that CSA modules increased motivation in learning ED ($Mdn = 3$, $IQR = 2-4$). | • 38.2% agreed or strongly agreed that CSA modules increased motivation in learning ED ($Mdn = 3$, $IQR = 2-4$). Details are on Table 6.2. |
| **Quality of technical problems**                                         | • 61.8% considered the problems in the CSA modules as “difficult” or “very difficult”, 11.8% as “easy” or “very easy” | • 61.8% considered the problems in the CSA modules as “difficult” or “very difficult”, 11.8% as “easy” or “very easy” |
|                                                                          | • 66.6% indicated learning from CSA is better than from the textbook while 13% thought oppositely | • 66.6% indicated learning from CSA is better than from the textbook while 13% thought oppositely |
| **Learning activities with CSA modules**                                  | • 63% access CSA modules from home                                             | • 63% access CSA modules from home |
|                                                                          | • 74.6% used modules for bonus homework and other purposes while 25.4% used only once for bonus homework | • 74.6% used modules for bonus homework and other purposes while 25.4% used only once for bonus homework |
|                                                                          | • 58.6% believed visualization features (animation, FBDs) increase conceptual understanding | • 58.6% believed visualization features (animation, FBDs) increase conceptual understanding |
|                                                                          | • 64% believed step-by-step worked problem increase procedural skill.           | • 64% believed step-by-step worked problem increase procedural skill. |
| **Correlations**                                                         | • Significant positive correlations between student’s CU and PS in the CG (negligible) and IG (moderate) | • Spearman’s correlation $r_{CG} = 0.188$, $n = 522$, $p < 0.001$, two tailed versus $r_{IG} = 0.575$, $n = 725$, $p < 0.001$, two tailed (Table 4.12). |
Table 5.6 (cont’d)

<table>
<thead>
<tr>
<th>Inquiries</th>
<th>Main Findings</th>
<th>Test results / Evidences</th>
</tr>
</thead>
<tbody>
<tr>
<td>An improved CU in the IG might better facilitate the acquisition of their PS and vice versa.</td>
<td></td>
<td>• Spearman’s correlation $r_{IG} = 0.575, p &lt; 0.001$, two tailed, increased from $r_{CG} = 0.188$, (Table 4.12)</td>
</tr>
<tr>
<td>Significant positive correlation between student’s confidence survey scores and their learning gain</td>
<td></td>
<td>Spearman’s correlation $r_S = 0.323, n = 46, p &lt; 0.001$, two tailed</td>
</tr>
</tbody>
</table>

*Note. CU = Conceptual understanding, PS = Procedural skills; CG = Comparison group, PS = Procedural skills*
CHAPTER 6
CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Conclusions

This study aims to investigate the effectiveness of interactive CSA modules on improving student learning of rigid body dynamics and to determine students’ attitudes towards and experiences with the CSA modules. A total of 161 engineering students taking engineering dynamics courses in two semesters participated in the study. In the first phase of this study, 10 interactive web-based CSA modules were designed and developed to address the key concepts and problem-solving skills in learning engineering dynamics course. In the second phase, the study employed the concurrent embedded strategy QUAN/qual presented by Creswell (2009) in the experimental design to collect and analyze both quantitative and qualitative data to seek answers to the two research questions. The findings from the analysis of learning gains and student surveys combined with the qualitative analysis of student interviews have provided a better understanding of the effects of the CSA modules in learning rigid body dynamics.

Research question #1. To what extent do students in the intervention group who use interactive CSA modules along with traditional lectures improve learning in RBD, as compared with students in the comparison group who use traditional lectures only?

From the analysis of student’s learning gains, it has been found that the CSA modules helped the intervention group students improve learning performance compared
to the comparison group students on three outcomes: overall learning, conceptual understanding, and procedural skills. The means of overall, conceptual understanding, and procedural skill learning gains of the intervention group students are statistically significantly higher than these of the comparison group students. This study confirmed findings of previous studies suggesting that CSA modules improve student learning (Dollar & Steif, 2008; Flori et al., 1996).

In term of Cliff’s $d$ effect size, the mean differences in three types of learning gains between the two groups reach medium and large effect sizes, with $d = 0.41$ for conceptual understanding, $0.47$ for procedural skills, and $0.49$ for overall learning gain. For nonparametric statistical analysis, Romano et al. (2006) suggested an effect size $|d| < 0.147$ as negligible, $0.147 < |d| < 0.33$ as small, $0.33 < |d| < 0.474$ as medium, and $|d| > 0.474$ as large. The effect sizes of the CSA modules in this study are higher than the average effect size of $0.4$ for all instructional interventions reported by Hattie (2009) as well as the average effect size of $0.37$ for all instructional animations reported by Hoffler and Leutner (2007).

From the analysis of effect sizes on the learning of five main rigid body dynamics knowledge areas, it has been found that the intervention group students improve learning gain of different knowledge areas at different rates. The CSA modules help students learn most with the impulse and momentum and work and energy knowledge and least with the relative motion and instantaneous center knowledge. Although the intervention group has higher mean learning gains on the relative motion and instantaneous center than the comparison group, the learning gain differences are either non-statistically significant or statistically significant with small effect sizes. This indicates that, even with the help of
the CSA modules, the intervention group students still struggle with the knowledge of relative motion and instantaneous center of general planar motion. This also reflects the high difficulty level of these learning materials for some students. In engineering dynamic, students usually study rigid body dynamics after finishing particle dynamics. Compared to particle dynamics, rigid body dynamics introduces new abstract concepts that require students to have strong spatial abilities and good mathematical skills. The conceptual and procedural knowledge on the planar kinematic and kinetics of a rigid body play pivotal role in acquiring knowledge for the rest of rigid body dynamics course.

