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Intelligent Statics Tutoring Systems as Tools for Undergraduate Mechanical Engineering
Education

A Thesis submitted in partial satisfaction
of the requirements for the degree of

Master of Science

in

Mechanical Engineering

by

Reyna De Los Angeles Garcia

March 2014

Thesis Committee:

Dr. Thomas Stahovich, Chairperson

Dr. Marko Princevac

Dr. Guillermo Aguilar

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The Thesis of Reyna De Los Angeles Garcia is approved:

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University of California, Riverside

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To my wonderful, loving fiancé and favorite fellow mechanical engineer, Vitali Brand,
for helping me keep my sanity relatively intact through the years.

To my supportive parents and brother, thank you for always believing in me and cheering
me on in spite of everything.

In memory of my beloved grandmother, Maria de Jesus Oropeza.

ABSTRACT OF THE THESIS

Intelligent Statics Tutoring Systems as Tools for Undergraduate Mechanical Engineering Education

by

Reyna De Los Angeles Garcia

Master of Science, Graduate Program in Mechanical Engineering
University of California, Riverside, March 2014
Dr. Thomas Stahovich, Chairperson

This thesis presents two intelligent tutoring systems for statics, Newton's Tablet and Newton's Pen, and the results from experiments examining their value as tools for undergraduate mechanical engineering education. The systems are unique in that they break down the problem-solving process in a manner which makes conceptual decisions explicit. This allows for focused feedback to correct conceptual errors that would otherwise lead to incorrect free-body diagrams and equilibrium equations. The intelligent tutoring systems were designed to help ease the intrinsic cognitive load associated with the first difficult engineering subject that mechanical engineering students encounter. Results from experiments indicate that the problem-solving method employed is beneficial, and that Newton's Tablet is more effective than Newton's Pen.

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Chapter 1

Introduction

Intelligent tutoring systems have played an increasingly significant role in education as computers have become a prevalent part of everyday life. This research has focused on developing intelligent tutoring systems with natural user interfaces. In particular, this research explored tutoring systems that can be operated with a natural pen-based interface as well as a standard keyboard and mouse interface. The tutoring systems we developed employ a scaffolded, step-by-step problem-solving approach which helps the student to explicitly examine every decision in the problem-solving process. This benefits the student and also helps the tutoring systems to better understand the student's behavior so that precise feedback can be provided whenever necessary.

We created the systems presented here, Newton's Tablet and Newton's Pen, to help students learn statics, a sub-discipline of mechanics which deals with stationary bodies and forces in equilibrium. Statics is a required course for all mechanical and civil engineers. It is taken early in the curriculum because it serves as a foundation for later courses. Because of the importance of this subject for success in the curriculum, it is important that students master the concepts of statics.

The design and development of the Newton's Pen and Newton's Tablet systems was a group effort, in which I was responsible for a number of general and domain-specific tasks. I helped to select, modify, and create the materials for the tutoring systems, including the conceptual help and error feedback messages as well as the problems used by both Newton's Pen and Newton's Tablet. I also helped to develop the work-checking logic for the graphical representations used to build the equilibrium equations, and even played a role in the initial proof-of-concept versions of gesture and trace recognizers. A complete description of how the systems work can be found in the thesis of Levi Lindsey [8].

My work, in addition to the contributions to the design and development of the systems, from initial storyboards to system deployment, involved their evaluation based on experiments carried out in a statics course and a separate user study conducted at the University of California, Riverside. The studies were meant to test the ease of use and effectiveness as learning tools of the latest versions of Newton's Pen and Newton's Tablet. The evaluation of the tutoring systems based on the results from the studies is my focus in this thesis.

One of the goals in education research is to ensure that the process of acquiring knowledge happens in a manner which is "efficient, effective, and appealing" [9]. Designing and creating traditional and technological tools that impose no undue extraneous cognitive load on the learner, is one effective approach to aiding the learning process [2]. This can be especially useful when the material at hand is inherently difficult and already carries with it high intrinsic cognitive load [2].

The dramatic increase in availability of computers and internet access in the past few decades has fueled the interest in technological tools for education, including engineering education. Computer Assisted Instructional (CAI) systems often ask a student a series of questions about material that has been presented and then tells the student whether or not the answers are correct [15]. This method can offer only a summative assessment of what the students have learned, providing little insight about the student's problem-solving process, and focusing on just the final expected result or answer [11].

Guiding the problem-solving process for particularly difficult or complex subjects can require a lot of one-on-one time and attention from an experienced instructor. This is unfortunately not always possible. Expert instructors guide a student's problem-solving by adapting to that individual's thought-process and offering very specific feedback and suggestions at each step. That is, the instructor must be familiar with the steps that need to be taken and decisions that need to be made to arrive at the correct solution. The instructor must be aware of common errors and pitfalls and know what feedback to give. This kind of support is known as scaffolding [14].

Intelligent Tutoring Systems (ITSs) are computer systems designed to provide this type of scaffolding without need for intervention by a human instructor [10]. ITSs have been developed for a wide range of different domains including electrical engineering and physics [1, 16]. There have also been several tutorial systems for statics, including both "intelligent" and "non-intelligent" systems [12, 13, 4, 5, 6, 7, 3]. These systems provided various levels of scaffolding.

The systems most relevant to the work presented here are the ones developed by Chia-Keng Lee and Josiah Jordan [4, 5] and WeeSan Lee et al. [7]. WeeSan Lee's statics tutoring system was also called Newton's Pen. However, for the remainder of this thesis, Newton's Pen and Newton's Tablet will refer to the versions described in this thesis and in the thesis of Levi Lindsey [8]. WeeSan Lee's system ran on the Leapfrog FLY pen, an early digital pen, and a set of prepared worksheets [7]. Chia-Keng Lee and Josiah Jordan's system ran on tablet PCs [4, 5].

Upon evaluating the effectiveness of the Lee and Jordan's system, we hypothesized that a more fine-grain problem-solving decomposition was needed to create a more effective instructional tool. Additionally, we hypothesized that separating conceptual reasoning from the mathematical expression of the concepts would facilitate learning. Our new tutoring systems were designed to test these hypotheses.

Chapter 2 provides an overview of previous work on intelligent tutoring systems, specifically those which pertain to the domain of interest, namely statics. Chapter 3 gives an overview of how our tutoring systems work, Chapter 4 discusses the designs of our experiments, Chapter 5 presents the results of the experiments, and Chapter 6 presents conclusions based on our results.

Chapter 2

Background

Prior to developing the new tutoring systems, we conducted a study examining the usefulness of an intelligent tutoring system for statics developed by Lee and Jordan [4, 5]. In this study, the system was used by 27 students during the winter 2012 offering of ME10 (Statics) at UC Riverside. These randomly selected students attended an hour-long session each week where they learned how to set up free-body diagrams and equilibrium equations using Lee and Jordan's system [4, 5]. They attended these sessions rather than attending traditional discussion sections lead by the course teaching assistants. The tutoring sessions were offered three times per week, with 9 students assigned to each.

Every week, the students were encouraged to complete as many problems as they could during their session. These sessions were supervised by at least one graduate student, and sometimes two or three. Students were free to ask questions about system usage as well as statics concepts that might not be clear from the feedback provided by the software.

Lee and Jordan's system, which was run on HP tablet PCs, included both single-body and multi-body problems [4, 5]. It was designed in a way that allowed the user a lot

of freedom in drawing free body diagrams and writing equilibrium equations. After the initial tracing of relevant bodies, the user could simply start drawing force arrows wherever they saw fit. Error feedback was provided in the form of a separate window that would open and display a list of errors, each with a hierarchical list of conceptual help. After the user had drawn the correct free body diagram(s), a blank space to write complete equilibrium equations, including any trigonometric functions, appeared. A full description of this tutorial system is found in Chia-Keng Lee [5] and Josiah Jordan's theses [4].

We interacted with the students and answered their questions about statics concepts and system usage while they gave us verbal feedback about the usability of the system during the weekly sections. We determined that the free form approach employed by this system might be better suited to advanced rather than novice students. The system required the users to understand the necessary problem-solving steps. Students that were struggling with statics concepts were more likely to use trial and error to obtain the correct solutions as opposed to using the feedback from the program to learn the concepts. Our observations in this experiment played a key role in guiding the development of our statics tutorial systems.

At the end of the quarter the students in the experimental sections were asked to fill out an attitudinal survey based on their experiences with the tutorial system. We used a similar survey in our other experiments.

Chapter 3

System Overviews

This chapter describes the tutoring systems examined in this work. Please refer to the thesis of Levi Lindsey [8] for an in depth description of both Newton's Pen and Newton's Tablet. This chapter also offers an overview of the traditional approach students use to solve statics problems, which our systems aim to facilitate and scaffold.

3.1 Traditional Statics Solutions

Traditional pen and paper solutions for the types of problems covered in undergraduate statics courses require a free-body diagram and corresponding equilibrium equations. In the following figure we see a sample solution that, to a novice, may seem intimidating at first glance. The free-body diagram consists of a single rectangular rigid body with a weight force, a tension force, and a pivot joint. A moment equation and two force equations are enough to solve for all of the unknowns. Finding the appropriate perpendicular distances for the moment arms is often a difficult challenge for novice students. Perhaps the most seemingly daunting part of this is finding the correct mathematical expression for these distances once they have been identified. Additionally,

with the background in geometry and trigonometry that students in statics are required to have, expressing these distances mathematically should not be a challenge, but often is. The key concepts required for this and similar problems are: selecting the correct rigid body to diagram, modeling all forces relevant to this body, finding all forces with components applicable to the force and moment equations, identifying the correct moment arms, and remembering that the sum of all forces and moments in statics is always equal to zero. Once the crucial decisions concerning those concepts have been made, solving for an unknown is a matter of algebra.

Unfortunately, this traditional model requires students that have not yet mastered all of these concepts to make many of those key decisions simultaneously and in an implicit manner. This is often overwhelming and one mistake can easily affect the rest of the solution. It is therefore important to pinpoint and understand which aspects of a solution each student is struggling with. For instance, extra forces and missing forces on free-body diagrams are among the most common errors that then lead to incorrect or incomplete equations. However, by just looking at a diagram on paper, instructors have no way of knowing the misunderstandings that led to a student's mistake. For example, if a student modeled a pivot joint with just one force arrow, this could be because the student does not know the difference between a pivot joint and a roller joint. Alternatively, the student may have recognized the object as a pivot, but not known how to model it. Requiring the student to label all supports prior to drawing force arrows would have forced this student to make an important mental distinction between rollers and pivots

and the way they are modeled, or at least given the instructor a glimpse into their thought process so that he or she could offer the appropriate feedback.

Because the solution to a statics problem consists of only rough diagrams and mathematical expressions, which are often convoluted, it is difficult and burdensome for an instructor to follow a student's thought processes and identify the conceptual errors. It is also a burden for a student, especially a beginner, to have to make many important decisions about their solution path all at once. Breaking down the problem-solving process into discrete conceptual steps eliminates the confusion and lightens the burden of both students and instructors.

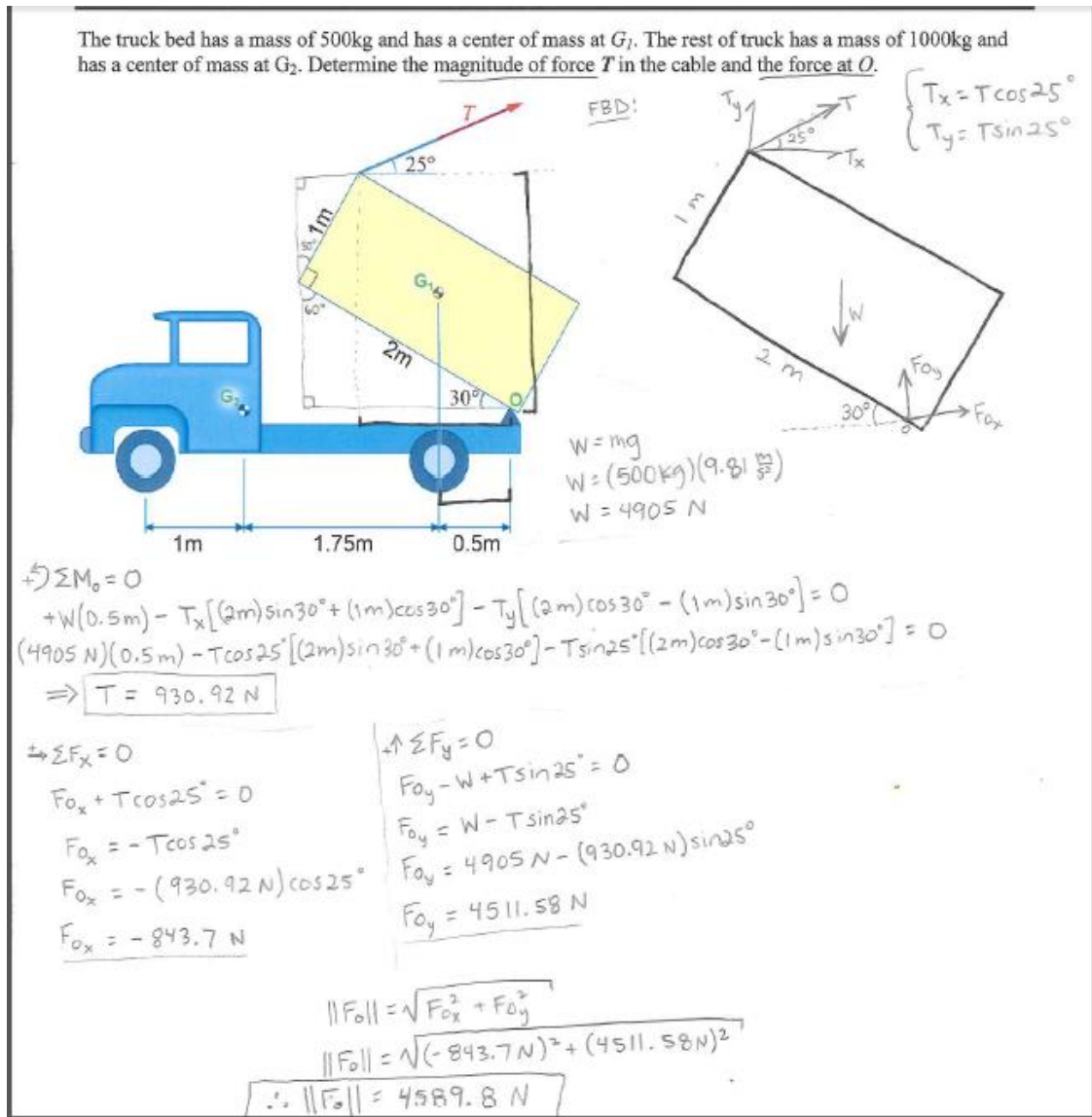


Figure 3.1: An example of a traditional solution to an undergraduate statics problem.

3.2 Newton's Tablet

Newton's Tablet takes the main underlying decisions required to solve a statics problem and dedicates a series of different problem-solving stages to making those decisions explicit. Newton's Tablet is a standalone application that can be operated using either a traditional mouse and keyboard interface or with a stylus interface.

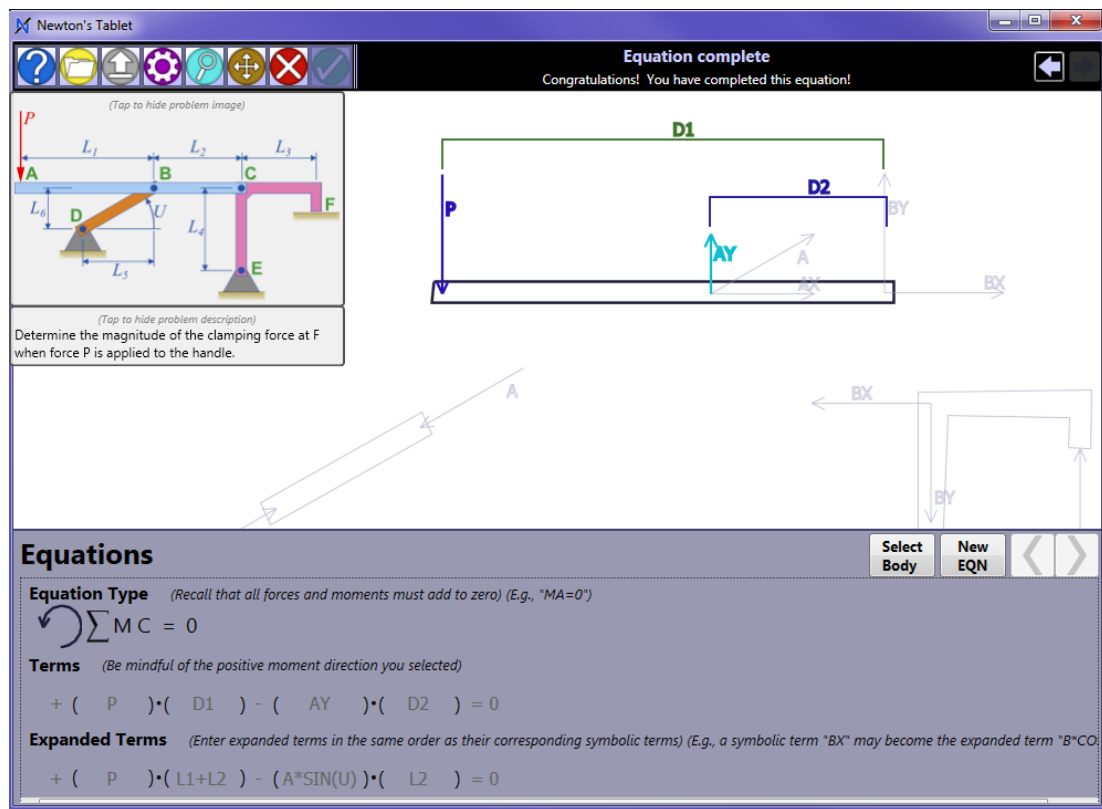


Figure 3.2: A screenshot of a completed Newton's Tablet problem.

To begin using the system, one must first pick a problem from the drop-down menu on the upper left side of the tool bar. A problem description and accompanying image will then appear on the left-hand side of the workspace. The instruction bar (black

bar) at the top of the main window displays instructions for the user. For example, when a new problem is started, the user is prompted to trace a body to form the free-body diagram. When the user is satisfied with the trace, he or she can click the “check body trace” button on the left-hand side of the workspace, causing the system to check the work. If the trace is determined to be correct, the instruction bar will ask the user to select “points of interaction,” the locations on the body where the forces act. After the user identifies all of the interaction points, the user clicks the green “check work button” to receive tutorial feedback. If the user has made errors, a yellow highlight will appear over the affected area. Clicking this highlight brings up a popup bubble with feedback specific to that error. The message bubbles also contain links to general information about statics concepts and system usage. Errors may be corrected by adding any missing interaction points or by clicking the red “erase button” and drawing a stroke through work that needs to be deleted. Once all points of interaction have been identified, the user is prompted to label each interaction to indicate its type. For example, interactions can be from applied force, roller joints, weight forces, tension forces, etc. The force types are assigned by selecting an interaction and then selecting the type from a list. Again, the user clicks the “check work” button to get feedback on the interaction types. For multi-body problems, the user is then prompted to identify any Newton’s third law pairs and two-force members. As before, the user clicks the “check work” button to get feedback on this work. To complete the free body diagram, the user must draw and label arrows representing the interactions identified in the previous stage. Force arrows are drawn with one stroke from tail to head. Forces must be labeled with one to three alphanumeric

characters. As with the other stages, the user clicks the “check work” button to get feedback on the force arrows and labels. If all of the arrows are correctly drawn and labeled, the free-body diagram is complete.