**Research question #2.** What are students’ attitudes towards and experiences with the interactive CSA modules?

The survey and interviews data suggest that the CSA modules had increased students’ conceptual understanding and procedural skills. On the one hand, a majority of students thought that animations, graphics, and diagrams helped them develop conceptual understanding of the course. On the other hand, a large percentage of students consider the step-by-step instruction and the derivation of mathematical equations in CSA modules were the two most helpful features that developed their procedural skills. The results are consistent with the findings of previous studies suggesting that visual aids facilitate students’ acquisition of conceptual understandings (Abulencia et al., 2012; Savander-Ranne & Kolari, 2003) and worked examples improve their procedural skills (Calfee & Stahovich, 2011; Rossow, 2005).

The result of survey analysis reveals that the CSA modules have enhanced students’ confidence to learn rigid body dynamics. Additionally, both survey and interview data indicate that it was the step-by-step presentation of worked problem
combined with the animation of complex motions has improved student confidence in solving bonus homework assignments. Spearman’s correlation analysis between student’s confidence survey scores and their learning gains has yielded a significant positive correlation. This result is consistent with the finding of a previous study (Shankar, Husman, Wells, & Chung, 2011) regarding the relationship between students’ confidence after learning with a new instructional software and their final exam scores. The result of survey analysis also indicates that the CSA modules are less influential in developing student’s motivation as compared to their confidence.

**Implications**

**Implications for Future Instructional Design for Engineering Mechanics Course**

Findings about usage pattern and student preference of CSA modules from this study are well aligned with the widespread adoption of blended learning in higher education. This mode of learning combines traditional face-to-face lectures with online and off-campus coursework, allowing students access learning materials from anywhere and at any time. Due to the expansion of technology, Graham (2006) predicted that blended learning systems would be the major method for course delivery in higher education in the future. Young (2002) anticipated a range of 80% to 90% of courses in higher education eventually becoming blended courses. Because the engineering dynamics course involves complex motions and spatially dependent concepts, the effort to make it an effective blended or online course requires instructors and instructional designers to use proper strategies.
Some of these strategies might include: a) uses of simulation and/or animation for dynamic visualizations and giving users partial or full control of animation; b) use of different visual representations and keep a balance of text and visual representations of the lesson content; c) presenting the whole lesson in step-by-step format and integrating the process of deriving mathematic equations for engineering mechanics problems into this format; d) providing the learners the opportunities to access hints, tips, and reviews during the learning process; and e) integrating the assessment of student learning and providing timely feedback during and after the learning process.

**Implications for Future Research**

This study justified the role of spatial abilities in learning rigid body dynamics through research findings from closely related field of physics and from psychological and behavioral science. A large body of research has found spatial abilities play critical roles in learning many subjects in science, technology, engineering, and mathematics (STEM) education (Newcombe, 2010; Uttal & Cohen 2012; Uttal et al., 2013). However, the relationship between students’ spatial abilities and performances in engineering dynamics or engineering mechanics has not been investigated thoroughly. There have been few studies identifying the roles of spatial ability subfactors in understanding different abstract and complex motions in engineering dynamics as well. With respect to the importance of engineering mechanics in engineering education, future research should pay attention not only to the identification of the roles of spatial abilities but also to the interventions to improve students’ spatial abilities in engineering mechanics instruction.
Recommendations

Recommendations for Engineering Dynamics Instruction

The first two chapters in rigid body dynamics, Planar Kinetics and Kinematics of a Rigid Body, can be very difficult for many engineering dynamics students. It covers the knowledge of planar kinematics of a rigid body with many abstract concepts and requires students to have strong spatial abilities and good competency in mathematics to support their learning. The conceptual understanding and procedural skills addressed in this chapter play pivotal roles in acquiring new knowledge for the rest of rigid body dynamics course. Research findings consistently show that there are strong relationships between the use of visual aids and students’ conceptual understanding and between the use of worked examples and students’ procedural skills. In this regard, engineering dynamics instructors might consider applying instructional strategies which have various types of visual aids and interactive features to improve students’ learning. CSA modules can complement and enhance student learning in a variety of ways that other types of visual aids might not have.

Recommendations for Engineering Dynamics Instructional Design

Providing support structures for new learning interventions. In the present study, CSA modules have been designed and developed following the dynamic visualizations design principles suggested by Plass et al. (2009) and the implications from the literature review. The CSA modules provide students with a variety of support structures such as multiple presentations, user interactivity, mathematics equations representations, and gradual presentation of the solution in step-by-step procedure.
However, the student survey analysis indicates that the support structures employed in the CSA modules are still under the expectations of students. For example, many students indicated that they were unaware about the available options to run the modules, including the possibility of downloading the modules from Canvas and then running them in separate windows. They expected the modules to provide instant feedbacks for their inputs, have multiple-choice questions for learning assessment, and give clear instructions on how to use the modules. Future studies should include these support structures and embed them within the CSA modules, or provide them to learners during the instruction.

**Using “Compare & Contrast” strategy.** The use of “Compare and Contrast” is one of the most effective strategies to improve student learning (Marzano, Pickering, & Pollock, 2001). Some CSA modules in this study present two cases of a problem next together and provide students with the opportunities to compare and reconstruct their conceptual understanding. For example, in CSA Module 20 (Figure 3.2), the “Compare & Contrast” strategy is used to help students learn the principle of Conservation of Energy and apply it to two rigid bodies that have almost similar properties except their weight distribution. This module got many positive comments from students in both survey and interviews because it helped them understand how energy is distributed differently on look-alike rigid bodies.

**Adding strategies to nurture learners’ intrinsic motivation in interactive learning modules.** According to Malone, there are two types of motivation, intrinsic motivation which is driven from within the learner and extrinsic motivation which is driven from the instructor, and online learning materials should use strategies to stimulate
learner's intrinsic motivation (as cited in Ally, 2004). For online and off-campus learning environments, because students interact with course materials and study at their own pace, their intrinsic motivation plays a critical role in the learning process. If students are not motivated, they are unlikely to learn, regardless how effective the interactive web-based learning modules are. Ally suggested that the strategy to nurture learners’ intrinsic motivation should include activities and support structures for different learning styles. For instance, Ally cited Keller’s model, ARCS - attention, relevance, confidence, satisfaction - as an exemplar strategy to motivate online learners.

**Recommendations for Using Measuring Instrument to Assess Learning Outcome**

The learning gain was first introduced by Hake (1998) and became the popular measuring instrument for the learning of many academic fields. Based on this study, there are two following issues that future researchers should know about this measuring instrument before adopting this measuring instrument.

**Learning gain bias.** With the same gain score change (i.e. posttest score minus pretest score) the change at upper range (for example, a 30% change from 60% to 90%) will result in higher learning gain than this change at lower range (for example, a 30% change from 10% to 40%). Mark and Cumming (2007) called this bias as non-symmetric range of scores. This measuring instrument of learning gain is also biased toward the low pretest score learners (i.e. for two learners with the same posttest scores, the learner with lower pretest score always has higher learning gain than the learner with higher pretest score). The nonlinearity and nonsymmetry of learning gain instrument sometimes make the interpretation of students’ performance become complicated.
**Learning gain extremes.** If a student has a perfect posttest score of 100%, he or she will have a learning gain of 1, regardless of his or her pretest score except when pretest score is at 100%. On the contrary, if a student has a perfect pretest score of 100%, his or her single-student learning gain $g$ cannot be determined ($g = -\infty$) and recorded, regardless of his or her posttest scores (Figure 6.1). As a sequence, a lot of legitimate data become useless. Future researchers who intend to use learning gain as a measuring instrument and want to avoid the above two issues with this instrument might use it along with another measuring tool such as pre- to posttest gain change (or net gain).

*Figure 6.1.* Learning gain lines in the pretest versus posttest scores chart.
REFERENCES


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Appendix A. Systematic review procedure for CSA literatures in Engineering Mechanics Domain
Review Procedure

Literature searches were performed on EBSCOhost, ERIC, and Web of Science to identify primary articles reporting the use of interactive computer simulation and animations in engineering education. Primary articles were identified by using the following keywords: “engineering mechanics”, “engineering statics”, “engineering dynamics”, statics, or dynamics in combination with one of the following words, simulation, animation, and visual*. Relevant additional articles were identified by searching the references listed in the initial primary articles.

Other searches were also conducted on popular online databases such as Google Scholar, Journal of Engineering Education, annual American Association of Engineering Education and Frontiers in Education conference proceedings. Papers that addressed spatial visualization and interactive learning in statics and dynamics were also examined. Papers published before 1996 were excluded because their findings about learning experience with older computer applications may be not generalizable to studies that employ today’s computing technology. Studies that did not administer at least one data collection method on students’ learning experience with their CSA programs were also excluded.
Appendix B. Study Characteristics of CSA Literatures in Engineering Mechanics Domain
<table>
<thead>
<tr>
<th>No</th>
<th>Study</th>
<th>Sample Sizes</th>
<th>Area of study</th>
<th>Authoring tools/ Development software</th>
<th>Math Equation Steps</th>
<th>Experiment Design</th>
<th>Data Collection Measures</th>
<th>Common Reported Outcomes</th>
<th>Students' performance assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flori et al., 1996</td>
<td>50 (1994) 85 (1995)</td>
<td>ED</td>
<td>Commercial Package (1)</td>
<td>Y</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning * Gain Motivation</td>
<td>Students were assessed separately on two studies that used different usage patterns of the software</td>
</tr>
<tr>
<td>2</td>
<td>Cornwell, 2000</td>
<td>Other (2)</td>
<td>ED</td>
<td>Commercial Package (3)</td>
<td>N</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning * Gain Motivation</td>
<td>No assessment</td>
</tr>
<tr>
<td>3</td>
<td>Flori et al., 2002</td>
<td>71</td>
<td>ED</td>
<td>Macromedia Flash</td>
<td>Y</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning</td>
<td>No descriptive statistics reported on performance test data.</td>
</tr>
<tr>
<td>4</td>
<td>Hubing et al., 2002</td>
<td>51 (Study 4: 24 CG 27 EG)</td>
<td>ES</td>
<td>Adobe Flash</td>
<td>Y</td>
<td>Static Group Comparison Design</td>
<td>* Comment content analysis * Performance Test with quizzes’ score * Questionnaire</td>
<td>* Enhance learning * Gain Motivation</td>
<td>* No statistical difference on mean quiz scores between two groups. * Strong ceiling effect has been detected</td>
</tr>
<tr>
<td>5</td>
<td>Mazzei, 2003</td>
<td>100</td>
<td>ED</td>
<td>Commercial Package (4)</td>
<td>Y</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning * Gain Enjoyment</td>
<td>No assessment</td>
</tr>
</tbody>
</table>
Table B. (Cont’d)

<table>
<thead>
<tr>
<th>No</th>
<th>Study</th>
<th>Sample Sizes</th>
<th>Area of study</th>
<th>Authoring tool / Development software</th>
<th>Math Equation Steps</th>
<th>Experiment Design</th>
<th>Data Collection Measures</th>
<th>Common Reported Outcomes</th>
<th>Students’ performance assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Sidhu, Singh, &amp; Narainasamy, 2004</td>
<td>Other (5)</td>
<td>ED</td>
<td>Macromedia Flash</td>
<td>Y</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning * Enhance visualization * Gain Enjoyment</td>
<td>No assessment</td>
</tr>
<tr>
<td>7</td>
<td>Ariz et al., 2007</td>
<td>16</td>
<td>ED</td>
<td>Free sources (6)</td>
<td>Y</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning * Enhance spatial visualization * Gain Enjoyment</td>
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<tr>
<td>8</td>
<td>Fong, 2008</td>
<td>94</td>
<td>ED</td>
<td>Free sources (7)</td>
<td>N</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>(8)</td>
<td>No assessment</td>
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<tr>
<td>9</td>
<td>Stanley, 2008, 2009</td>
<td>70</td>
<td>ED</td>
<td>Adobe Flash</td>
<td>N</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning * Enhance visualization * Gain Enjoyment</td>
<td>No assessment</td>
</tr>
<tr>
<td>10</td>
<td>Dollar &amp; Steif, 2008</td>
<td>Other (9)</td>
<td>ES</td>
<td>Adobe Flash</td>
<td>Y</td>
<td>One Group Pretest- Posttest Design</td>
<td>* Performance Test with learning gain * Questionnaire</td>
<td>* Enhance learning * Enhance visualization</td>
<td>* Average learning gain of 0.62 for 4 modules, statistical significant * Learning gain of 0.5 for one module, not statistical significant.</td>
</tr>
</tbody>
</table>
Table B. (Cont’d)