Once the free body diagrams are complete, the equilibrium equation panel then appears at the bottom of the workspace. Using a virtual or physical keyboard, the student then fills in the equation type text boxes in the equation panel. This specifies whether the student will be working on a force balance equation or a moment equation about a particular point. After deciding on an equation type and checking to see that it is a valid equation that has not been previously entered, the instruction bar will prompt the user to click on the force arrows of all forces relevant to the equation at hand. If the work checking code determines this to be correct, a popup will ask if there are forces that need to be broken down into component that are aligned with the x and y axis. If this is indeed the case then force arrows are drawn to represent these components. If the current equation is a moment equation then the instruction bar will ask that moment arm distances be drawn and labeled. This is done by using square brackets to represent the perpendicular distance from each force relevant origin of the moment equation. Once all of the work is done with the free-body diagram, the bottom panel will bring up text boxes in which to type in a symbolic representation of the equation using the labels that have been given to the forces and any moment arm brackets. The check work button will ensure that the entered equation terms are correct, if not, it will highlight the text boxes containing an error. Clicking on any highlighted text boxes will bring up the familiar error help messages. Next, a similar set of text boxes will appear on the bottom panel but

will expect an expanded version of the equation, one with more complete mathematical expressions instead of the user-selected symbolic terms from before. The terms can have trigonometric components and make use of any appropriate geometric information provided in the problem description. Finally, if the expanded equation is correct, the user can click on a button on the right of the bottom panel to begin work on a new equation or navigate back to any previously completed ones using the arrow buttons.

3.3 Newton's Pen

Newton's Pen was developed to run on Livescribe digital pens and make use of preprinted dot-patterned worksheets. This version of the statics tutorial system helped guide students to draw free-body diagrams in a manner similar to Newton's Tablet, but because of limitations inherent to the pen, equilibrium equations were not supported. The Livescribe digital pen uses a time-stamped record of the coordinates of pen strokes on the dot-patterned paper as input and words on its small text display as well as sounds to communicate with the user.

There are two worksheets required per problem, the first has the problem description and accompanying image as well as the buttons needed to interact with the system, including a keyboard, erase mode button, check work button, and interaction type label buttons. The other worksheet provides two workspaces, each with a "ghost" of the problem description image over which to trace and draw all necessary work.



Figure 3.3: A Livescribe digital pen similar to those used for Newton's Pen. It has a small dynamic text display and a small built-in speaker among other capabilities.

Tutorial
Problem Description
Tutorial

The diagram shows a horizontal blue beam supported by a roller at point A and a pivot at point B. Three downward-pointing red arrows represent forces: P at point C, F at point D, and R at point E. Green labels A, B, C, D, and E mark the respective points. Blue dimension lines below the beam indicate distances: L_1 from A to C, L_2 from C to B, L_3 from B to D, and L_4 from D to E.

Instructions: Three known loads are applied to the beam as shown. Neglecting the weight of the beam, determine the reactions at A and B.

CHECK WORK

ERASE

DONE
 YES NO

BACKSPACE
 ↑
 ↓

1	2	3	4	5	6	7	8	9	0	Applied Force (AF)	Tension Force (TF)
Q	W	E	R	T	Y	U	I	O	P	Weight Force (WF)	Roller Joint (RJ)
A	S	D	F	G	H	J	K	L	+	Smooth Contact (SC)	Pivot Joint (P.I)
Z	X	C	V	B	N	M	()	-		Contact w/ Friction (CF)	POI Done

Start Over

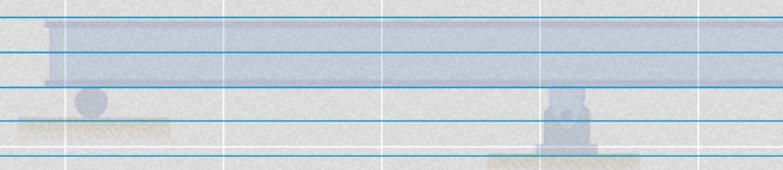
Recent Messages

SFX
23
↑ ↓ ↻
volume

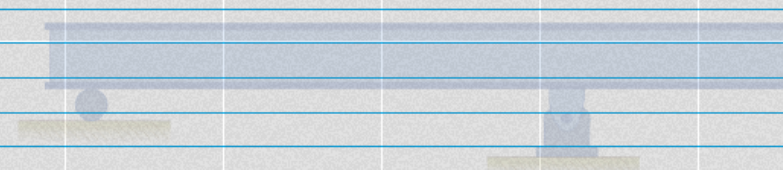
Figure 3.4: A Newton's Pen problem description worksheet

Tutorial Free Body Diagrams Tutorial

1 Boundary Name:



2 Boundary Name:



24

volume

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Figure 3.5: A Newton's Pen free-body diagram worksheet

To begin a problem it is important to first turn on the digital pen by pressing the button located on the end opposite to the ink cartridge tip. One must then start up the Newton's Pen application by tapping on the navigation arrows found on the lower left-hand corner of any worksheet. As soon as the tutorial system starts it will display its first instruction, to trace the body of interest using a single pen stroke. Any initial tap or stroke on a workspace worksheet automatically loads that problem. After tracing a rigid body using a single stroke, the system will check to see if it is valid as soon as the pen is lifted from the paper. If deemed correct, the next prompt on the text display will ask for that particular body to be given a specified label in the box located at top right corner of that workspace. This label is useful for future reference, especially in problems that require the free body diagram of more than one rigid body.

The next step is to circle every point of interaction (POI) located on the previously traced body and identify all of the interaction types at each location. This is done by drawing one circle at a time, waiting for feedback from the pen that the circle has been recognized as being in a correct location, and using the interaction type buttons found on the problem description page. When an interaction type button is tapped, it will let the user know right away whether or not that is a valid interaction for that point. The "POI Done" button signals that there are no more interactions at the current location, and once tapped will change the pen display to let the user know if they are indeed done selecting interaction types for that point. If they have finished, the pen display will ask the user to write the corresponding interaction type initials in the workspace next to the circle. This process is repeated for every POI. Tapping the check work button after this

process is completed will ensure that no points were missed. Multi-body problems would then prompt the identification and labeling of Newton's third law pair locations and two-force members, this would be done by tapping and writing in its given label.

Afterwards, the interactions at the previously identified locations must be modeled using force arrows. These are drawn one at a time using a single stroke starting at the tail of the arrow and ending with the head, one of which must be in its matching circle. The pen will say if it has recognized the pen stroke as an arrow and will then ask the user to write in its label next to it. This label must then also be entered using the keyboard printed on the problem description sheet. The yes button on this page is used to confirm the entered characters and the left arrow button doubles as a backspace in case of a typo. Arrow force label values can be reentered at any time by double-tapping on the label that was written next to the arrow on the free-body diagram. This process is repeated until all necessary force arrows have been drawn and labeled, and tapping the check work button will verify that the free-body diagram has been correctly completed. If a problem requires more than one free-body diagram, the whole process can be restarted, on another workspace if need be.

If there are any errors along the way, the pen text display will show this. These error messages or any other feedback messages can be accessed using the up, down, left, and right arrow buttons on the problem description worksheet. The initial messages give error type and location information but scrolling to the right provides a bit more detailed and conceptual guidance or may refer the user to the extended manual or other reference materials.

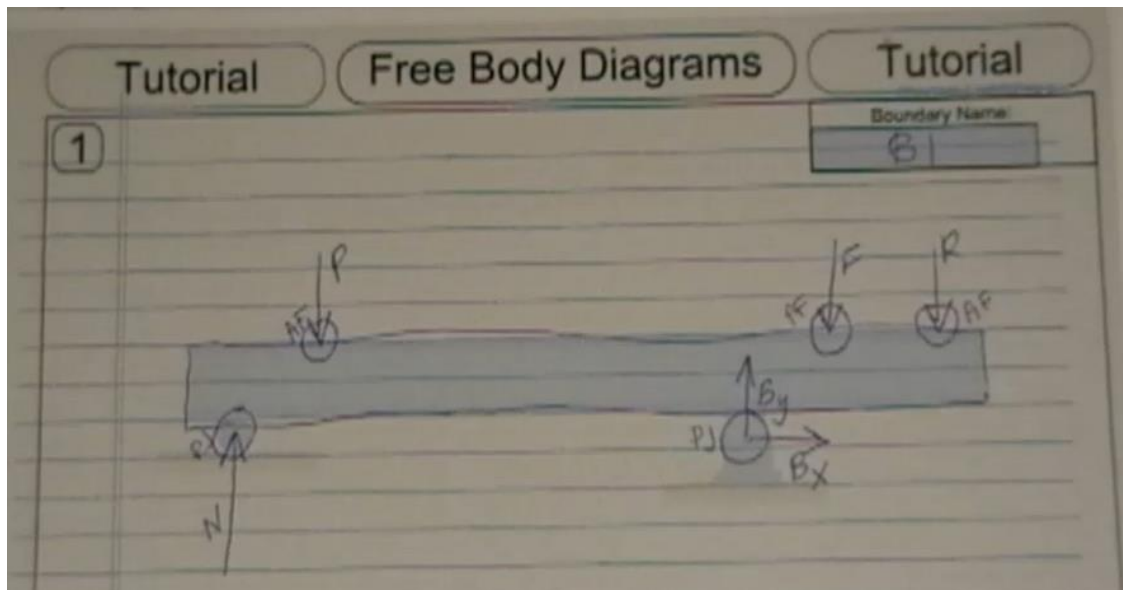


Figure 3.6: Example of a completed free-body diagram using Newton's Pen.

3.4 Special Instructions

The paper based experimental tutorial consisted of five guiding steps for constructing a free-body diagram. These instructions asked students to do on their own what Newton's Tablet and Newton's Pen were designed to do, without the benefit of the feedback and work checking. Students simply used these special instructions when completing the regularly assigned homework problems. The steps and the example they were given were as follows:

Step 1: Draw system boundaries.

Step 2: Identify points at which external objects and fields (e.g., gravity) interact with your system(s). Circle each point of interaction. Label the circle to indicate the type of interaction that occurs there. Use the following labels:

AF: applied force

WF: weight force

SC: smooth contact

CF: contact with friction

TF: tension force

RJ: roller joint

PJ: pivot joint

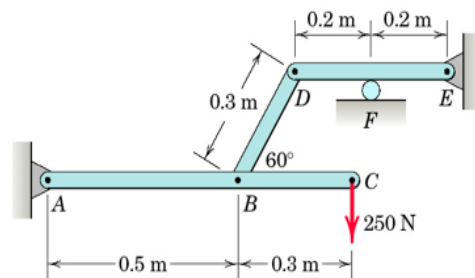
SJ: slider joint

Step 3: Identify any pairs of forces that must satisfy Newton's third law.

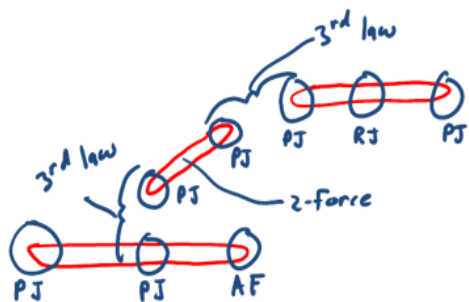
Step 4: Identify any two force members.

Step 5: Represent the forces at the interaction points with force arrows. Name each force.

Problem description:



Interactions:



Final free body diagram:

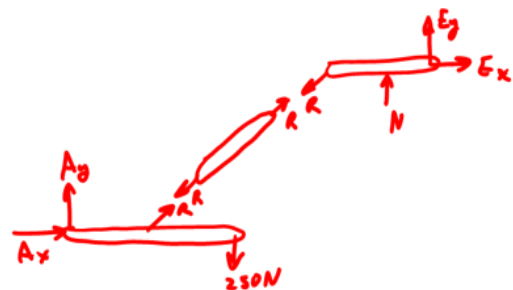


Figure 3.7: An example of a free-body diagram completed using the special instructions

Chapter 4

Experiments

This chapter gives further detail on how each of the tutorial systems was used in the experiments that were performed. During the winter 2013 offering of the undergraduate statics course (known as ME10 at the University of California, Riverside), 29 students were selected to use Newton's Tablet, 29 were selected to use Newton's Pen, and 29 were selected to follow special instructions when completing free-body diagrams for two homework assignments. Of these, 18 reported having used Newton's Tablet, 15 said they used Newton's Pen, and 15 said they followed the special instructions; all other students who completed a general course survey at the end of the quarter and had not been selected to be part of the three experimental groups were considered part of the control group. Lastly, in the spring of 2013, a separate user study of Newton's Tablet (with both free-body diagram and equilibrium equation support) was conducted with 10 volunteers that had not yet completed an undergraduate statics course.

4.1 Winter 2013 ME10 Experiments

To evaluate Newton's Tablet and Newton's Pen, we divided the undergraduate statics class of approximately 150 students into four different experimental groups. The students in each group were selected at random.

The participants in the experimental groups had access to some sort of added guidance for two of the weekly problem sets that quarter, one dealing with single-body problems and one with multi-body problems. Because the single-body problems only involved one rigid body, only one free-body diagram was required, whereas the multi-body problems had multiple rigid components and therefore needed several free-body diagrams. The extra guidance came in the form of Newton's Tablet, Newton's Pen, or a set of special instructions for how to complete those assignments. The control group, everyone else in the class that was not chosen to be a part of any of the three experimental groups, was given just the written problem statements and relevant figures for every problem. No matter which group students were in, they were all expected to turn in only the work they had done on the blank dot-patterned Livescribe notebook paper. Students who had completed free-body diagrams with the help of Newton's Pen or Newton's Tablet had to copy over their diagrams onto the blank notebook paper and proceed from there.

It is important to note that regardless of which experimental group, if any, a student happened to be in, they were all encouraged to attend class lectures, weekly discussion sections lead by a teaching assistant, as well as all office hours held by the TAs and the professor. In addition, every student enrolled in the class was given a

Livescribe digital pen and notebook with which to complete their assignments, quizzes, and exams. No additional points were granted or deducted for using or failing to use the tutoring systems or following the special instructions. All grading was done without knowing which group students were in.

After each homework assignment was submitted, students were given an in-class quiz with a problem similar to one from the homework.

4.1.1 Newton's Tablet Group

The Newton's Tablet group used the program to generate correct free-body diagrams for certain homework problems. For this experiment, the system was not used for constructing equilibrium equations. Students in this group had online access, to materials to help them get started with the system including a quick start guide and a video overview which showed them how to successfully get through a sample problem. These materials were in addition to the help provided by the system itself.

The students in this group were reminded that they could use the software in the computer clusters whenever convenient for them. However, of the 29 that were given access to it, only 18 reported ever having used it, and many who did use it failed to submit log files for us to study. Many that used it only completed a couple of problems with the system. Getting students to actually use the software as intended without supervision was more difficult than expected. Because of low student compliance, students probably did not get as much benefit out using Newton's Tablet as was originally intended.

4.1.2 Newton's Pen Group

The students that were a part of the Newton's Pen group had their Livescribe pens preloaded with the tutoring system software. They were given online access to a comprehensive user manual, quick help overview sheets, and videos walking them through an entire problem as well as one demonstrating common errors and how to handle them. The user manual was quite lengthy because it included conceptual help as well as all of the system usage help that could not be preloaded onto the pen due to a small dynamic text display and limited memory availability. The feedback messages displayed on the pen frequently referred the user to a specific section of the manual. In addition to the online tools students also participated in a supervised, in-person session during which the professor and five graduate students walked around answering questions as they worked their way through a simple problem with the help of Newton's Pen. The majority of students were able to arrive at the correct free-body diagram and left the session with a basic understanding of how to use the tutorial system. Newton's Pen included only support for free-body diagram drawing and not the formation of the corresponding equilibrium equations.

On the days that the experimental assignments were posted, the necessary preprinted worksheets used with the homework problems that had been loaded onto the pen were made available to the students during lecture and thereafter during weekly sections, office hours, and by appointment. We made every effort to ensure that all students in this group received the worksheets that they needed to use the tutorial system, including sending out email reminders and making announcements throughout the week.

Unfortunately, student participation was rather low in this experimental group as well. Only 15 students reported having used Newton's Pen at all, and based on the log files retrieved from the pens, those that did use it tended to not attempt all problems. This, again, means that the intended impact of the tutorial system was most likely not achieved.

4.1.3 Special Instructions Group

The special instructions group was asked to complete the two experimental homework assignments using a set of instructions that followed the same logical breakdown of steps as the tutorial systems. However, because they were just done on pen and paper, there would be no automatic feedback from a tutorial system. The instructions were aimed at getting students to think about the underlying decisions they were making when drawing their free-body diagrams.

The instructions were emailed to every member of the group as soon as the assignments were posted. Moreover, students in this group that attended their weekly discussion section were shown how to complete a sample loaded beam problem using the method described in the instructions in addition to the example that was included in the email with the instructions.

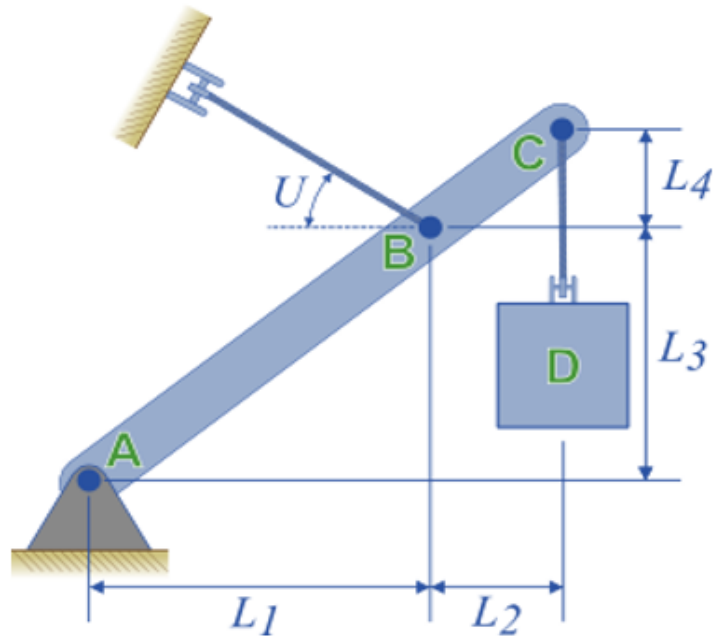
Once again we saw that student participation was reported to be much lower than anticipated, with 15 students reported having tried to comply with the instructions at least on some of their homework problems.

4.2 User Study

The user study experiment was in many ways the most telling despite its relatively small sample size. Volunteers for this trial run of Newton's Tablet were asked to participate in an hour-long, in-lab session in return for \$15 gift certificates to on-campus eateries. Advertisements were posted on bulletin boards in the engineering buildings, and we made an in-class announcement about our study to students taking ME9, introduction to mechanical engineering. Details for how to sign up online for a time slot to participate in the study were also posted as an ME9 online announcement.

Participants sought for this study were those who had not yet taken ME10 but had at least some familiarity with basic statics concepts such as free-body diagrams and rigid bodies in equilibrium. There were 20 students who signed up online but only 10 showed up in spite of numerous email reminders.

The session time slots were scheduled so that no more than two participants were in the lab at the same time because we wanted everyone to have a graduate student there to observe their progress. For this user study we used Wacom tablets connected to core i7 desktop computers with full keyboards. The tablets were pen-based rather than touch screen, something which we mentioned to all students so that the setup would allow students to work comfortably for the whole hour.



If the mass of crate D is 50 kg, what is the magnitude of the tension in the rope which connects to the bar at point B? Assume that the bar itself is massless and that the system shown is in static equilibrium.

$$g = 9.81 \text{ m/s}^2 \quad U = 30^\circ \quad L_1 = 3 \text{ m} \quad L_2 = 1 \text{ m} \quad L_3 = 2 \text{ m} \quad L_4 = 0.75 \text{ m}$$

Figure 4.1: User study pretest and posttest problem

At the beginning of each session, participants were given a maximum of 15 minutes to complete a pre-test statics problem using a Livescribe digital pen and a blank sheet of dot-patterned notebook paper that would record their pen strokes but not offer any assistance. After that, the designated graduate student walked the new user through a trial problem, showing them how to use the tutorial system to access any necessary help along the way. For this study the user had to draw the correct free-body diagram as well as any equilibrium equations they felt were needed to solve the problem at hand. During

the trial problem walkthrough, the user was expected to do the majority of the work as the graduate student explained how the tutorial system functioned but could stop at any time if they had questions. Once the trial problem was done, the users were asked to complete free-body diagrams and corresponding equilibrium equations for two more problems with only the assistance of the tutoring system. After successfully getting through all of that, participants were once again handed a Livescribe pen and notebook paper for the post-test, which gave them a new chance to attempt to solve the problem they had been presented with in the pre-test prior to using Newton's Tablet. Finally, user study participants all filled out a survey based on their experiences with the tutoring system.