<table>
<thead>
<tr>
<th>No</th>
<th>Study</th>
<th>Sample Sizes</th>
<th>Area of study</th>
<th>Authoring tools / Development software</th>
<th>Math Equation Steps</th>
<th>Experiment Design</th>
<th>Data Collection Measures</th>
<th>Common Reported Outcomes</th>
<th>Students’ performance assessment</th>
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<tr>
<td>11</td>
<td>Deliktas, 2011</td>
<td>383</td>
<td>EM</td>
<td>Macromedia Flash</td>
<td>Y</td>
<td>One Shot Case Study</td>
<td>* Questionnaire</td>
<td>* Enhance learning  * Enhance visualization  * Gain Enjoyment</td>
<td>No assessment</td>
</tr>
<tr>
<td>12</td>
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<td>304</td>
<td>ED</td>
<td>Adobe Flash</td>
<td>Y</td>
<td>One-Group Pretest- Posttest Design</td>
<td>* Comment content analysis  * Performance Test with learning gain  * Questionnaire</td>
<td>* Enhance learning  * Enhance visualization</td>
<td>* Average learning gains in four semesters vary from .36 to .85. The statistical significance is not reported</td>
</tr>
</tbody>
</table>

Note:  
(1): ToolBook by Asymetrix Corporation (now known as SumTotal Systems)  
(2): Numbers of students in questionnaire surveys (1994, 1999) were reported as “students in the courses,” no specific number found.  
(3): Working Model  
(4): MSC Adams  
(5): Number of students in this study was reported as “students in the courses,” no specific number found.  
(6): VRML, Java, and Jython  
(7): C++ and GDI+  
(8): No positive feedbacks found from the author’s survey.  
(9): Number of students in this study was reported as “students in two sections,” no specific number found.  
CG = Control group; EG = Experiment group; ED= Engineering Dynamics; ES= Engineering Statics; EM = Engineering Mechanics.
Appendix C. Summary of Literature Review
Table C.
Summary of Literature Review

<table>
<thead>
<tr>
<th>Study Characteristic</th>
<th>Frequency</th>
<th>Percentage</th>
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<tr>
<td><strong>Experiment Sample Size</strong></td>
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<tr>
<td>&lt; 50</td>
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<tr>
<td>51-100</td>
<td>5</td>
<td>42%</td>
</tr>
<tr>
<td>&gt; 101</td>
<td>3</td>
<td>25%</td>
</tr>
<tr>
<td>Other reported number</td>
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<tr>
<td><strong>Area of Study</strong></td>
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<td></td>
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<tr>
<td>Engineering Mechanics</td>
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<tr>
<td>Engineering Dynamics</td>
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<td>75%</td>
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<tr>
<td>Engineering Statics</td>
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<td>17%</td>
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<tr>
<td><strong>CSA usage in engineering mechanics instruction</strong></td>
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<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td>No</td>
<td>11</td>
<td>92%</td>
</tr>
<tr>
<td><strong>Worked examples usage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>7</td>
<td>58%</td>
</tr>
<tr>
<td>No</td>
<td>5</td>
<td>42%</td>
</tr>
<tr>
<td><strong>Authoring tools / Software Package</strong></td>
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<td></td>
</tr>
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<td>Adobe Flash</td>
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</tr>
<tr>
<td>Macromedia Flash (1)</td>
<td>4</td>
<td>33%</td>
</tr>
<tr>
<td>Commercial Package</td>
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<td>25%</td>
</tr>
<tr>
<td>Free Sources</td>
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<td>17%</td>
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<tr>
<td><strong>Mathematic equation steps</strong></td>
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<td></td>
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<tr>
<td>Yes</td>
<td>9</td>
<td>75%</td>
</tr>
<tr>
<td>No</td>
<td>3</td>
<td>25%</td>
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<tr>
<td><strong>Experiment Design</strong></td>
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<td></td>
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<td>One Group Pretest-Posttest Design</td>
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<td>One Shot Case Study</td>
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<td>67%</td>
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<tr>
<td>Static Group Comparison Design</td>
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<tr>
<td><strong>Data Collection Measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comment content analysis</td>
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<td>17%</td>
</tr>
<tr>
<td>Performance test</td>
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<tr>
<td>Questionnaire</td>
<td>12</td>
<td>100%</td>
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<tr>
<td><strong>Common reported outcomes</strong></td>
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<td></td>
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<tr>
<td>Enhance learning</td>
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<td>Gain enjoyment</td>
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<td>Gain motivation</td>
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<td><strong>Performance Assessment</strong></td>
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<td>Learning gains</td>
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<td>Average score &amp; grade A percentage</td>
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<tr>
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<td>17%</td>
</tr>
<tr>
<td>No performance test</td>
<td>7</td>
<td>67%</td>
</tr>
</tbody>
</table>

*Note: (1): Adobe has acquired Macromedia since April, 2005 (Abode, 2005).*
Appendix D. Internet enabled PCs – Penetration
Statistic: PC Penetration


Notes
1. Mature markets include United States, Canada, United Kingdom, France, Germany, Japan, Australia, and New Zealand.

Retrieved on April 4th, 2015 from:
Appendix E. Examples of Actionscript 3.0 Code to animate
the crank and slider mechanism of Module 13
How to use this flash file:

This flash file uses the following AS files:

Segment, Wall, Block, Arc, Arrows, ArcArrow, PutMyText, and Pivot.

At time of compilation, is is necessary to put this flash file and all AS files in the same folder.

The AS file Segment is adapted from the code in Chapter 14, *Foundation Actionscript 3.0 Animation: Making Things Move*, 2007, Keith Peters

by O. Ha 7/2012

// File Name: Module13.fla, Frame 3 //

```actionscript
import flash.display.Sprite;
import flash.events.Event;
import flash.geom.Point;
import flash.text.TextField;
import flash.text.TextFieldAutoSize;
import flash.text.TextFormat;
import flash.display.Stage;
import flash.sensors.Accelerometer;

//Parameter Values (makes the program robust for all slider widths)
var knobWidth:Number = Object(this).Slider1.sliderKnob.width;
var trackWidth:Number = Object(this).Slider1.sliderTrack.width;
var trackX:Number = Object(this).Slider1.sliderTrack.x;
var maxUnit = trackWidth – knobWidth;
var saved:Boolean = true;
var BX,BY,AX,AY,Chi,RX,RY,OmegaAB,VB:Number;

//calibration and output variables (not given a value until the if condition)
var calibration:Number = maxUnit / (maxValue - minValue);

// declare the bars' specifications (width, lengths, and their coordinations on the stage board)
var segmentWidth:Number = 20;
var segment0Length:Number = 90;  //short bar
var segment1Length:Number = 180;  //long bar
var anchorX:Number = 920;
var anchorY:Number = 200;
var pivot:Pivot;
```
var segment0:Segment;
var segment1:Segment;
var block:Block;
var wall0, wall1, wall2:Wall;
var arc0:Arc;
var arc1:Arc;
var myText:PutMyText = new PutMyText("60");
var arrow1:Arrows;
var arrow0:Arrows;
var cwArcArrow:ArcArrow;
var ccwArcArrow:ArcArrow;
var temp:uint = 60;
var omegaAB:Number;
var charA:MovieClip = new letterA();
var charB:MovieClip = new letterB();
stage.addEventListener(Event.ENTER_FRAME, onChange3);
stage.removeEventListener(Event.ENTER_FRAME, onChange4);

knobWidth = Object(this).Slider1.sliderKnob.width;
trackWidth = Object(this).Slider1.sliderTrack.width;
trackX = Object(this).Slider1.sliderTrack.x;  //the track's x position
maxUnit = trackWidth - knobWidth;              //max distance knob can go

calibration = maxUnit / (maxValue - minValue);

saved = true;
if (saved = true)
{
    sliderValue = (outputValue - minValue) * calibration + .6;
    Slider1.sliderKnob.x = sliderValue + trackX;
}

while (myStage4.numChildren > 0)
{
    myStage4.removeChildAt(0);
}

init();
gfx4.clear();

//--------- Start of function to draw mechanism details on Frame 3 ---------
function init():void
{
    pivot = new Pivot(26,18,0x66CCFF);
    myStage3.addChild(pivot);
}
pivot.rotation = 90;
pivot.x = anchorX;
pivot.y = anchorY;

segment0 = new Segment(segment0Length,segmentWidth,true,0x999999);
myStage3.addChild(segment0);
segment0.x = pivot.getPin().x;
segment0.y = pivot.getPin().y;
segment0.rotation = 150;
myStage3.removeChild(pivot);

myStage3.addChild(pivot);
pivot.x = anchorX;
pivot.y = anchorY;

segment1 = new Segment(segment1Length,segmentWidth,false,0x666666);
myStage3.addChild(segment1);
segment1.x = segment0.getPin().x;
segment1.y = segment0.getPin().y;
segment1.rotation = 150;

//Add slider and two walls on the stage board
block = new Block(40,60);
myStage3.addChild(block);
block.x = segment1.getPin().x;
block.y = segment1.getPin().y;
myStage3.removeChild(segment1);
myStage3.addChild(segment1);

wall1 = new Wall(20,150,0x66CCFF);
myStage3.addChild(wall1);
wall1.x = block.x - 30;
wall1.y = block.y;
wall1.rotation = 180;

wall2 = new Wall(20,150,0x66CCFF);
myStage3.addChild(wall2);
wall2.x = block.x + 30;
wall2.y = block.y;

myStage3.addChild(segment1);
segment1.x = segment0.getPin().x;
segment1.y = segment0.getPin().y;
Slider1.addEventListener(Event.ENTER_FRAME, onChange3);

arc0 = new Arc(pivot.getPin().x, pivot.getPin().y, 90, 130, 180, 0.5, 0x00FFFF);
    myStage3.addChild(arc0);
    arc0.alpha = 0;

cwArcArrow = new ArcArrow(pivot.getPin().x, pivot.getPin().y, 45, 70, 200, 1, true, 0xFF6600);
    myStage3.addChild(cwArcArrow);
    cwArcArrow.alpha = 0;

ccwArcArrow = new ArcArrow(pivot.getPin().x, pivot.getPin().y, 45, 70, 200, 1, false, 0xFF6600);
    myStage3.addChild(ccwArcArrow);
    ccwArcArrow.alpha = 0;

    myStage3.addChild(charA);
    charA.x = segment0.getPin().x - 5;
    charA.y = segment0.getPin().y + 35;

    myStage3.addChild(charB);
    charB.x = segment1.getPin().x - 45;
    charB.y = segment1.getPin().y;

    myStage3.addChild(myText);
    myText.x = 940;
    myText.y = 260;

gfx.lineStyle(1, 0, 1);
gfx.moveTo(segment0.x, segment0.y);
gfx.lineTo(segment0.x, segment0.y + segment0Length/2);
gfx.beginFill(0, 1);
gfx.drawCircle(segment0.x, segment0.y + segment0Length/2, 2);
gfx.endFill();
}