Chapter 5

Results

In this chapter, the results of the experiments described in the last chapter are presented and analyzed.

5.1 User Study Results

The results from the user study accurately demonstrate the potential of the Newton's Tablet statics tutorial system because the experimental design ensured that each user completed at least three problems and that learning gains could be quantitatively measured. Specifically, the pre and posttests used in the study provided an accurate way to quantify learning gains.

Every volunteer who signed up online for the user study was assigned a number from 1-20 to distinguish them from one another while maintaining their anonymity. While 20 students originally signed up for the study, only 10 actually participated. Of the 10 students who participated in the study, 70% were male and 30% female. Furthermore, 60% self-identified as Mexican-American/Chicano or another Latino, 20% as Caucasian/White, 10% as Chinese/Chinese-American, and 10% as East Indian/Pakistani.

Nine of the 10 participants had taken or were enrolled in ME9 at the time of the study but had not yet enrolled in ME10, while one student was enrolled in ME10 at the time of the study but came in because he felt he needed help. This is significant because although ME9, introduction to mechanical engineering, covers some statics concepts, ME10 is the designated undergraduate statics course for engineers. The results of the pre and posttests demonstrate a rather marked improvement in the students' abilities to solve statics problems after working with Newton's Tablet.

User	PreTestScore	PostTestScore	improvement
1	3	4.5	1.5
4	8.5	9.5	1
7	10	10	0
8	3.5	10	6.5
9	9	9	0
12	2	10	8
15	3	9	6
16	3	9	6
17	10	10	0
18	2	10	8
avg:	5.4	9.1	3.7
stDev:	3.479	1.680	3.474

Table 5.1: User study pretest and posttest results

I graded the tests as I would have graded any quiz or exam problem as a teaching assistant for the undergraduate statics course. I deducted points for errors on the free-body diagrams and equilibrium equations. To achieve a perfect score of 10 points, the student needed to have a correct free-body diagram and correct equations. Either a half point or a full point was deducted for each mistake. The error categories are described

below. If a mistake cascaded to other parts of the solution, those parts were not assessed point deductions.

The average pretest score was 5.4 out of 10 with a standard deviation of 3.48, while the average posttest score was 9.1 out of 10 with a standard deviation of 1.68. The average improvement in the score was 3.7 points. There were two students who achieved perfect scores on the pretest, indicating that they already had knowledge of the statics concepts that Newton’s Tablet was designed to teach. Excluding those users from the analysis, as shown in the following table, provides a better picture of how the tutoring system helps novice students.

user	PreTestScore	PostTestScore	improvement
1	3	4.5	1.5
4	8.5	9.5	1
8	3.5	10	6.5
9	9	9	0
12	2	10	8
15	3	9	6
16	3	9	6
18	2	10	8
avg:	4.25	8.875	4.625
stDev:	2.828	1.827	3.260

Table 5.2: User study pre and post test results excluding those who scored 10/10 on the pretest to better demonstrate improvement.

Here we see that of the users that needed help with statics, the average improvement in scores was 4.625. All students performed better on the posttest than on pretest. All but one of the participants achieved a score of 9 or higher on the posttest, and

the two students that scored the lowest on the pretest achieved perfect scores on the posttest. This demonstrates that Newton's Tablet is an effective instructional tool.

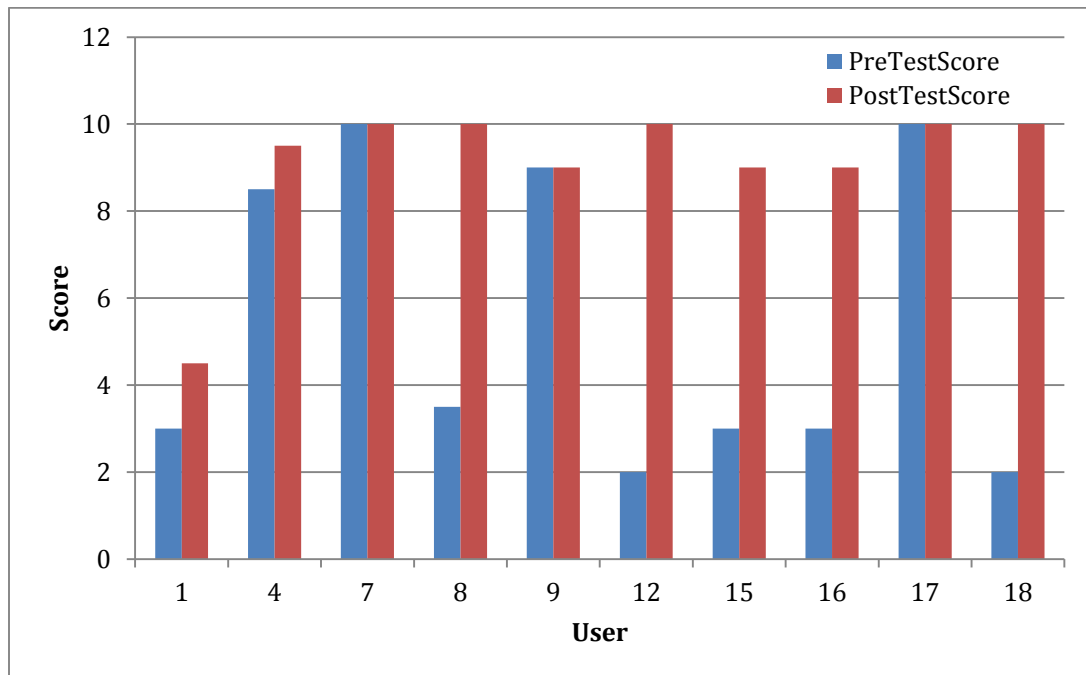


Figure 5.1: A comparison of user study pre and post test scores

To understand what concepts students struggled with the most, and to ensure that these are areas our software can help with, it is important to identify the particular types of errors students made. To that end, I tabulated the types of errors made on both pre and posttests across all users as shown in the following graphs.

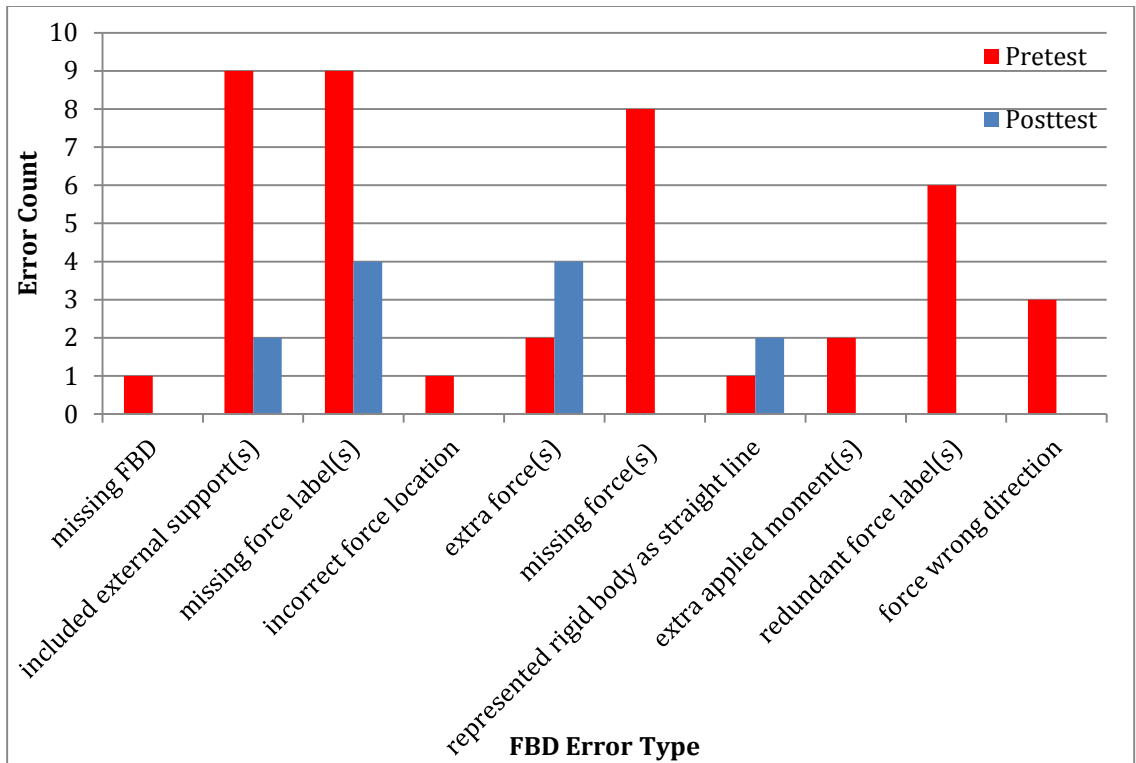


Figure 5.2: Pre and posttest comparison of free-body diagram error counts across all user study participants

FBD Error Type	Description
Missing FBD	No free-body diagram attempted
Included external support(s)	Included external supports in rigid body selection
Missing force label(s)	Force arrows left unlabeled
Incorrect force location	Force arrow drawn in incorrect location on body
Extra force(s)	Unnecessary force arrows added to diagram
Missing force(s)	Necessary force arrows missing from diagram
Rigid body as straight line	Rigid body improperly modeled in diagram
Extra applied moment(s)	Unnecessary applied moment curved arrows added
Redundant force label(s)	Same force label used for more than one arrow
Force wrong direction	Force drawn in the wrong direction

Table 5.3: User study pre and posttest FBD errors and their descriptions

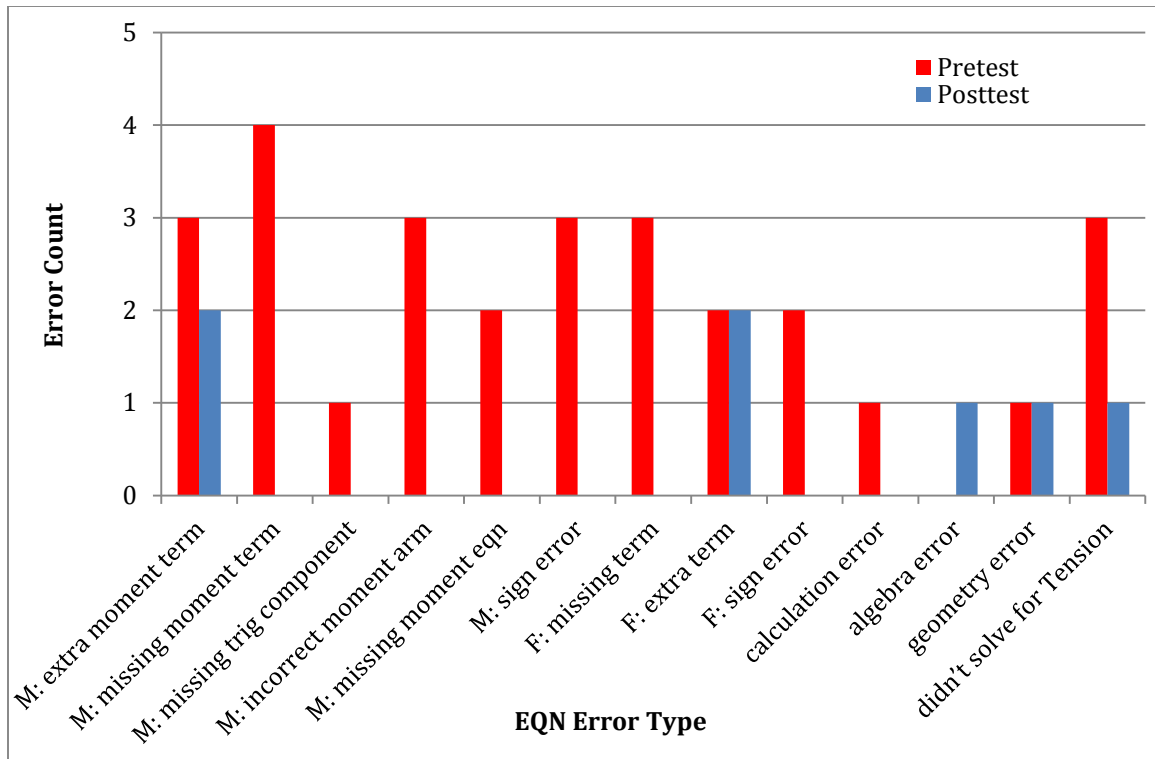


Figure 5.3: Pre and posttest comparison of equilibrium equation error counts across all user study participants

EQN Error Type	Description
M: extra moment term	Unnecessary term added to moment equation
M: missing moment term	Necessary term missing from moment equation
M: missing trig component	Trigonometric function missing from moment equation
M: incorrect moment arm	Incorrect moment arm found in moment equation term
M: missing moment eqn	Necessary moment equation not included
M: sign error	Moment equation term given incorrect sign (+/-)
F: missing term	Force equation missing necessary term
F: extra term	Force equation includes unnecessary term
F: sign error	Force equation term given incorrect sign (+/-)
Calculation error	Incorrect result due to calculator error
Algebra error	Algebraic equations incorrectly simplified
Didn't solve for Tension	Did not solve for necessary unknown

Table 5.4: User study pre and posttest EQN errors and their descriptions

User study participants made a combined 42 free-body diagram errors in the pretest, but only 12 in the posttest, which is a reduction of 71.4%. Of the ten types of free-body diagram errors, six did not occur after students used Newton's Tablet. Similarly, for equilibrium equation errors, users made a total of 28 errors on the pretest and 7 on the posttest, for a 75% reduction. Eight of the thirteen error types that were an issue in the pretest no longer troubled any student in the posttest. Many of the errors students made initially, such as including external supports in their free-body diagrams and selecting incorrect moment arms for their moment equilibrium equations, were ones that we had anticipated in the design of the tutoring system.

Newton's Tablet generates detailed log files describing a student's interaction with the system. We are able to examine the log files to determine the number and types of errors students made while using the software. When students completed the first problem with Newton's Tablet, a researcher guided them through the use of the software. The students completed the second and third problem without any guidance from the researcher. The average number of errors for problem one across all users was 19, with a standard deviation of 9.1. For problem two, the average was 21.7 with a standard deviation of 15.2, and for problem three the average was 9.3 with a standard deviation of 5.1. In addition, 70% of the students made the least number of mistakes on the third problem. This suggests that students were able to learn to use Newton's Tablet quickly, after having guidance on only one problem. Furthermore, this also demonstrates that Newton's Tablet is effective at teaching statics concepts.

Prob.	u1	u4	u7	u8	u9	u12	u15	u16	u17	u18	avg	stDev
1	18	6	16	13	13	33	36	20	19	16	19	9.1
2	29	10	44	12	5	10	37	30	3	37	21.7	15.22
3	15	9	2	13	5	7	14	7	4	17	9.3	5.14
total	62	25	62	38	23	50	87	57	26	70		

Table 5.5: Number of problem-solving errors identified by Newton’s Tablet for each user study participant

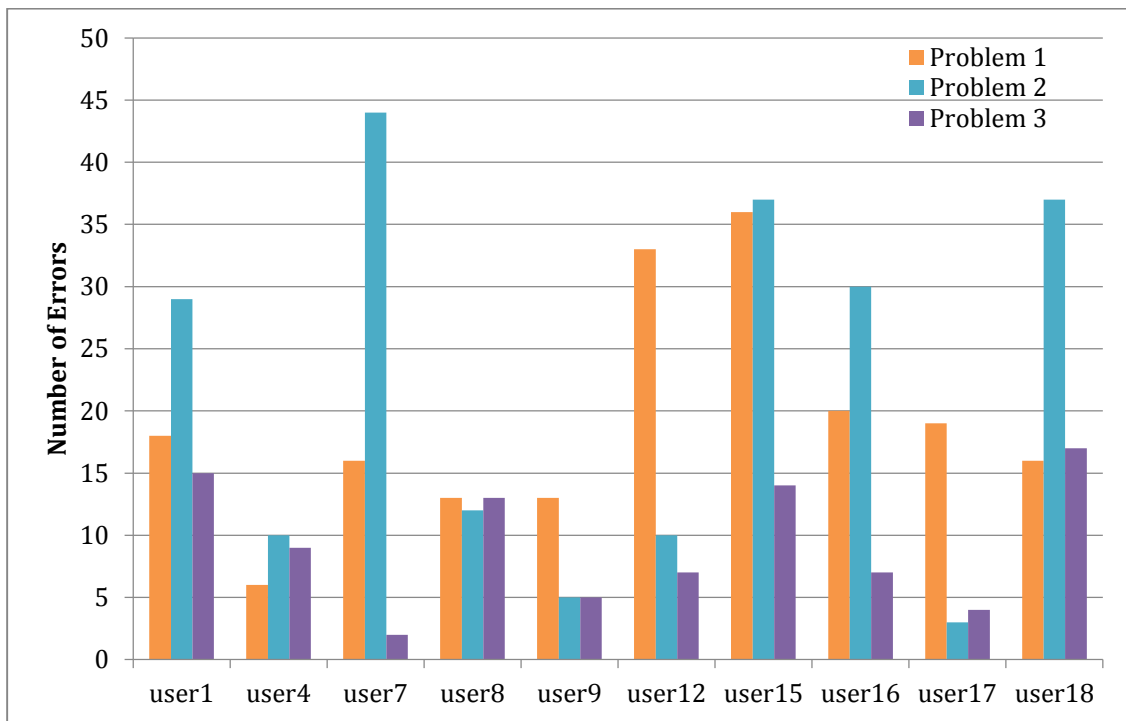


Figure 5.4: Number of problem-solving errors identified by Newton’s Tablet for each user study participant

Newton’s Tablet identified and helped students correct a total of 500 errors during the user study, which is approximately 50 errors per user. There was a negative correlation between the number of errors students made when using the system and the pretest score. As shown in Figure 5.5, the coefficient of determination, R^2 , for a linear

regression model relating pretest scores and errors is 0.37. The students who performed worst on the pretest tended to have more errors corrected by the system. Thus, those who needed the most help received the most feedback. The coefficient of determination for a regression is shown in Figure 5.5.

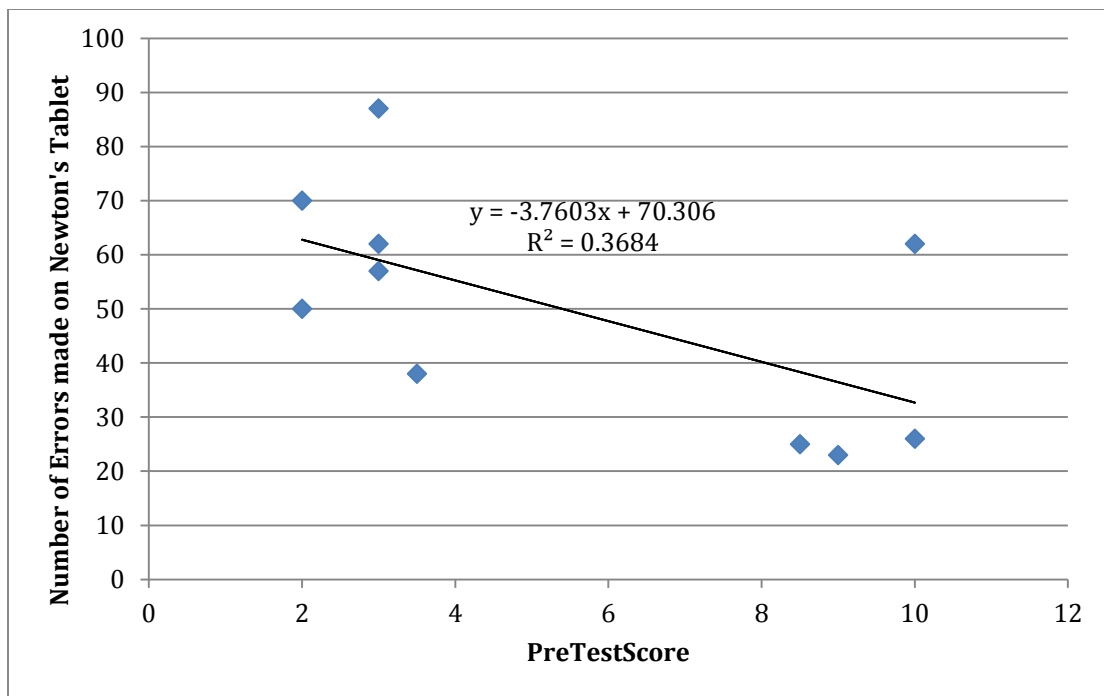


Figure 5.5: Total number of errors students made while using Newton's Tablet plotted against pretest score (linear trend line and R^2 value included).

The types of errors that Newton's Tablet corrected were the types of errors observed in the pretest. For example, the system identified errors such as including external supports in free-body diagrams, missing locations where external forces act upon the rigid bodies, incorrect moment arms, and issues with the signs in the equilibrium equations, which were often due to mistakes in applying the right hand rule. This once

again demonstrates that the tutoring system works as intended. Students initially made the same mistakes they had previously made on paper, but the feedback from Newton’s Tablet helped them to overcome these errors, leading to the improvements observed in the posttest.

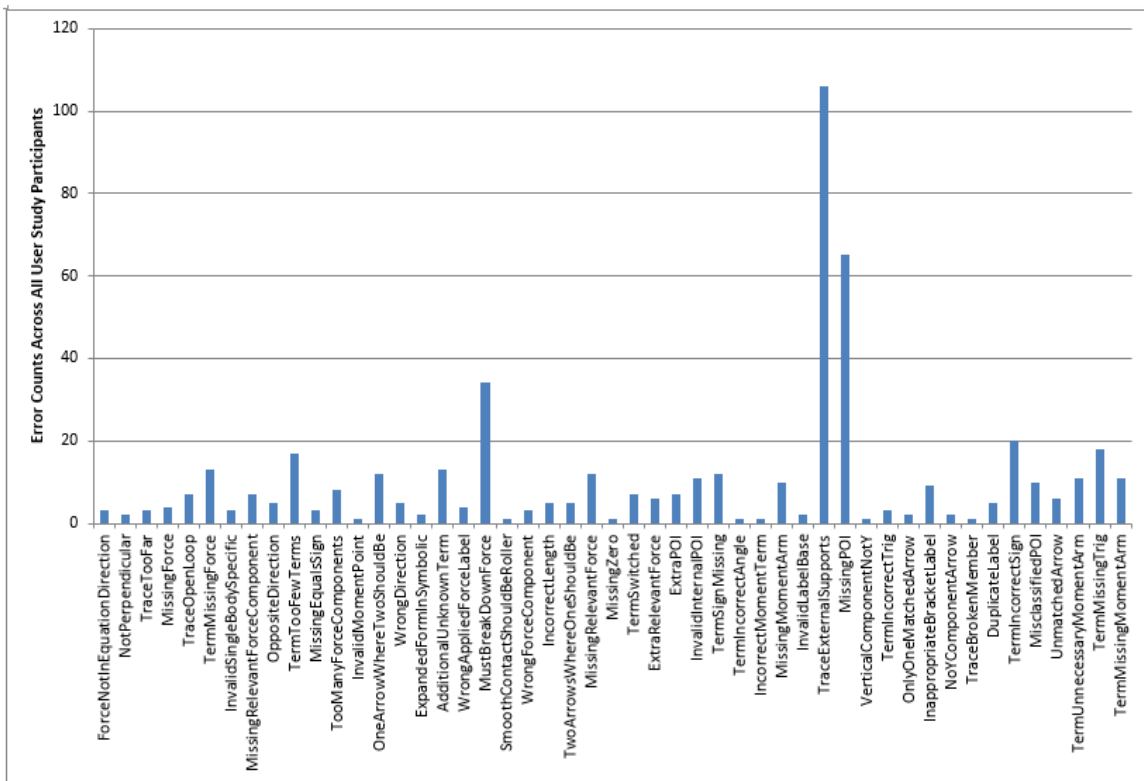


Figure 5.6: Newton’s Tablet error type counts across all user study participants. The most common errors were attempting to trace external supports, missing points of interaction, and subsequent equation term mistakes.

After students used Newton’s Tablet, they also became faster at problem solving. Because the pre and posttests were completed using Livescribe digital pens, we had a time-stamped record of every pen stroke. Using this information, we determined that students spent an average of 9.32 minutes on the pretest and only 8.27 minutes on the

posttest, as first presented in Lindsey [8]. This reduction of 1.05 minutes, or 11.26%, indicates that students were able to do better work in a shorter period of time. In fact, as we see in the chart and graph below, 80% of user study participants finished the posttest in less time than the pretest, with 100% of them scoring better on the posttest.

user	pre-test duration (sec)	post-test duration (sec)
1	513.8	402.6
4	443.5	404.4
7	462.4	349.7
8	448.0	425.3
9	431.9	346.4
12	634.0	225.7
15	938.4	788.9
16	954.8	1097.2
17	353.0	306.5
18	410.5	613.9
avg:	559.0	496.1

Table 5.6: User study participant pre and posttest durations

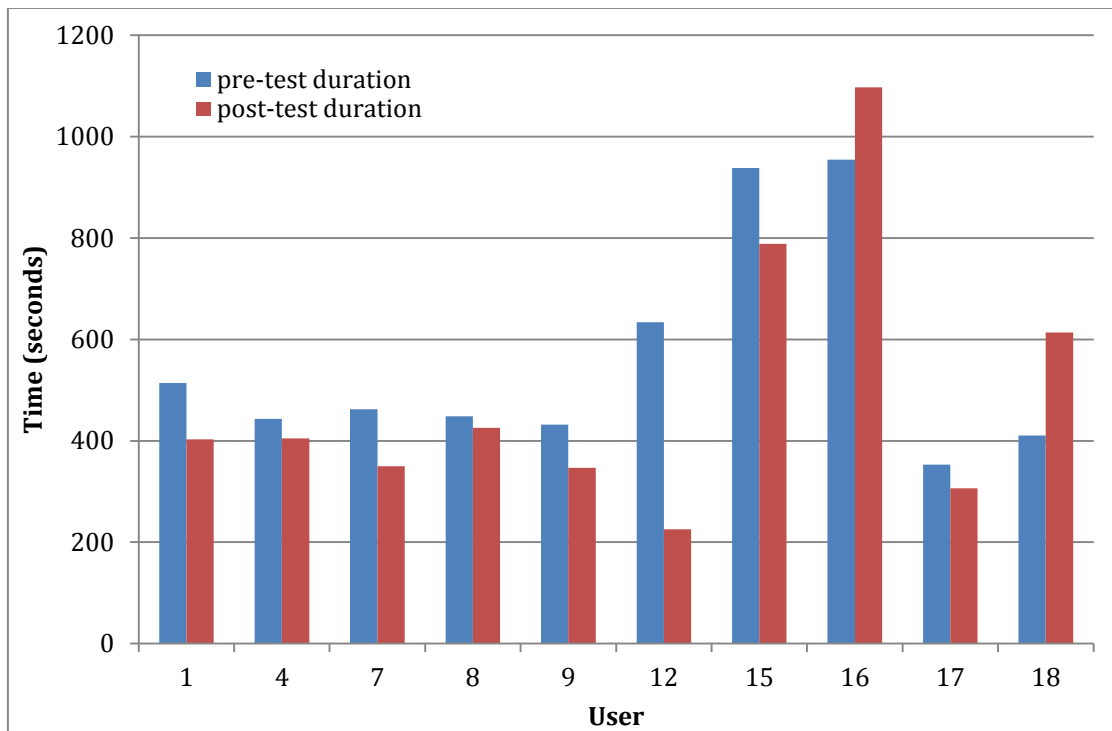


Figure 5.7: Comparison of the time each student took to complete the pre and post tests

Perhaps the most striking indication of learning gains resulting from the system is the qualitative differences in the quality of the work on the posttest compared to the work on the pretest. For example, one student had no free-body diagram on the pretest and struggled with moment arms for the moment equation (Figure 5.8(a)). On the posttest, this student used the strategies from Newton's Tablet to correctly solve the problem (Figure 5.8(b)). Moreover, the student drew brackets, as required with Newton's Tablet, to help identify the moment arms for the forces. With the help of Newton's Tablet, the student had impressive learning gains, advancing from a pretest score of 3.5 to a posttest score of 10.

Figure 5.9 shows the work of another student from the study. With the help of Newton's Tablet, the student also had impressive learning gains, advancing from a pretest score of 2 to a posttest score of 10. In this case, on the pretest the student's attempt at a free-body diagram is essentially a reproduction of the image included in the problem statement, even including external supports. This student was also unable to correctly construct equilibrium equations. In fact, the student was unable to construct a moment equation at all. Nevertheless, after using Newton's Tablet for three problems, this student constructed a perfect solution to the posttest. Again, this student used brackets to help identify the moment arms. The brackets appear to be a particularly effective tool as several of the students that improved by six or more points used brackets in their solutions to the posttest.

Pre

$$D = 50 \text{ kg} \quad \theta = 30^\circ$$

$$\sum M_A = 0; \quad \sum F_x = 0; \quad \sum F_y = 0$$

$$T \cos 30^\circ = A_x$$

$$T \sin 30^\circ L_1 + T \cos 30^\circ L_2 - W_D(L_1 + L_2) = 0$$

$$T = W_D(L_1 + L_2) / (\sin 30^\circ L_1 + \cos 30^\circ L_2)$$

$$T = 50(9.81)(4\text{m}) / (\sin 30^\circ(3) + \cos 30^\circ)$$

$$T = 1962 / (1.5 + 0.86602) = \boxed{829.2 \text{ N}}$$

Figure 5.8(a): User study pretest example 1

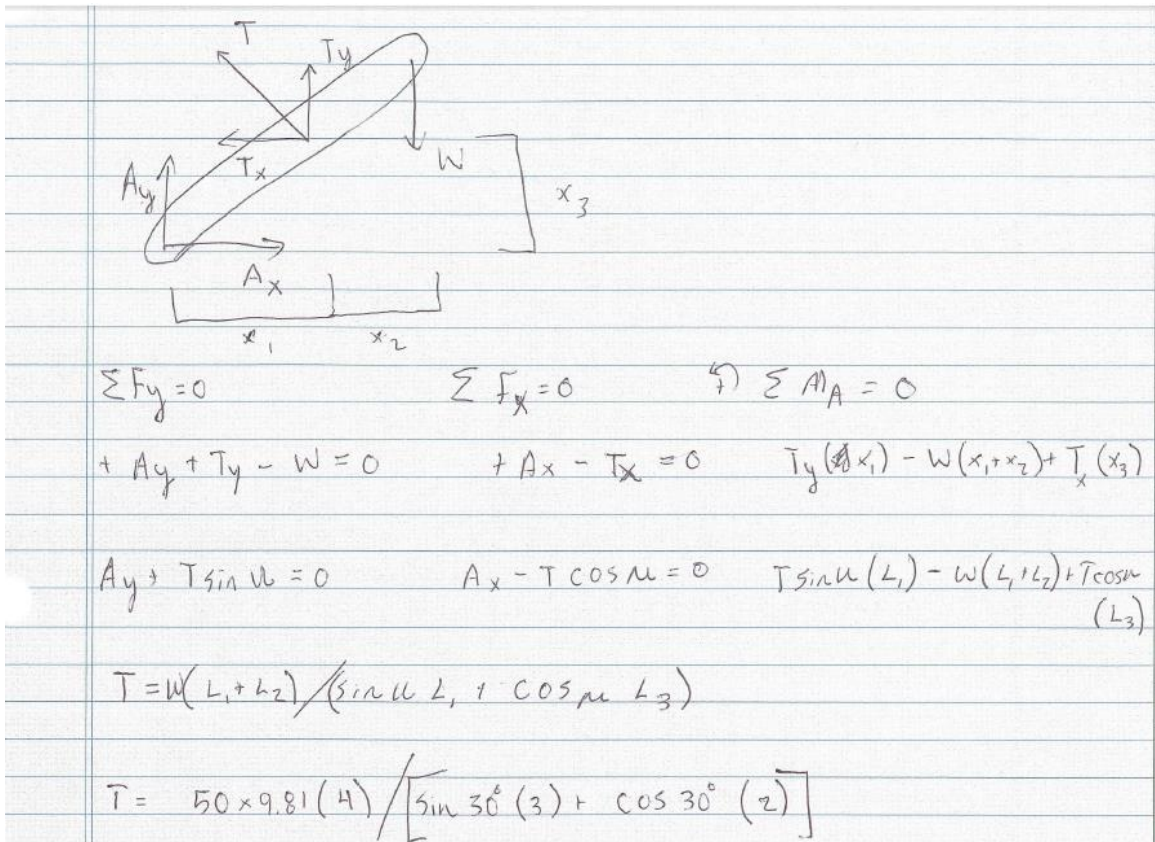


Figure 5.8(b): User study posttest example 1. Figures 5.8.a & 5.8.b are from the same user.

Pretest

$F_x = F \cos \theta$
 $F_y = F \sin \theta$
 $\Sigma F_y = 0 \quad T \sin \theta = 0$
 $\Sigma F_x = 0 \quad -T \cos \theta = 0$

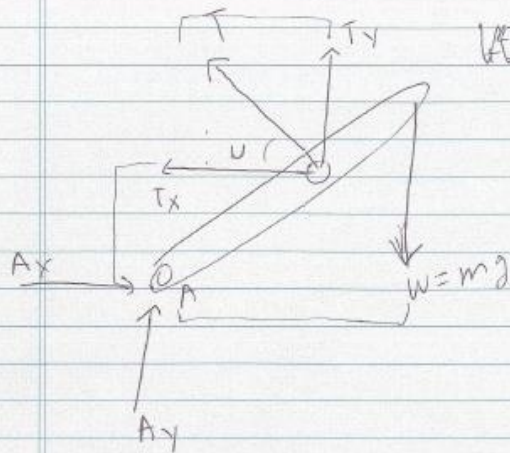
$\Sigma F_y = 0 \quad T \sin(30^\circ) - W = 0$
 $T \sin(30^\circ) - m(9.81 \frac{m}{s^2})$

$\Sigma F_x = 0 \quad -T \cos 30^\circ = 0$

$\Sigma M_c =$

Figure 5.9(a): User study pretest example 2

Post test



$$\sum F_x = 0$$

$$-T_x = 0$$

$$-T \cos(30^\circ) + A_x = 0$$

$$-T_x + A_x = 0$$

$$\sum F_y = 0$$

$$-W + A_y + T_y = 0$$

$$-W + A_y + T \sin(30^\circ) = 0$$

$$\sum M_A = 0$$

$$T_x (L_2) + T_y (L_1) - W(L_1 + L_2) = 0$$

$$0 = T \cos(30^\circ) (2m) + T \sin(30^\circ) (3m) - W(3m + 1m)$$

$$W(4m) = T [(\cos 30^\circ)(2m)] + T$$

$$W(4m) = T [\cos 30^\circ 2m + \sin 30^\circ 3m]$$

$$\frac{W(4m)}{\cos 30^\circ 2m + \sin 30^\circ 3m} = T$$

Figure 5.9(b): User study posttest example 2. Figures 5.9.a & 5.9.b are from the same user.

One more important factor that lets us know that Newton's Tablet is making a difference in the user study results is the time students spent reading the information provided in the targeted, localized error message feedback popup bubbles. For this we compare the average time user study participants spent reading the popups to that of the winter 2013 ME10 Newton's Tablet group, whose results will be discussed in more detail in the next section. The charts and graph below indicate that, on average, the user study participants spent 20.4 seconds looking through each error feedback message compared to their winter 2013 ME10 experiment counterparts who only spent 4.9 seconds looking at each popup before closing it. Interestingly, the user study participant who spent the least amount of time with the bubbles open, just over 8 seconds, still had them on screen for more time than 93.75%, all but one, of the ME10 tablet experimental group members whose log files we had access to. With the help of SPSS, a statistical analysis software package, we indeed determined that the behavior of the two groups with regards to the time spent with the feedback that the tutoring system provided was significantly different. An independent samples t-test for equality of means with unequal variances, yielded $t(9.124) = 2.602$ and $p = 0.028$, which is safely below the statistically significant threshold of 0.05. This statistically reliable difference helps account, at least in part, for some of the discrepancies in learning outcomes observed between the user study and the ME10 experimental group.

userStudySubj.	time (s)
1	8.1
4	10.3
7	10.9
8	8.0
9	65.8
12	9.8
15	24.9
16	40.4
17	13.3
18	12.8
avg:	<i>20.4</i>
stDev:	<i>18.9</i>
var:	<i>355.1</i>

W13ME10NTSubj.	time (s)
1	7.6
2	4.5
3	2.5
4	7.5
5	4.6
6	9.6
7	4.3
8	3.8
9	3.0
10	3.1
11	4.3
12	6.5
13	4.5
14	4.2
15	5.1
16	2.9
avg:	<i>4.9</i>
stDev:	<i>2.0</i>
var:	<i>3.9</i>

Table 5.7(a) & Table 5.7(b): Average time Newton’s Tablet users spent reading each error feedback message. (a) Results from the user study and (b) results from the winter 2013 ME10 Newton’s Tablet group.

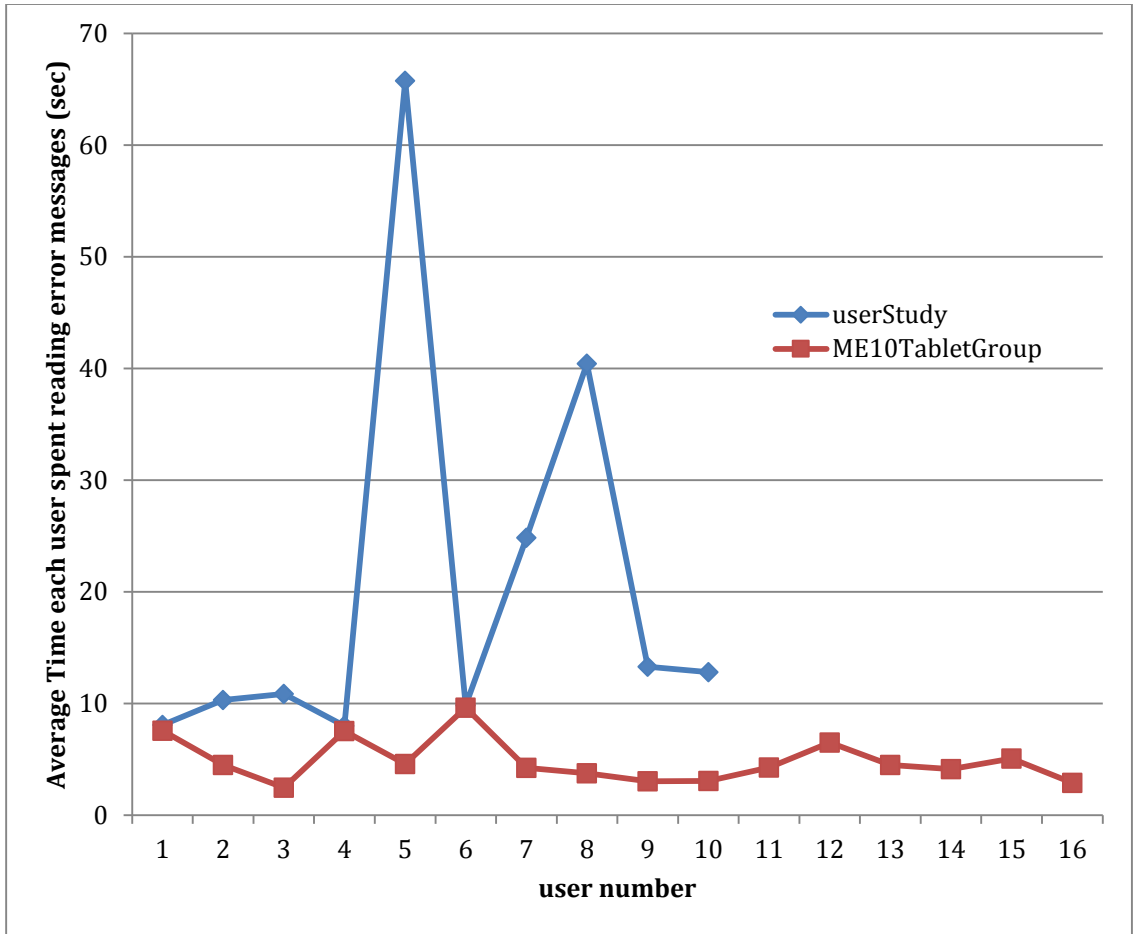


Figure 5.10: Comparison of the average time each user spent reading error feedback messages for the two Newton’s Tablet experiments.