//--------End of Function to draw mechanism details on Frame 3-----

onChange3(event:Event):void
{
var Bx:Number = -0.52;
var By:Number = Math.sqrt(0.16 - Math.pow((-0.52 + 0.2*Math.sin((outputValue)*Math.PI/180)), 2)) - 0.2*Math.cos((outputValue)*Math.PI/180);
var Ax:Number = -0.2*Math.sin((outputValue)*Math.PI/180);
```javascript
var Ay:Number = -0.2*Math.cos((outputValue)*Math.PI/180);
var test:Number = Math.pow((-0.52+0.2*Math.sin((outputValue)*Math.PI/180)), 2);
var chi:Number = Math.atan((By - Ay)/(Bx - Ax));
var rX:Number = -0.4 * Math.cos(chi*Math.PI/180);
var rY:Number = -0.4 * Math.sin(chi*Math.PI/180);
var omegaAB:Number = 0.6*Math.cos((outputValue)*Math.PI/180))/rY;
var vB:Number = 0.6*Math.sin((outputValue)*Math.PI/180) - omegaAB*rX;
sliderValue = Slider1.sliderKnob.x - trackX;
outputValue = sliderValue / calibration + minValue;
outputValue = int(outputValue*10)/10;
thetaText.text = outputValue.toFixed(1);
segment0.rotation = outputValue + 90;
segment1.x = segment0.getPin().x;
segment1.y = segment0.getPin().y;
segment1.rotation = 180 - chi * 180 / Math.PI;
block.x = segment1.getPin().x;
block.y = segment1.getPin().y;
arc0.alpha = 1;

if ((outputValue > temp)|| (outputValue==90))
{
    ccwArcArrow.alpha = 0;
    cwArcArrow.alpha = 1;
    temp = (outputValue-1);
}
else
{
    ccwArcArrow.alpha = 1;
    cwArcArrow.alpha = 0;
    temp = (outputValue + 1);
    temp = 60;
    ccwArcArrow.alpha = 0;
    cwArcArrow.alpha = 0;
}
myText.display_txt.text = outputValue.toString();
charA.x = segment0.getPin().x - 5;
charA.y = segment0.getPin().y + 35;
charB.x = segment1.getPin().x - 45;
charB.y = segment1.getPin().y;
```
package
{
    import flash.display.Sprite;
    public class ArcArrow extends Sprite
    {
        var deg_to_rad = 0.0174532925;
        public function ArcArrow(center_x, center_y, radius, angle_from, angle_to, lineThickness, wise: Boolean = true, color:Number=0)
        {
            var angle_diff = angle_to - angle_from;
            var steps = Math.round(angle_diff);
            var angle = angle_from;
            var px=center_x+radius*Math.cos(angle*deg_to_rad);
            var py=center_y+radius*Math.sin(angle*deg_to_rad);
            var tempx1,tempx2,tempy1,tempy2,lastx,lasty:Number = 0;
            graphics.moveTo(px,py);
            graphics.lineStyle(lineThickness, color);
            for (var i:int=1; i<=steps; i++)
            {
                angle = angle_from + angle_diff / steps * i;
                if (wise)
                {
                    if (i == steps-7)
                    {
                        tempx1= center_x+(radius-4)*Math.cos(angle*deg_to_rad);
                        tempy1 = center_y+(radius-4)*Math.sin(angle*deg_to_rad);
                        tempx2= center_x+(radius+ 4)*Math.cos(angle*deg_to_rad);
                        tempy2 = center_y+(radius+4)*Math.sin(angle*deg_to_rad);
                        } //wise
if (i == steps) {
    lastx = center_x + radius * Math.cos(angle * deg_to_rad);
    lasty = center_y + radius * Math.sin(angle * deg_to_rad);
} else {
    if (i == 7) {
        tempx1 = center_x + (radius - 4) * Math.cos(angle * deg_to_rad);
        tempy1 = center_y + (radius - 4) * Math.sin(angle * deg_to_rad);
        tempx2 = center_x + (radius + 4) * Math.cos(angle * deg_to_rad);
        tempy2 = center_y + (radius + 4) * Math.sin(angle * deg_to_rad);
    }
    graphics.lineTo(center_x + radius * Math.cos(angle * deg_to_rad), center_y + radius * Math.sin(angle * deg_to_rad));
}
if (wise) {
    graphics.moveTo(lastx, lasty);
    graphics.lineTo(tempx1, tempy1);
    graphics.moveTo(lastx, lasty);
    graphics.lineTo(tempx2, tempy2);
} else {
    graphics.moveTo(px, py);
    graphics.lineTo(tempx1, tempy1);
    graphics.moveTo(px, py);
    graphics.lineTo(tempx2, tempy2);
}
}
.package
{
    import flash.geom.*;
    import flash.display.*;

    public class Segment extends Sprite
    {
        private var color:uint;
        private var segmentWidth:Number;
        private var segmentHeight:Number;
        private var centerLine: Boolean;
        private var vx: Number = 0;
        private var vy: Number = 0;

        public function Segment(segmentWidth:Number, segmentHeight:Number, centerLine:Boolean = false, color:uint = 0xffffff)
        {
            // constructor code
            this.segmentWidth = segmentWidth;
            this.segmentHeight = segmentHeight;
            this.centerLine = centerLine;
            this.color = color;
            init();
        }

        public function init():void
        {
            //graphics.beginFill(color, 0.75);
            var fillType:String = GradientType.LINEAR;
            var colors:Array = [color,0xffffff];
            var alphas:Array = [1,1];
            var ratios:Array = [0x00,0xFF];
            var matr:Matrix = new Matrix();
            matr.createGradientBox(127, 190);//possible value range [0, 63, 127, 190, 255]
            var spreadMethod:String = SpreadMethod.REFLECT;
            graphics.lineStyle(0);
this.graphics.beginGradientFill(fillType, colors, alphas, ratios, matr, spreadMethod);

graphics.drawRoundRect(-segmentHeight/2, -segmentHeight/2, segmentWidth + segmentHeight, segmentHeight, segmentHeight, segmentHeight);
  graphics.endFill();