5.2 Winter 2013 ME10 Results

The members of the winter 2013 ME10 experimental groups, unlike the participants of the user study, were tasked with using the tutoring systems in an unsupervised environment with different incentives at play. For these students, the main incentive was getting extra help on homework from the software because the tutorial problems were the same as some of the homework problems. The students were, however, on their own in deciding how much time and attention to give to the experimental treatments. When using Newton's Tablet, for instance, they could start a problem, get half way through and return to it hours or even days later, only do one or two problems out of six for the first trial assignment, or simply not do any at all. On the other hand, all user study volunteers finished three problems from beginning to end all in one sitting, with nothing else to distract them. As previously mentioned, the differences in how students approached their experiences with the tutoring systems led to marked differences in the time spent reading feedback relevant to the mistakes they made along the way. Incidentally, the time spent reading help messages first became a concern during observations in the winter of 2012 of student interactions with Lee and Jordan's system [4, 5], which had error messages appear in a separate window. These concerns were a major factor in the decision to design the error messages in Newton's Tablet as on-screen popup bubbles next to the errors themselves. .

Nonetheless, there were some motivating results from the winter 2013 ME10 results. Using self-reported data from the surveys given at the end of the quarter, we

found that, for the first experimental problem set, on average students did 4.6 problems on Newton’s Tablet, 4.6 with Newton’s Pen, and 6.7 using the special instructions. For the second trial problem set, they did an average of 1.9 on Newton’s Tablet, 1.8 with Newton’s Pen, and 5.2 following the special instructions. There were a total of six single-body problems available on the tutoring systems for that first experimental assignment, which was the third homework assignment for the quarter, and three multi-body problems on the second, which was the fifth overall assignment. The quiz which corresponded to homework 3 was quiz 3 and for homework 5 it was quiz 4. As can be seen from the following chart and graphs, the Newton’s Tablet group on average did slightly better than the control group for every homework, quiz, and exam of interest. The Newton’s Pen group also did better on assignments and tests except for homework 5, where their average was 0.32 points below that of the control group. The paper-based special instructions group did better than the control for all exams and outperformed the other three groups on homework 3 but did the worst of all the other groups on quiz 3, homework 5, and quiz 4. All three experimental groups did better than the control average on both midterms as well as on the final exam.

	Homework 3 (h3)	Quiz 3 (q3)	Homework 5 (h5)	Quiz 4 (q4)	Midterm 1 (mt1)	Midterm 2 (mt2)	Final (f)
control	7.48	6.82	7.21	6.4	46.41	34.84	81.45
pen	8.67	7.47	6.89	7.4	48.7	39.7	91.13
tablet	8.47	7.29	7.8	7.41	46.83	37.06	84.22
paper	8.69	6.1	5.42	5.5	47.93	38.87	83.71

Table 5.8: Average homework, quiz, and exam scores for the four experimental groups

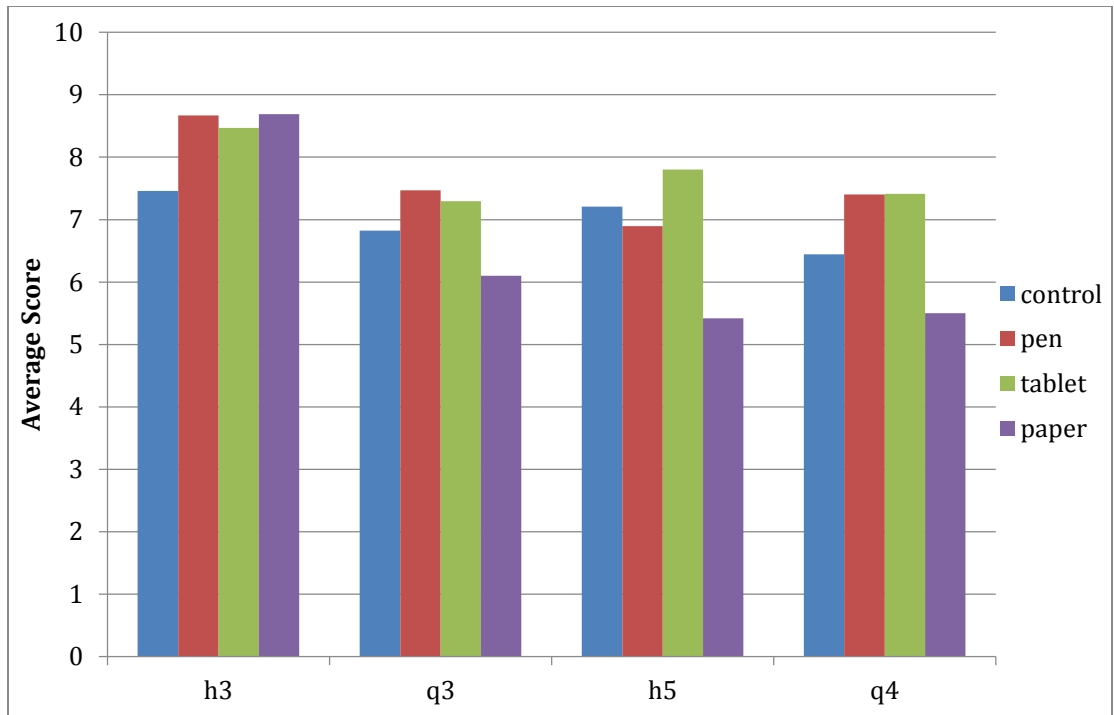


Figure 5.11: Comparison of quiz and assignment scores for all experimental groups

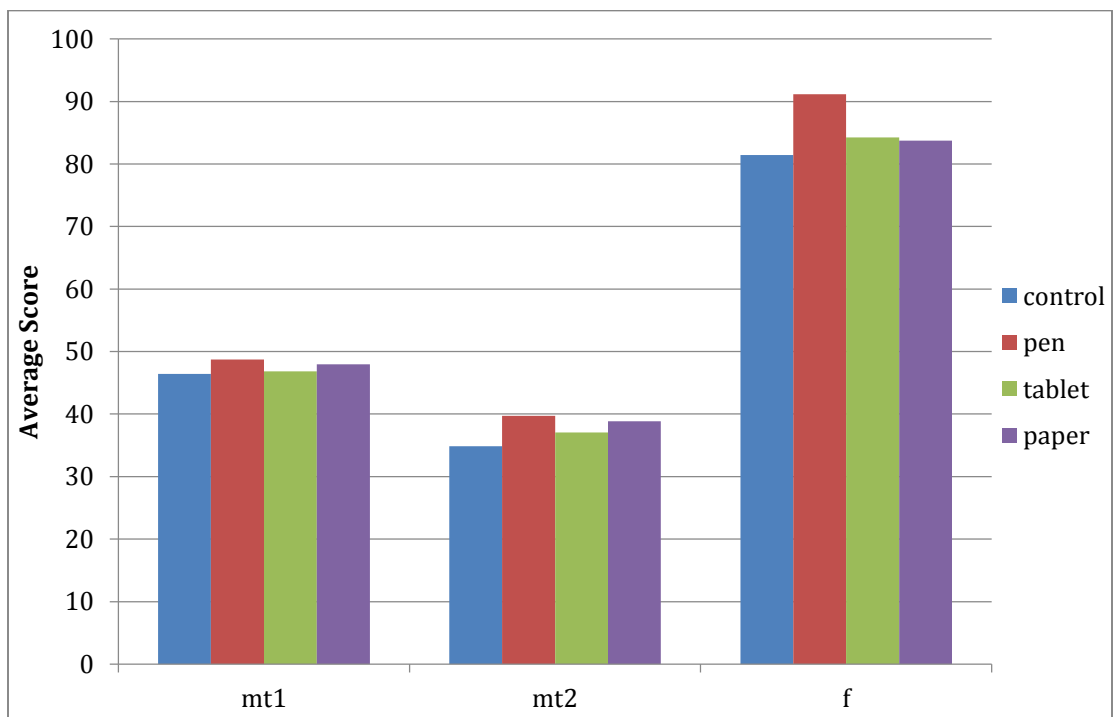


Figure 5.12: Comparison of exam scores for all four experimental groups

This data hints that perhaps the structured problem-solving approach in which each decision made in solving a statics problem is explicitly made is a helpful one and that a software tutoring system facilitating the process in real time can indeed have positive learning outcomes. It appears that students found the special instructions a helpful tool for the problem set dealing only with single rigid bodies on paper, but that it became a heavy extraneous cognitive load when presented with multi-part problems without the scaffolding and feedback from an intelligent tutoring system.

Although the previously discussed data serves as an initial frame of reference, at this point we did not find the differences encountered in student performance on the homework assignments, quizzes, and exams between the four experimental groups to be statistically significant. Nevertheless, within each group there were some correlations between the number of problems done with the tutoring systems and performance that are worth exploring.

For instance, from the plots below, the number of single-body problems done with Newton's Tablet and those students' scores on the first midterm show a directly proportional relationship with a coefficient of determination of 0.3733. Likewise, a linear fit of the relationship between the number of multi-body problems done on Newton's Tablet and scores on the second midterm yields an R^2 of 0.2679. The next correlation, with an R^2 of 0.2656, between the total number of problems done on Newton's Tablet, both single and multi-body problems, and the score on the second midterm is included because the exams build on previously learned material. The relationship between final exam scores and the total number of Newton's Tablet problems done had a smaller R^2 of

0.143. Unfortunately, when it came to homework assignment and quiz scores plotted against problems done with Newton's Tablet, the only one with an R^2 greater than 0.07 was homework 5 versus number of multi-body problems done; its R^2 was 0.151.

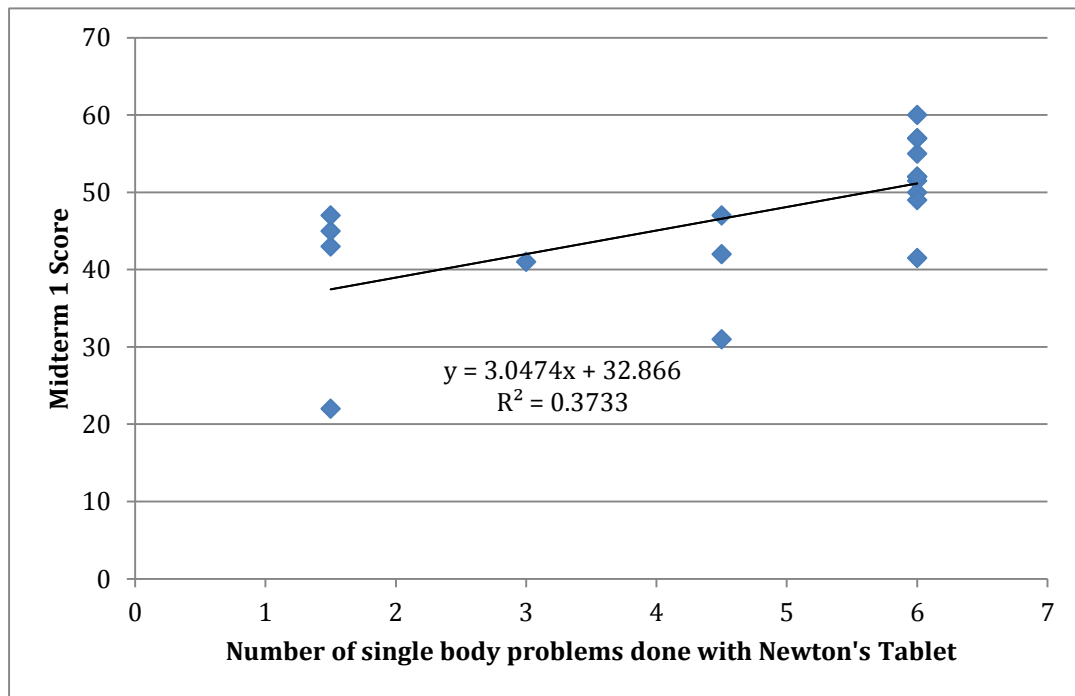


Figure 5.13.a

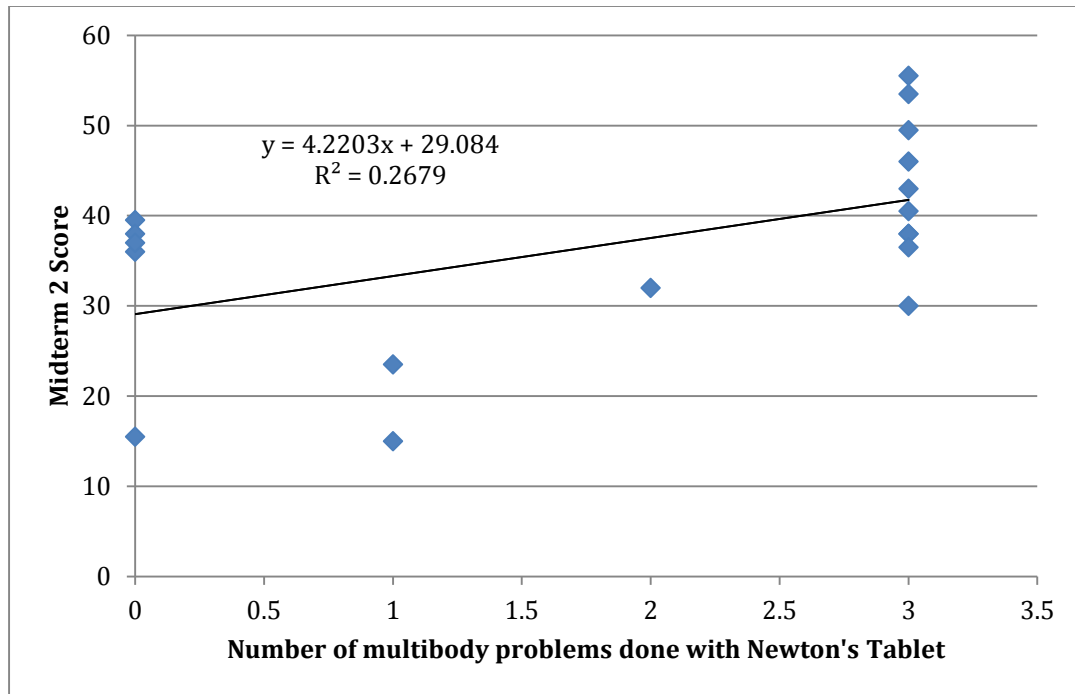


Figure 5.13.b

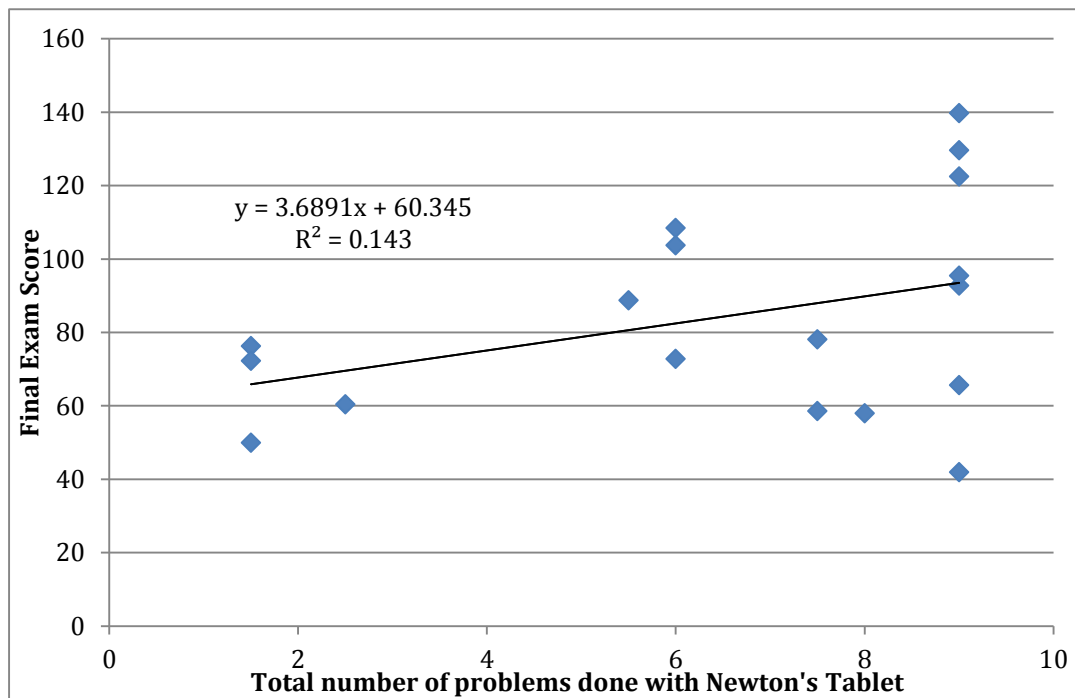


Figure 5.13.c

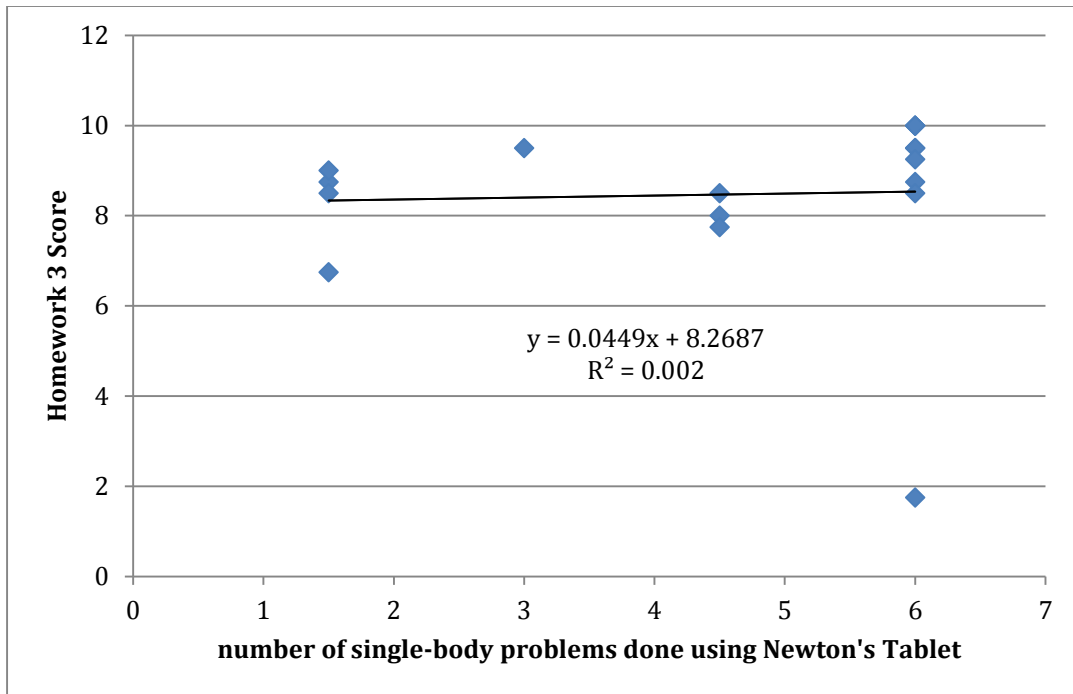


Figure 5.13.d

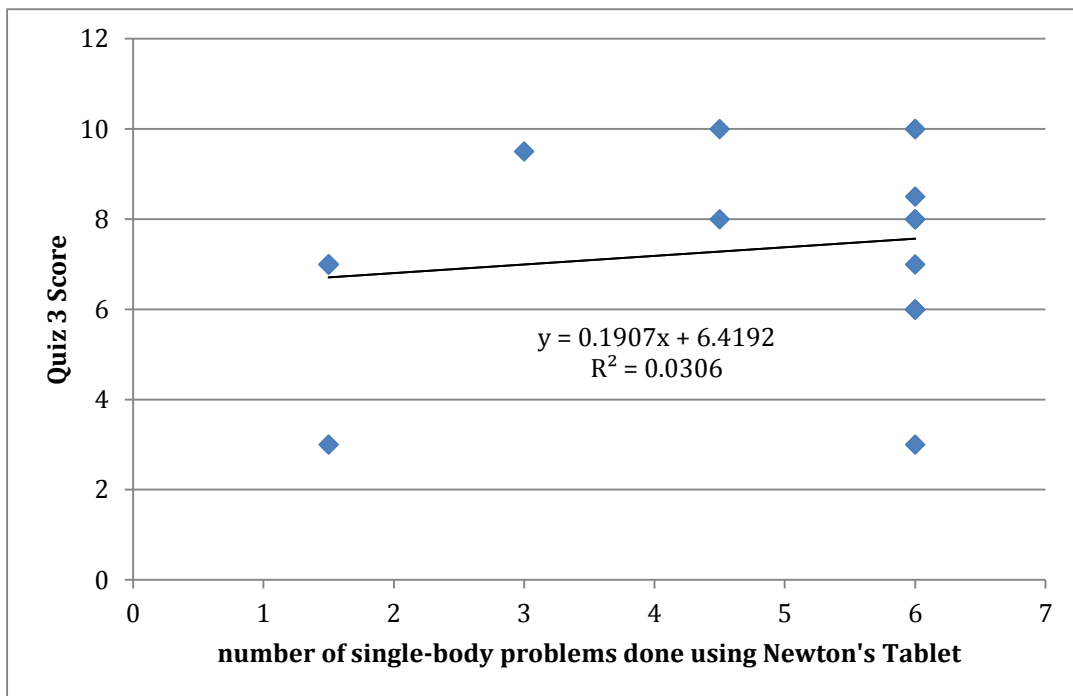


Figure 5.13.e

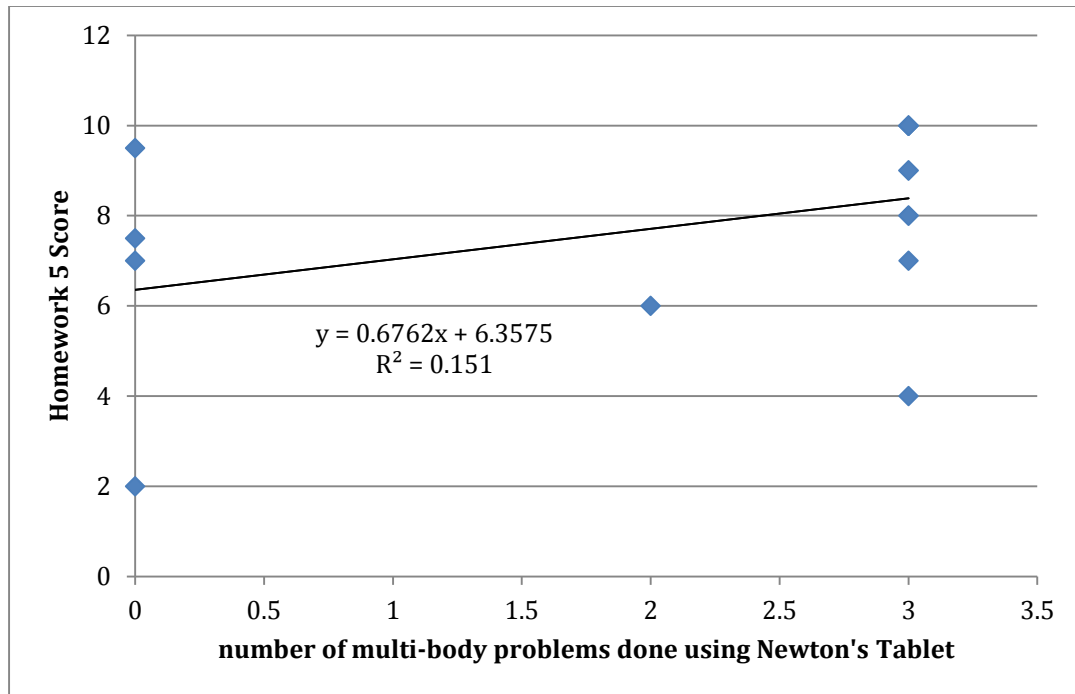


Figure 5.13.f

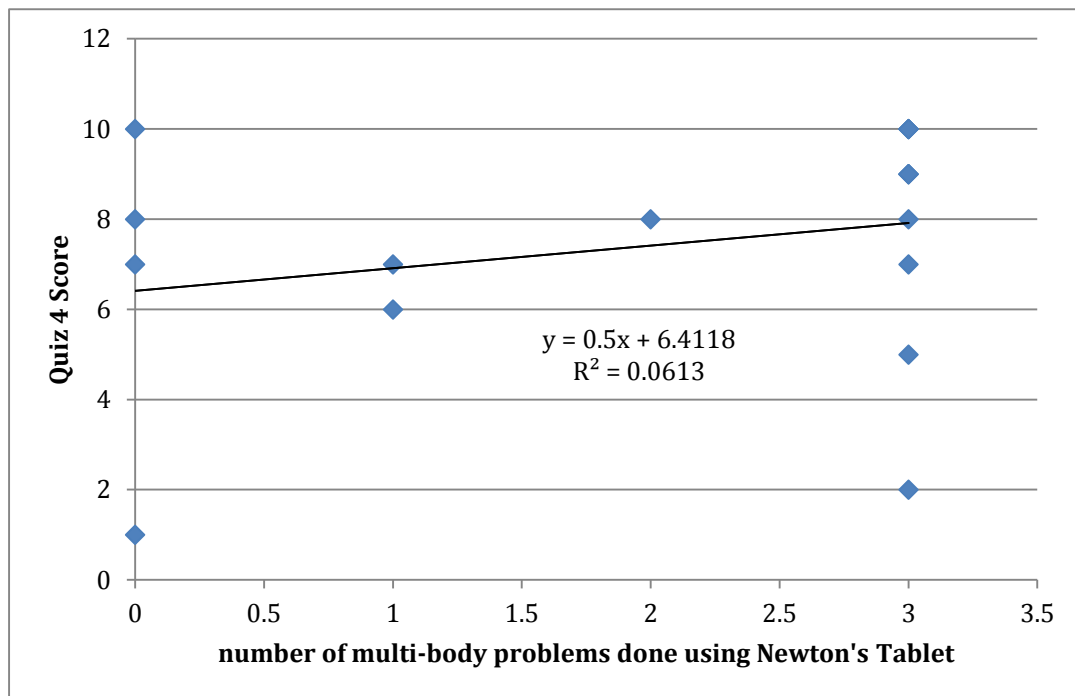


Figure 5.13.g: Figures 5.13.a-g plot performance against tutorial system usage

After attempting to find similar correlations in the data of the Newton's Pen group, the only thing that stood out with an R^2 greater than 0.07 was quiz 3 score versus the number of single-body problems done using Newton's Pen, which produced an R^2 of 0.3407. All other exam, quiz, and assignment scores did not show a very predictable pattern when plotted against the number of problems students reported having done with this version of the statics tutorial system.