// draw two pins;
  graphics.beginFill(0xffffff, 0.85);
  graphics.drawCircle(0,0,segmentHeight*0.4);
  graphics.drawCircle(segmentWidth,0,segmentHeight*0.4);
  graphics.endFill();
  graphics.beginFill(0xffffff, 0.75);
  graphics.drawCircle(0,0,segmentHeight/6);
  graphics.drawCircle(segmentWidth,0,segmentHeight/6);
  graphics.endFill();

if (centerLine) // draw center line
{
  // draw center line along bar
  graphics.lineStyle(1,0, 0.5);
  graphics.moveTo(0,0);
  graphics.lineTo(segmentWidth/2, 0);
  graphics.beginFill(0, 1);
  graphics.drawCircle(segmentWidth/2, 0, 2);
  graphics.endFill();

  // draw vertical center line
  graphics.lineTo(0, segmentWidth/2);
  graphics.beginFill(0x0000FF, 1);
  graphics.drawCircle(0, segmentWidth/2, 3);
  graphics.endFill();
}

public function getPin():Point
{
  var angle:Number = rotation * Math.PI / 180;
  var xPos:Number = x + Math.cos(angle) * segmentWidth;
  var yPos:Number = y + Math.sin(angle) * segmentWidth;
  return new Point(xPos, yPos);
}
Appendix F. IRB Approval
INFORMED CONSENT

The Effects of Interactive Computer Simulation and Animation on Student Learning of Rigid Body Dynamics: A Mixed Method Study

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. The proposed duration of this study for all research activities to be completed is about 4 years. A student researcher Oai Ha 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 letter) 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 this Informed Consent letter) 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 an 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 those dynamic problems; the other group will be provided computer simulations to help solve the dynamic problems. The think-aloud, problem-solving process of students in these groups will be video-recorded. The video transcripts as well as your written responses to those dynamic 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 dynamic 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 dynamic problems with or without the assistance of computer simulations.
INFORMED CONSENT

The Effects of Interactive Computer Simulation and Animation on Student Learning of Rigid Body Dynamics: A Mixed Method Study

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 take approximately one hour to complete think-aloud, problem-solving activities (if you are willing to participate in these activities). Your participation in this research will not impact your class grade.

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 study may involve some added risks or discomforts. These include: The students who do not perform well in pre-post tests may feel a little bit frustration about their learning. This frustration is typical when a learner learns any subject of study. Other than this potential frustration, there is no other risk. Student participation will not impact their 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 will 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 Ning Fang by phone at (435) 797-2948 or by e-mail at ning.fang@usu.edu

Extra Cost(s) There will be no any additional costs in participating.

Payment/Compensation If you choose to participate in the study (either Phase 1 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.
INFORMED CONSENT
The Effects of Interactive Computer Simulation and Animation on Student Learning of Rigid Body Dynamics: A Mixed Method Study

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 maintain confidentiality. 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. After the data have been gathered and the analysis is completed, the coding sheet linking you to this study will be destroyed in the approximate date of December 2015. 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 in the approximate date of December 2015.

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
(435) 797-2948; ning.fang@usu.edu

Oai Ha, Student Researcher
eco.andy@gmail.com

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

Participant’s signature

Date

Participant’s last name, first name (please print)
Appendix G. Survey Questions
STUDENT SURVEY

I. Accessibility and functionality of CSA modules

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

2. How often did you 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) Strongly agree
   B) Agree
   C) Neutral
   D) Disagree
   E) Strongly disagree

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:

II. Motivation and confidence of student learning

9. Do you agree with the statement: "Overall, these modules increase my confidence for learning engineering dynamics"?
   A) Strongly agree
   B) Agree
   C) Neutral
   D) Disagree
   E) Strongly disagree

10. Do you agree with the statement: "Overall, these modules increase my motivation for learning engineering dynamics"?
    A) Strongly agree
    B) Agree
    C) Neutral
    D) Disagree
    E) Strongly disagree

III. 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?

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

12. Among the 10 modules for rigid-body dynamics (Modules 13-22 that cover textbook chapters 16, 17, 18, and 19), which technical dynamics problems designed for modules do you like most? Select all that apply:
   1) Technical problem addressed in Module 13
   2) Technical problem addressed in Module 14
   3) Technical problem addressed in Module 15
   4) Technical problem addressed in Module 16
   5) Technical problem addressed in Module 17
   6) Technical problem addressed in Module 18
   7) Technical problem addressed in Module 19
8) Technical problem addressed in Module 20
9) Technical problem addressed in Module 21
10) Technical problem addressed in Module 22

13. Explain why you like those technical problems that you have selected in answering the above Rigid-Body Dynamics Question.

14. Among Modules 13-22 for rigid-body 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 13-22 for rigid-body dynamics?
   A) Very easy 5
   B) Easy 4
   C) Neutral 3
   D) Difficult 2
   E) Very difficult 1

V. Student learning outcomes associated with CSA modules

16. Among Modules 13-22 for rigid-body dynamics, which modules did you learn the most from? Why?

17. Among Modules 13-22 for rigid-body dynamics, which modules did you learn the least from? Why?

18. Do you agree with the statement: "Overall, Modules 13-22 increase my conceptual understanding of rigid-body dynamics problems"? "Conceptual understanding" means the understanding of dynamics concepts and principles.
   A) Strongly agree 5
   B) Agree 4
   C) Neutral 3
   D) Disagree 2
   E) Strongly disagree 1

19. Please provide a few examples of how Modules 13-22 increase your conceptual understanding of rigid-body dynamics problems.

20. Do you agree with the statement: "Overall, Modules 13-22 increase my procedural skills of solving rigid-body 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) Strongly agree 5
B) Agree 4
C) Neutral 3
D) Disagree 2
E) Strongly disagree 1

21. Please provide a few examples of how these Modules 13-22 increase your procedural skills of solving rigid-body dynamics problems.