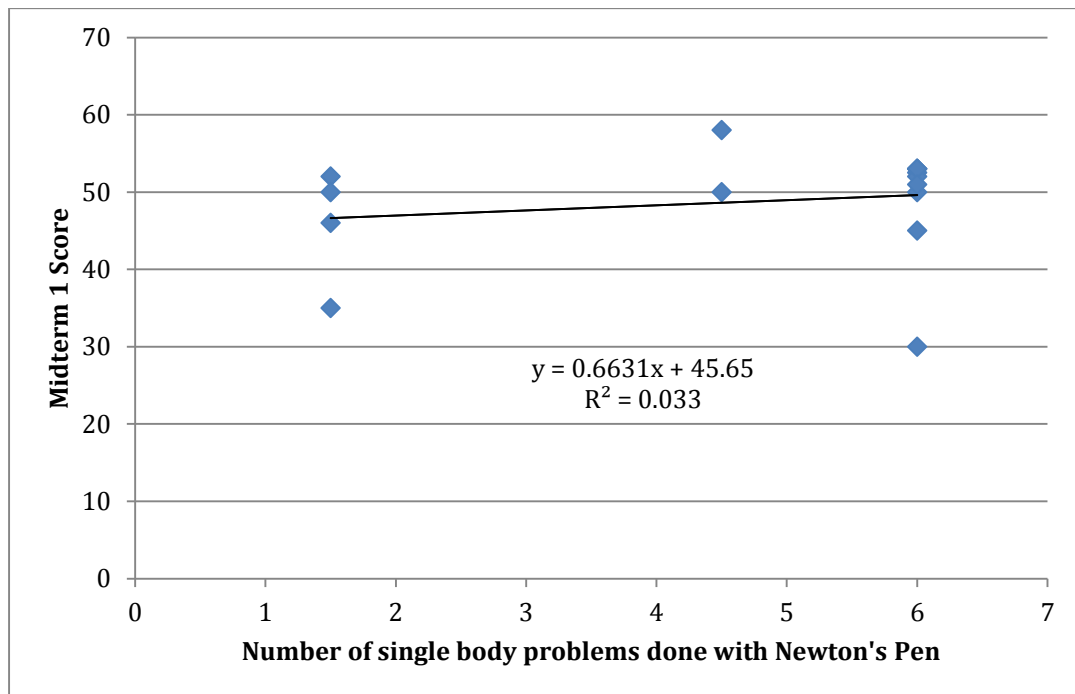


Figure 5.14.a

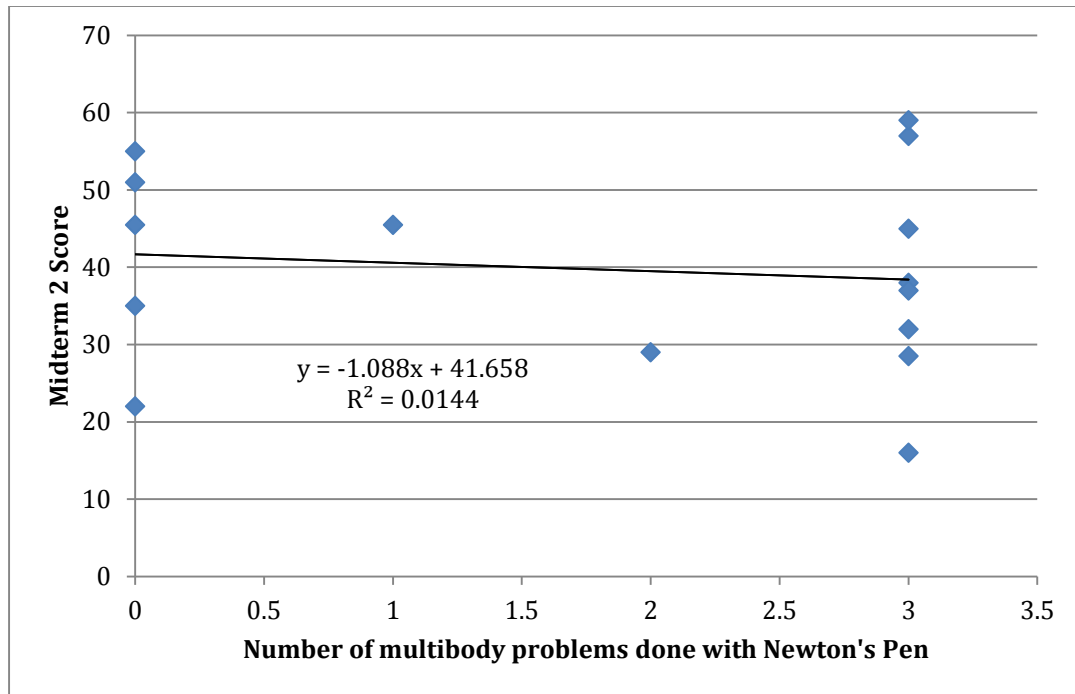


Figure 5.14.b

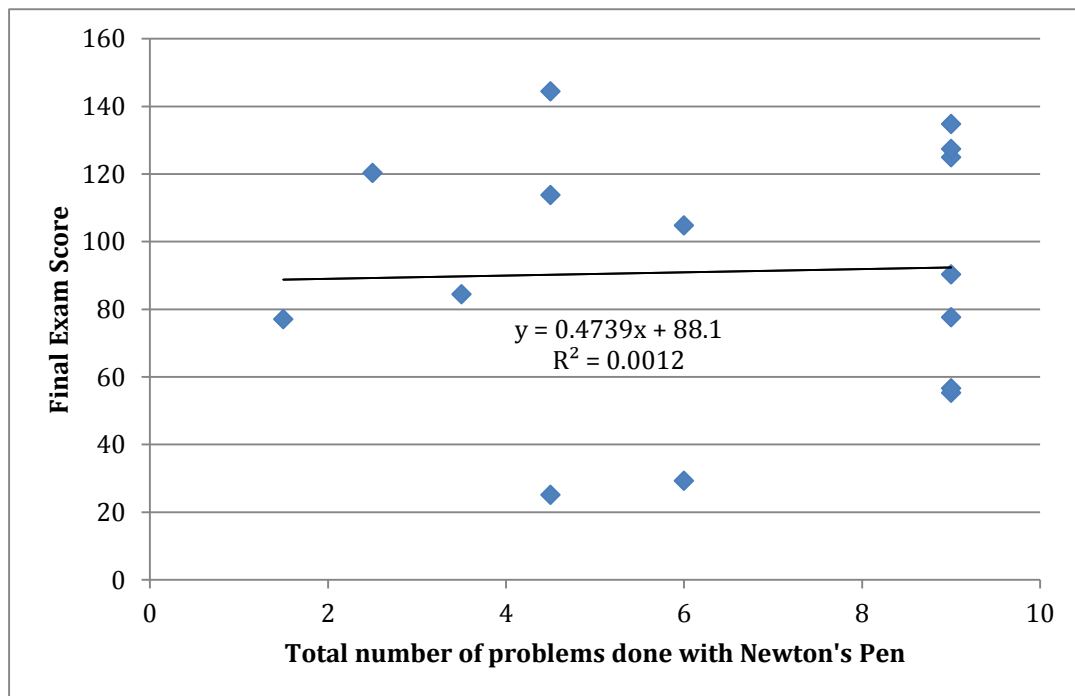


Figure 5.14.c

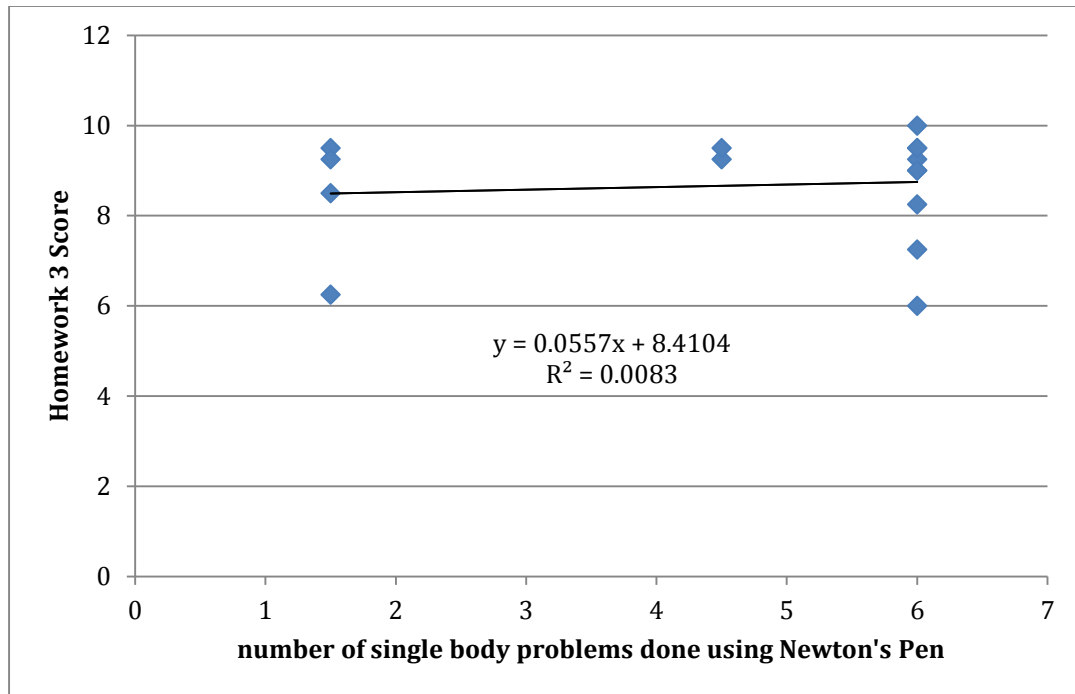


Figure 5.14.d

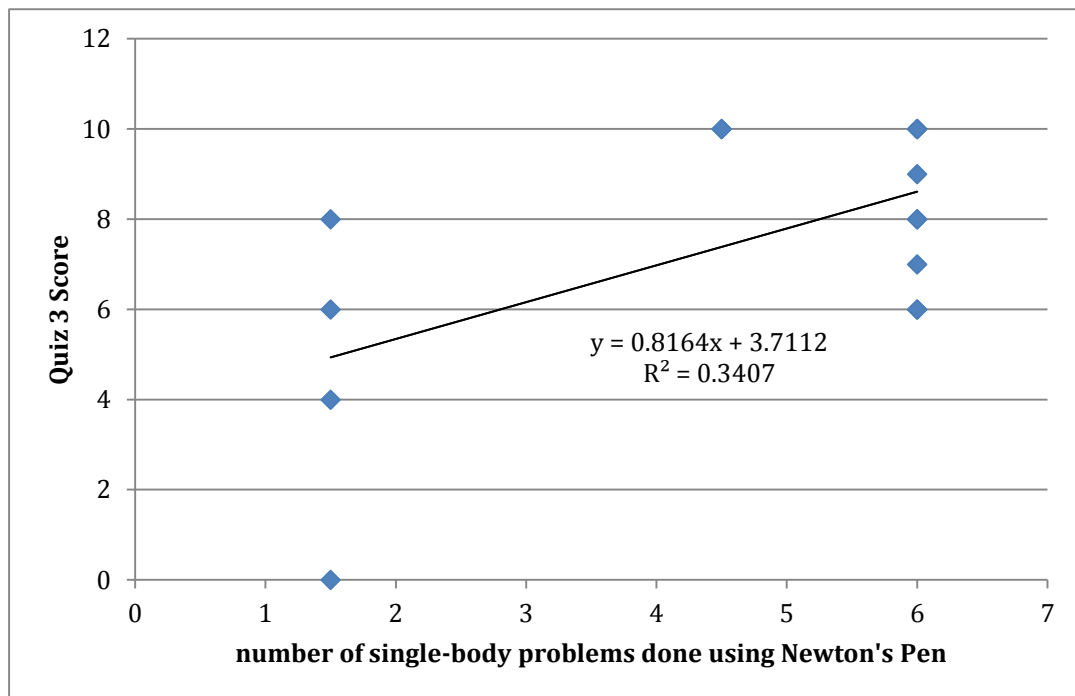


Figure 5.14.e

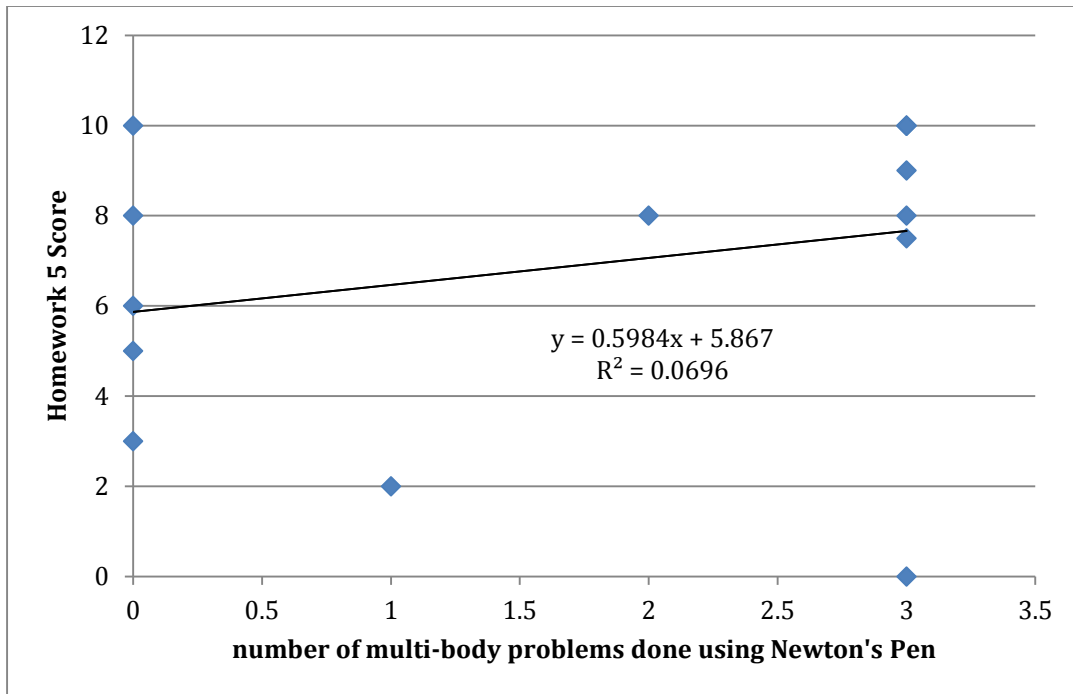


Figure 5.14.f

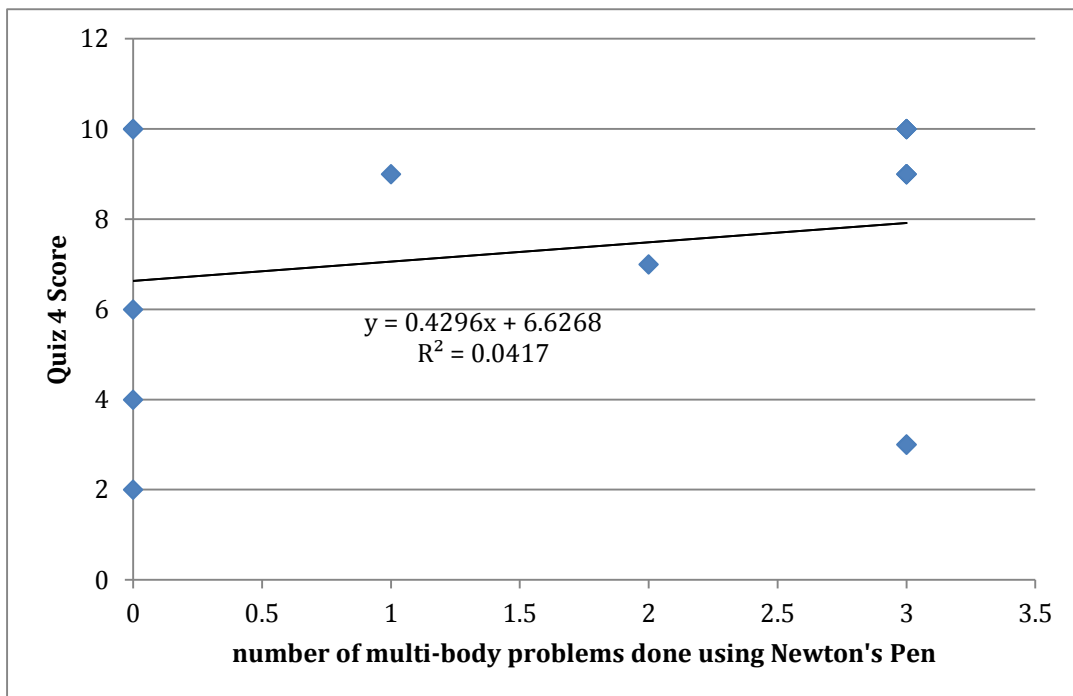


Figure 5.14.g: Figures 5.14.a-g plot performance against tutorial system usage

Lastly, the data of the paper-based special instructions experimental group revealed two fascinating results. There were only two R^2 values greater than 0.09, but one was the highest we found overall and one correlation was inversely proportional. For the relationship between the number of single-body problems completed whilst adhering to the extra instructions given and scores on the first midterm there was an R^2 of 0.4799. This means that almost 48% of the variance in this subset of students can be explained by this linearly proportional model whereby the more problems they did by following the special instructions, the higher their midterm exam scores. The surprisingly inversely proportional correspondence was that of homework 5 scores and the number of homework 5 problems done with the extra instructions; the R^2 for that correlation was 0.1855.

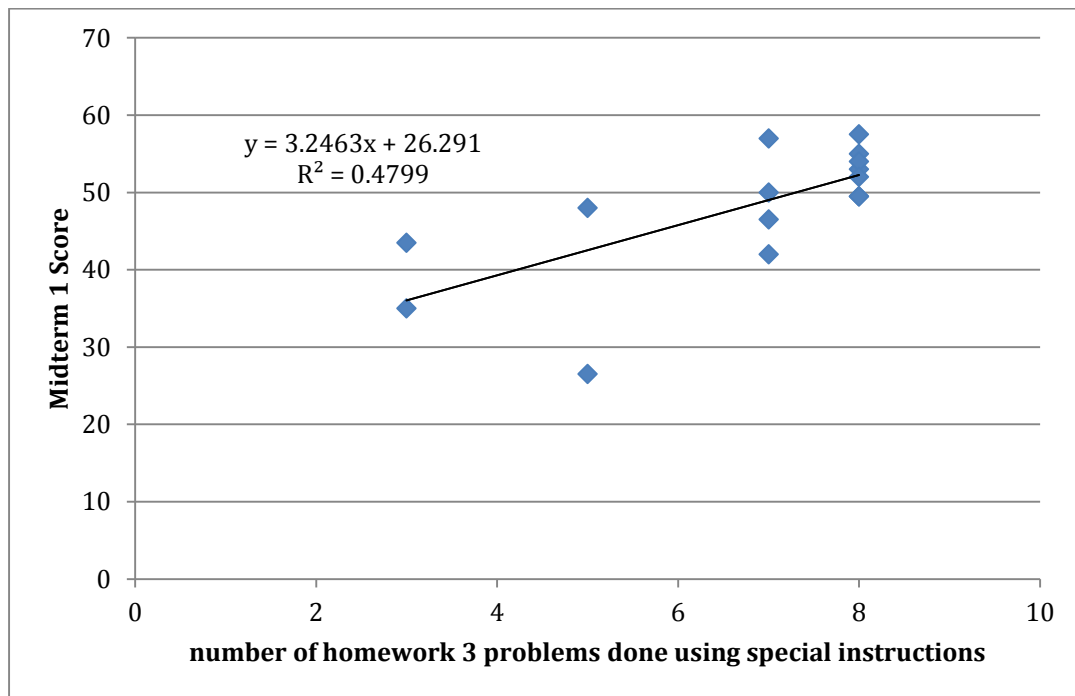


Figure 5.15.a

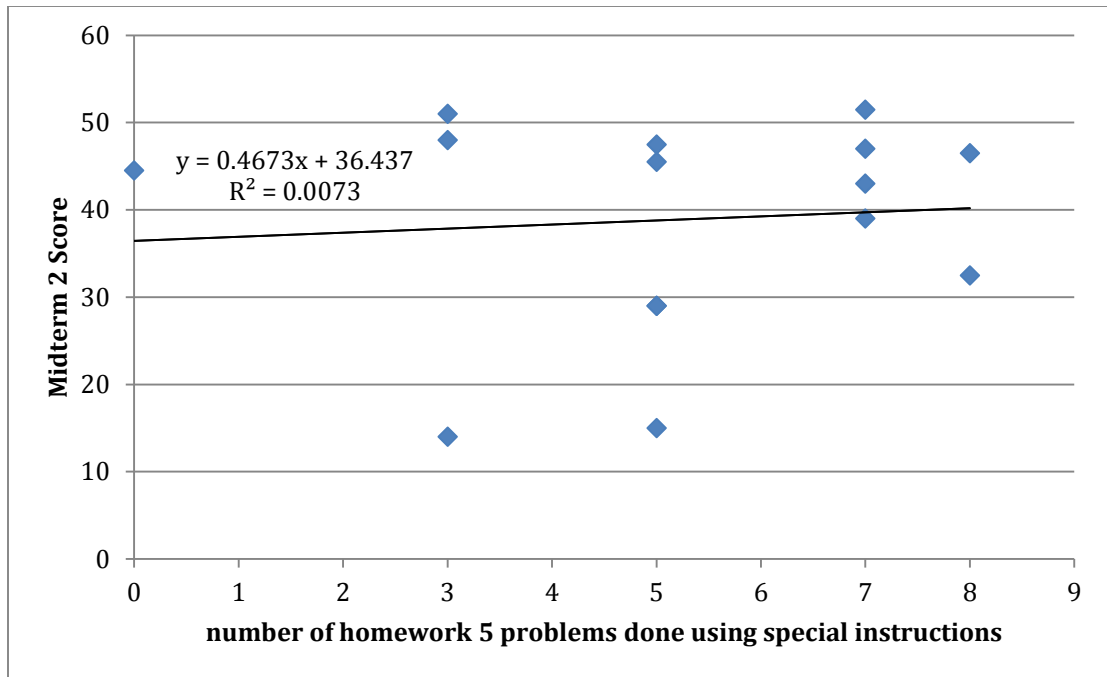


Figure 5.15.b

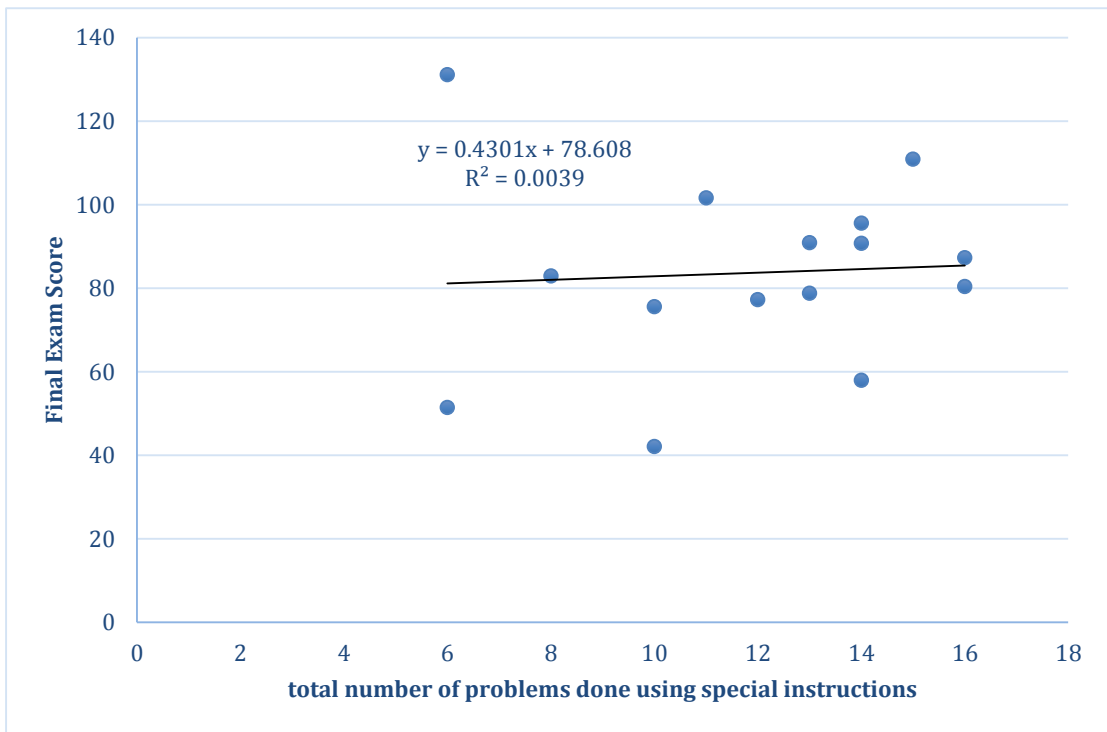


Figure 5.15.c

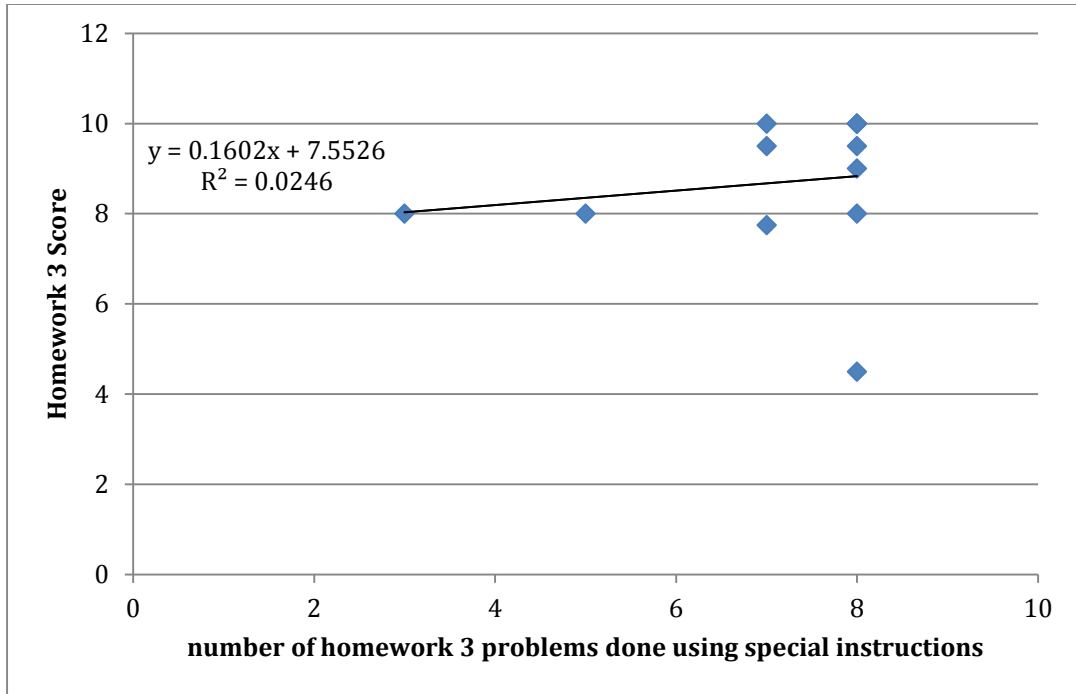


Figure 5.15.d

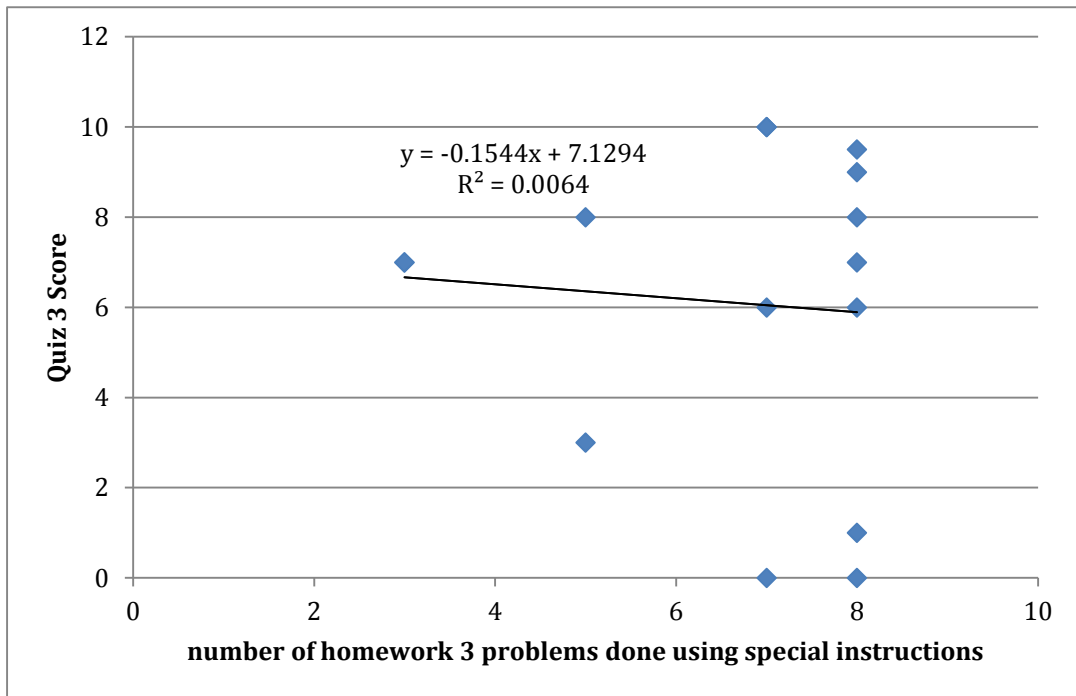


Figure 5.15.e

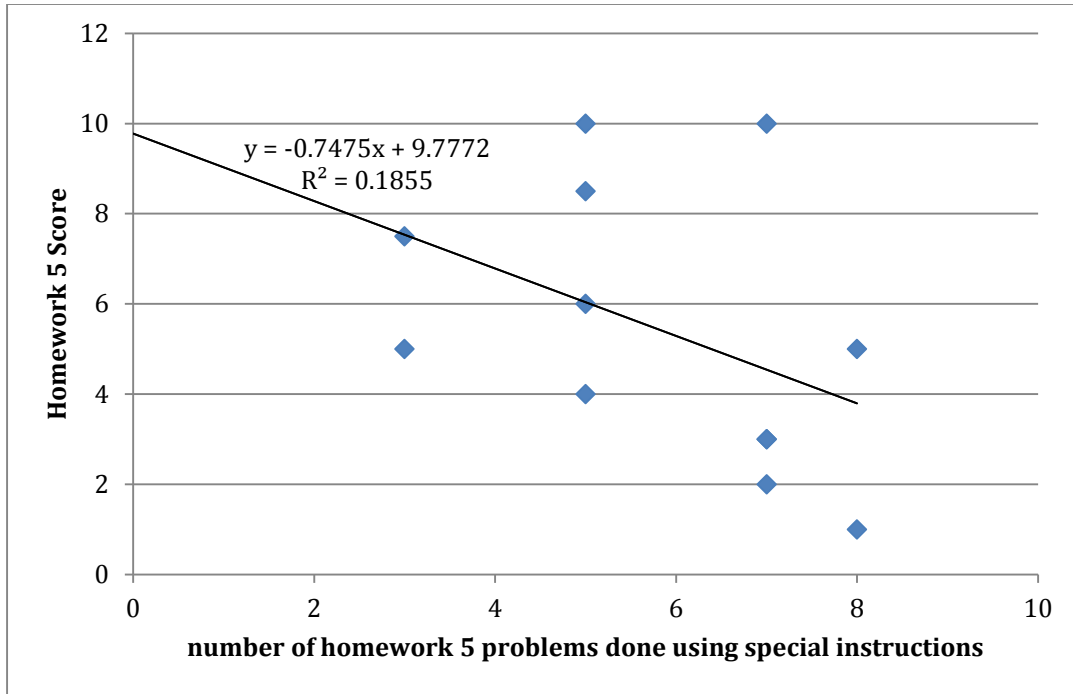


Figure 5.15.f

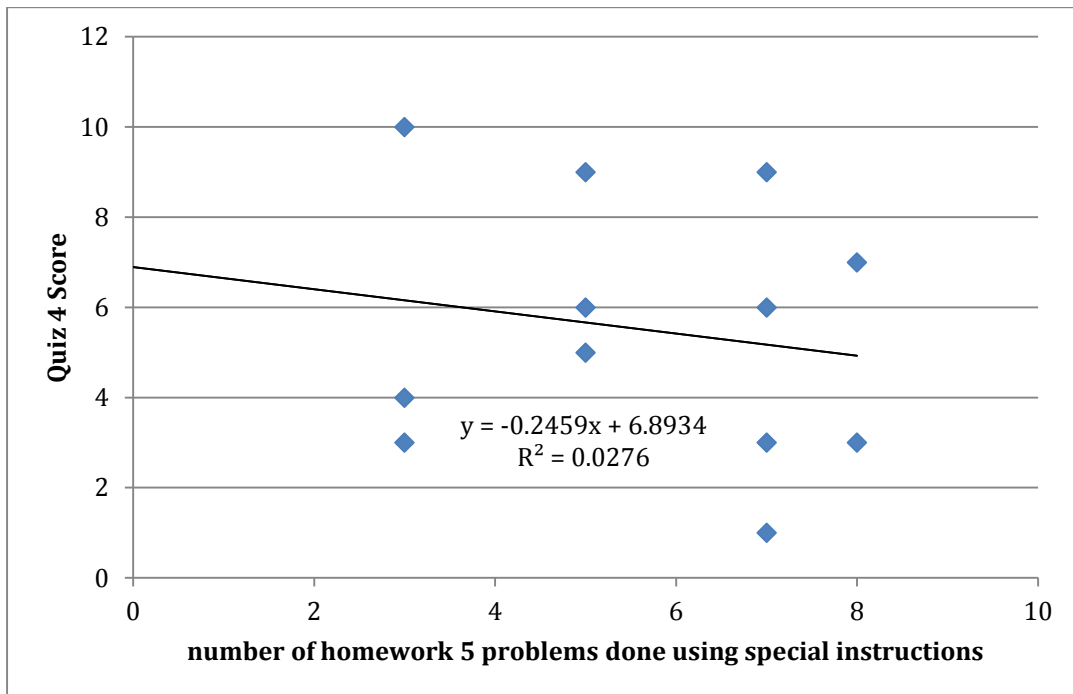


Figure 5.15.g: Figures 5.15.a-g plot performance against special instruction usage

This all reinforces the notion that the problem-solving approach espoused by the tutoring systems has merit, but that without the automatic feedback and guidance provided by an intelligent tutoring system, there comes a point where it can hinder rather than help students, especially when dealing with more complex problems such as those requiring multiple free-body diagrams. Of the two versions of the tutorial system that were tested, Newton's Tablet and Newton's Pen, the one that seemed to have the more promising positive outcomes was Newton's Tablet. It also has greater potential to be expanded to provide additional tutoring capabilities. The digital pen, by contrast, is limited by its low computational resources.