22. Do you agree with the statement: "Overall, Modules 13-22 increase my learning of rigid-body 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) Strongly agree 5
B) Agree 4
C) Neutral 3
D) Disagree 2
E) Strongly disagree 1

23. How do you compare the ways in which you learn from Modules 13-22 and from textbook problem examples?

24. What challenges did you have in using Modules 13-22 to learn particle dynamics?

25. Provide your comments on how to make the design of Modules 13-22 better. Also provide any other comments that you want us to be aware of.

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

26. We have used computer simulation and animation as "bonus homework" in this semester. This might not be the best way to use computer simulation and animation. Provide your final comments on how to more effectively use computer simulation and animation in teaching and learning dynamics, or on which dynamics topics you want to see more computer simulation and animation modules.

Data types
1. Likert questions: 6, 9, 10, 15, 18, 20, 22
2. Multiple choice questions: 1-5, 7, 12
3. Open question: 8, 11, 13, 14, 16, 17, 19, 21, 23, 24, 25, 26
Appendix H. Coding table
<table>
<thead>
<tr>
<th>Features</th>
<th>Special notes for coding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Technical design</strong></td>
<td></td>
</tr>
<tr>
<td><strong>1.1. Graphics User Interface</strong></td>
<td></td>
</tr>
<tr>
<td>1.1.1. Vertical</td>
<td></td>
</tr>
<tr>
<td>1.1.2. Horizontal</td>
<td></td>
</tr>
<tr>
<td><strong>1.2. Visualization</strong></td>
<td>Any technical issue related to hardware or software, including accessing, viewing, running modules in Canvas environment.</td>
</tr>
<tr>
<td><strong>1.3. Hardware or software limitations</strong></td>
<td>Any interact with modules, including manipulation of parameters, to experiment the changes in animation’s motions and final outcomes.</td>
</tr>
<tr>
<td>1.3.1. Download CSA from Canvas</td>
<td></td>
</tr>
<tr>
<td>1.3.2. Access/Viewing CSA on Canvas</td>
<td></td>
</tr>
<tr>
<td>1.3.3. CSA runs slow on Canvas</td>
<td></td>
</tr>
<tr>
<td>1.3.4. Unresponsive features</td>
<td></td>
</tr>
<tr>
<td><strong>1.4. Interactivity</strong></td>
<td>The possibility to access Modules from other electronics devices (iPad) rather than PCs</td>
</tr>
<tr>
<td>1.4.1. Manipulation/Interaction</td>
<td></td>
</tr>
<tr>
<td><strong>1.5. Editing limitations</strong></td>
<td>Any opinion other than the previous 6 categories</td>
</tr>
<tr>
<td>1.5.1. Numerical Errors</td>
<td></td>
</tr>
<tr>
<td>1.5.2. Wording</td>
<td></td>
</tr>
<tr>
<td>1.5.3. Text use (font, size, color)</td>
<td></td>
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<tr>
<td><strong>1.6. Playable on other devices</strong></td>
<td></td>
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<tr>
<td><strong>1.7. Others</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2. Instructional design limitations</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2.1. General contents</strong></td>
<td></td>
</tr>
<tr>
<td>2.1.1. Too easy</td>
<td></td>
</tr>
<tr>
<td><strong>2.2. Integrate assessments or quizzes in the modules</strong></td>
<td>Integrate assessments, short quizzes, and provide timely feedback</td>
</tr>
<tr>
<td>2.2.1. Quick quizzes</td>
<td></td>
</tr>
<tr>
<td>2.2.2. Answer feedback</td>
<td></td>
</tr>
<tr>
<td><strong>2.3. Scaffolding strategies</strong></td>
<td>Provide hints, tips, review options</td>
</tr>
</tbody>
</table>
2.4. Math equation editor

Provide tools to create mathematic notation and enter equations

3. Usage Pattern

3.1. Running pattern

3.1.1. Solve, Watch, Check (SWC)

SWC: Students solve the BHs first without the modules’ help. Then they run, watch, and interact with the modules. They may use the modules to experiment the quantitative change of the final outcomes by changing parameters on scrollbars, and make any inference to their specific BHs.

3.1.2. Watch, Solve, Check (CSW)

WSC: Students run, watch, and interact with the modules first. Then they solve the BHs based on the framework setup in the modules. Finally, they may use the modules to experiment the quantitative change of the final outcomes by changing parameters on scrollbars, and make any inference to their specific BHs.

3.1.3. Combined method (S/WC)

S/WC: Students use both strategies depending on their time budgets and their understandings about the module’s contents.

3.2. Locations of access

3.2.1. Access at Home

3.2.2. Access at Campus

3.3. Group/Individual

3.3.1. Run module with group

3.3.2. Run module individually

3.4. Purposes, & length of access

3.4.1. Assess for specific homework

Run modules only once to finish bonus homework

3.4.2. Assess for homework & exam

Run modules multiple times

3.4.3. Prior exposure to animation

Rough number of minutes

3.5. Preferences

3.5.1. Most liked module

List module numbers

3.5.2. Most liked feature

List features

3.5.3. Most learned module

List module numbers

3.5.4. Most difficult module

List module numbers

3.5.5. Least liked module

List module numbers

3.5.6. Least liked feature

List features

3.5.7. Least learned module

List module numbers

4. Benefits

4.1. Improve conceptual understanding

4.1.1. Variables and relationships

By exploring the relationship of variables

4.1.2. Visualization/animation

By watching animation

4.1.3. Interactivity

By manipulating scrollbar to control animation and input
4.2. Improve procedural skills
   4.2.1. Step-by-step
   By step-by-step format
   4.2.2. Deriving/setting up math equations
   By learning the approach of setting up equations
   4.2.3. Drawing free-body-diagram
   By learning the FBD
4.3. Enhance motivation to learn
4.4. Enhance confidence to learn