5.3 Tablet System Comparisons

The trial runs of the tablet systems produced the best results of student performance as a function of the attention students dedicated to it. Based on what we saw in both the winter 2013 and the separate user study, a tablet-based rather than pen-based smart tutoring system is the most promising. In comparing student reactions to the different experiments with the tablet-based systems, we see that on average the version students preferred was Newton's Tablet as presented in the user study. This is not yet a significant difference but one that was certainly noticeable in the attitudinal surveys.

The difference between the two iterations of Newton's Tablet, the winter 2013 ME10 version and the user study version, was mainly the addition of the equilibrium

equation capabilities but also the manner in which students were expected to work with it, in a haphazard manner versus a set number of problems in one sitting. Plus, there were minor technical fixes such as improved arrow and bracket recognition thresholds as well as additions to post-recognition on-screen gesture beautification, such as setting moment arm brackets to horizontal or vertical if the student intended them to be. The winter 2012 run of Jack's system happened in a controlled manner somewhat similar to that of the user study, but on average that system scored the lowest in all areas of the attitudinal surveys.

The surveys asked questions with answers on a Likert scale to gauge their responses to specific features of the systems in addition to overall reactions. The responses were then translated to a scale of zero to four, where four signals the most positive response and 0 the most negative. As can be seen below, the user study subjects were the most positive about the system as a whole, with the best scores in all but two of the categories presented.

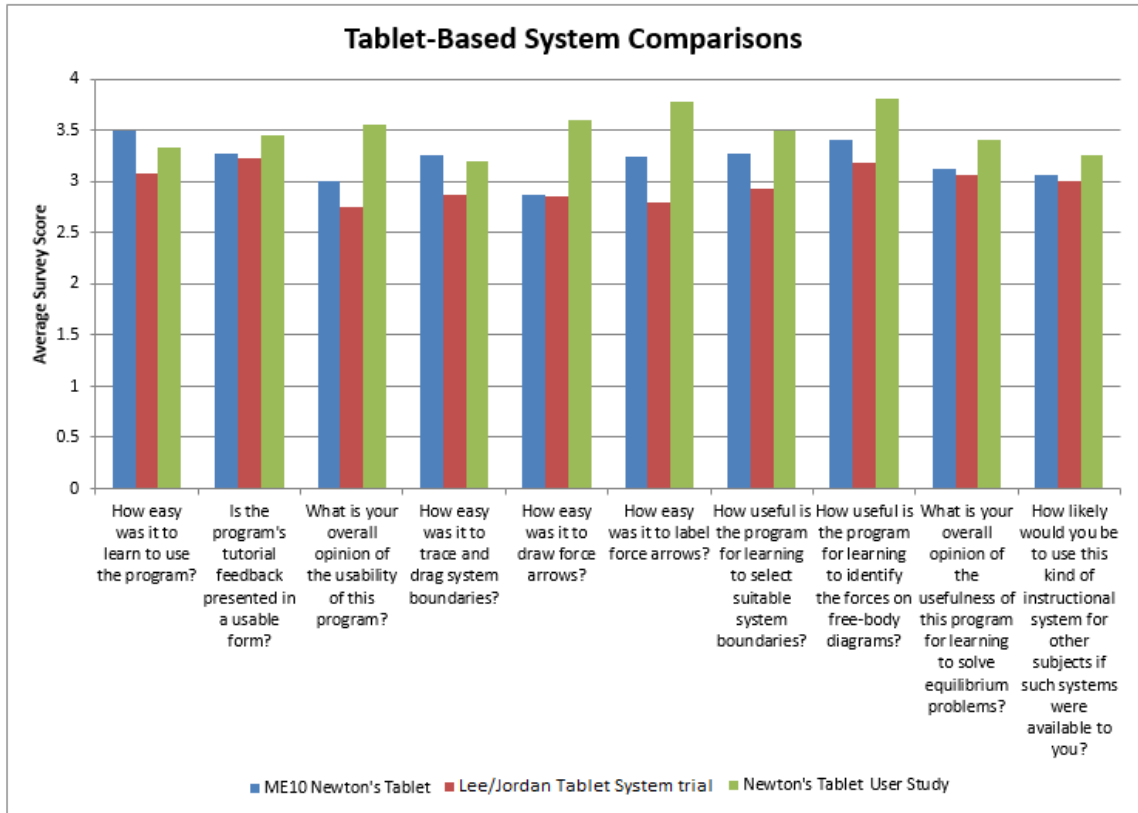


Figure 5.16: Comparison of tablet system attitudinal survey results

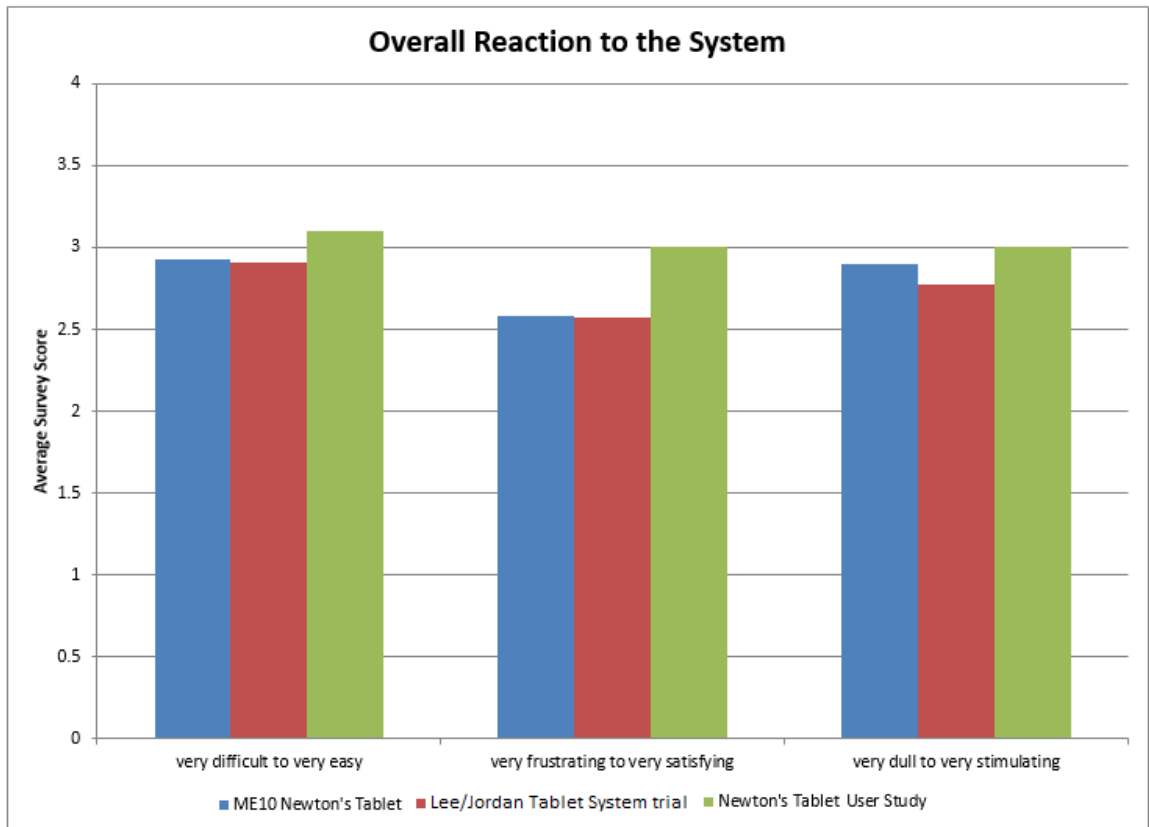


Figure 5.17: Comparison of tablet system attitudinal survey results

Chapter 6

Conclusion

In this thesis, we present an evaluation of tutoring systems designed to help student learn statics. Prior to developing these new tutoring systems, we conducted a study examining the usefulness of an intelligent tutoring system for statics developed by Lee and Jordan [4, 5]. We determined that the free form approach employed by this system might be better suited to advanced rather than novice students. To use this system, students had to already understand the necessary problem-solving steps. Students that were struggling with statics concepts were more likely to use trial and error to obtain the correct solutions as opposed to using the feedback from the program to learn the concepts.

From our evaluation of the Lee and Jordan system, we hypothesized that a more fine-grain problem-solving decomposition was needed to create a more effective instructional tool. Additionally, we hypothesized that separating conceptual reasoning from the mathematical expression of the concepts would facilitate learning. Our new tutoring systems, Newton's Tablet and Newton' Pen, were designed to test these hypotheses.

The experiments that we conducted in the winter 2013 offering of statics at UC Riverside, combined with a user study evaluating Newton's Tablet, demonstrated that our new systems were effective instructional tools. Our sample sizes for the different experiments were not as large as we would have liked because of low student compliance and low turnout from volunteers. However, those students who used the tutoring systems in the statics course performed, on average, better than those who did not, although the differences are not statistically significant. The user study, on the other hand, did provide compelling evidence of the effectiveness of Newton's Tablet. This may indicate that the tutoring systems are most effective when students use them in earnest.

Our results show that students can learn how to solve statics problems with the help of Newton's Tablet. Its unique problem-solving methods bring to the forefront many of the underlying decisions that those that have mastered the subject take for granted, like deciding which forces are acting on a rigid body and how best to model them. Learning how to use the system itself does not present a major hurdle to the users. Furthermore, after using the system in our user study, novices performed on par with more experienced students.

Intelligent tutoring systems can play an important role in undergraduate engineering education, where class sizes can limit the amount of time professors and teaching assistants spend one-on-one with each student. Increasingly ubiquitous tablet technology and the results from our experiments hold the promise that Newton's Tablet can be used on a large scale as an effective teaching tool.

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Appendix

The materials included in this appendix are some of the supplementary materials students were provided online. Other materials including other user guides and the problems that were part of the tutorial systems can be found in the thesis of Levi Lindsey [8].

Newton's Pen

Quick Reference Guide

1. Read the pen display

- Read the pen display; it will tell you what to do next.
- After writing, always look at the display for the pen's response before continuing.

2. Point of Interaction (POI) and Interaction Types

- There may be multiple interactions to take into consideration at any particular POI.
- Using the buttons on the problem description page, select each of the relevant interaction types. (Make sure the pen responds to each button tap.)
- Tap the "POI Done" button when you have identified all relevant interaction types for the POI you are currently working on.

Applied Force (AF)	Tension Force (TF)
Weight Force (WF)	Roller Joint (RJ)
Smooth Contact (SC)	Pivot Joint (PJ)
Contact/Friction (CF)	POI Done

3. Drawing Arrows

- Arrows must be drawn using a single stroke.
- Draw arrows from tail to head.
- Either the tip or the tail of each arrow must be inside a POI circle.
- Make sure arrows are not too short (an inch long is good).
- If your arrow is not recognized, the pen will inform you of this. Simply draw it again.

4. Entering Arrow Labels

- After you write the label on the page, use the keyboard key in the label when prompted to do so by the pen. Tap the "YES" button when you have finished keying in the label.
- Except for the names of applied forces, you cannot reuse labels that exist in the problem description.

5. Pivot Joints (and their labels)

- Pivot Joints are modeled by two forces which are aligned with the x and y axes.
- In accordance to Newton's Pen convention, these arrows must have labels that share a base character and end in X and Y respectively. (e.g., BX and BY)

6. Erasing

- To erase an arrow (which has previously been successfully recognized and labeled), tap the "ERASE" button to enter erase mode.
- Cross out arrows using single strokes.
- Tap the "ERASE" button one more time to exit erase mode.

7. Exploring error messages

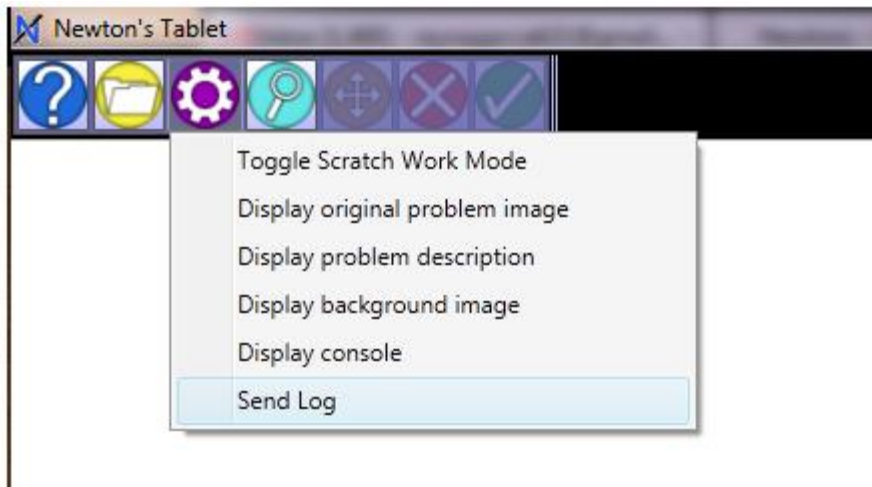
- Use the arrows on the problem description page to navigate through error/help messages.
- Scrolling up and down will select different errors.
- Scrolling to the right will give you more information about the current error.



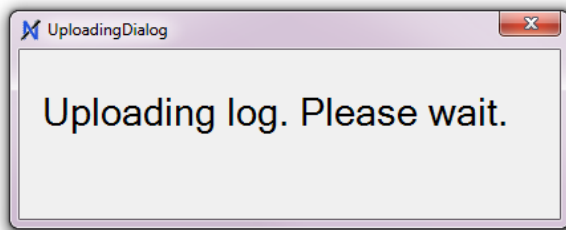
How to submit Newton's Tablet log files

Once you have finished working through the homework problems using Newton's Tablet, click on the "Adjust program settings" button (the gear with the purple background) and select "Send Log" from the dropdown menu.

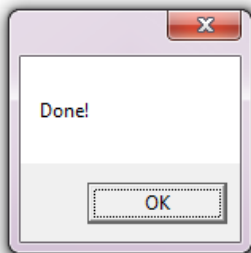
Note: You do not have to work through all of the problems in one sitting; your log files are automatically saved. Only submit your log files once you have finished working through all of the assigned problems.



When you click on "Send Log," the following dialog box should appear:



A popup will let you know when the files have been successfully sent.



Click 'OK' and close the Newton's Tablet program window.

Newton's Tablet

Menu Buttons

- a) **General help**
 - Tapping on this button brings up a popup window which provides help for general system usage for the current stage.
- b) **Load a new problem**
 - Tapping on this button displays a list of problems which you can load to work on.
- c) **Settings**
 - Tapping on this button displays a list of some technical program settings.
- d) **Query mode**
 - Tapping on this button toggles whether tooltips will appear describing your previous work when the cursor hovers over the canvas.
- e) **Drag mode**
 - Tapping on this button toggles whether you can drag and re-space your selected system boundaries.
- f) **Erase mode**
 - Tapping on this button toggles whether your strokes are meant to erase parts of your work for the current stage.
- g) **Check work**
 - Tapping on this button prompts the system to check whether your work is successful for the current stage.

The screenshot shows the Newton's Tablet interface with a beam problem. The top bar contains menu buttons labeled a through g. Below the toolbar is a 'Trace boundaries' status bar. The main workspace shows a beam with forces P , F , and R and distances L_1 , L_2 , L_3 , and L_4 . A callout box on the left contains the problem image and description. A callout box on the right explains the status bars. A callout box at the bottom explains the workspace. A callout box at the bottom left explains stage-specific buttons.

Problem Image and Description

- These popups describe the overall system for the current problem and can be collapsed by tapping on them.

Status Bars

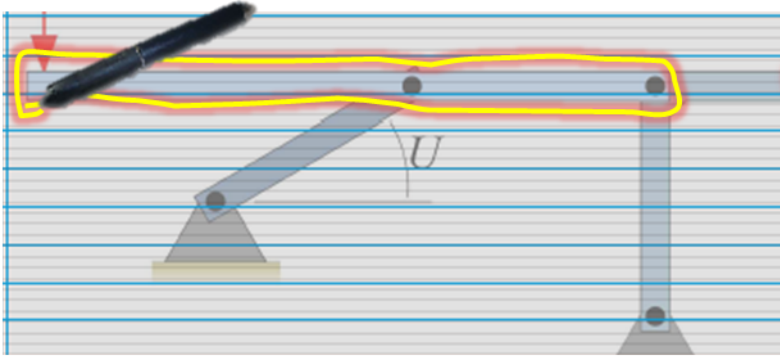
- These two status bars instruct you as to what you should be doing to solve the current stage.
- There are two buttons on the side here which allow you to review previous messages.

Workspace

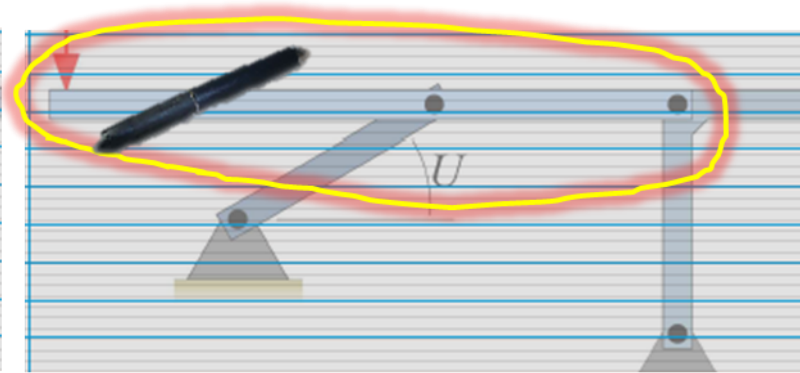
- This main workspace is where you draw all of your work in the process of solving a statics problem.

Stage-Specific Buttons

- Some stages will display dynamic buttons here and will then prompt you how to use them.



OK



BAD