ViPS

An Intelligent Tutoring System for Exploring and Learning Physics through Simple Machines

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Abstract: Students tend to retain naive understandings of concepts such as energy and force even after completing physics lessons in science classes. We developed a learning environment called the Virtual Physics System (ViPS) to help students master these concepts in the context of pulleys, a class of simple machines that are difficult to construct and experiment with in the real world. Several features make ViPS unique: it combines simulation and tutoring, it customizes tutoring to address common misconceptions and it employs a pedagogical strategy that identifies student misconceptions and guides students in solving problems through virtual experimentation. This paper describes the ViPS system and studies in which we evaluated its efficacy. Our results indicate that ViPS is effective in helping students learn and overcome their misconceptions.

1 INTRODUCTION

Computers have been extensively used in education since the sixties (Martin and Mitrovic, 2001). Teachers and students use computers in all aspects of education such as researching, organizing information, and doing or grading homework. At the present time, it is hard to imagine a modern education without computers. The use of computers can be beneficial for teachers and learners. Intelligent Tutoring Systems (ITS) exemplify this benefit, by tracking a student's progress and providing tailored feedback and hints along the way. By collecting information on a particular student's performance and modelling that student's progress, an ITS can make inferences about a student's strengths and weaknesses, and can suggest additional work. This paper presents the design and evaluation of an intelligent simulation and tutoring system called the Virtual Physics System (ViPS) for exploring and learning physics concepts within the context of a particular class of simple machines.

Our research is part of a large multi-university project to investigate the teaching and learning of physics concepts in middle schools. We have seen that it is difficult for a teacher to track the progress of students individually in a class with many students. A teacher may not always know who is having difficulty during group work in the class or laboratory, may not be able to tell why a student is having difficulties, and may not have enough time to look into every student's needs in a large class. A tutoring system coupled with an experimentation and simulation environment, on the other hand, will be able to track each individual student's problem solving activities, such as the construction of a simple machine, the running of it, and solving problems based on such simulations, and provide individualized feedback. This is the primary motivation behind the development of ViPS. One goal of middle school science instruction is to inculcate deep knowledge of fundamental physics concepts such as energy, force, work and mechanical advantage in students through hands-on work with simple machines like inclined planes, levers and pulleys. However, learning about simple machines, especially pulley systems, is in itself a challenging task for many students. In addition, teachers face the difficulty of helping students abstract what is learned in the context of hands-on work to a more general understanding of physics concepts. Several design and project-based approaches have integrated software and innovative curricula to address this. Though students have exhibited better understanding following such interventions, there is still room for improvement as mis-

conceptions regarding important physics concepts persist often into college years.

We addressed this problem through a two-pronged approach: (1) by making it easier for students to construct, simulate and experiment with simple machines in a virtual environment, and (2) by integrating a tutoring component with the simulation component. We chose one class of simple machines, pulley systems, as the domain for the tutoring and simulation environment because students generally find pulleys harder to understand than simpler machines like inclined planes. Another reason for this choice is that complex pulley setups (e.g., those involving compound pulleys with multiple grooves or many movable pulleys) are so difficult to correctly build and experiment with in the real world within the limited class time available that teachers tend to limit hands-on activities to very simple setups only. Furthermore, there are experimental setups such as those with no friction that are impossible to construct and test in the real world. The rest of this paper is structured as follows. Section 2 discusses research literature that forms the background of our work. Section 3 describes the architecture of the simulation and tutoring system ViPS. Section 4 presents empirical evidence for the efficacy of ViPS and section 5 concludes the paper.

2 BACKGROUND

Tutoring is an instructional activity known to improve student learning. For instance, Reiser, Anderson and Farrell (1985) reported that students working with private tutors could learn material four times faster than students who attended traditional classroom lectures, studied textbooks and worked on homework alone. When a human tutor is not available, the next best option maybe an Intelligent Tutoring System (ITS). An ITS is a computer-based instructional system that has knowledge bases for instructional content and teaching strategies. It attempts to acquire and use knowledge about a student's level of mastery of topics in order to dynamically adapt instruction. Anderson & Skwarecki (1986) reported that an ITS is a cost-effective means of one-on-one tutoring to provide novices with the individualized attention needed to overcome learning difficulties. ITS have been built for various domains such as mathematics, medicine, engineering, public services, computer science, etc. (Ritter el al., 2007). The potential of ITS for helping students learn is well recognized.

Another learning activity that is beneficial is problem solving through experimentation. It is a hands-on activity that involves designing and building an experimental setup, letting it perform its function and collecting data from it in order to solve a problem, to better understand the underlying phenomena or to test a scientific hypothesis. Computer modelling and simulation often take the place of physical manipulation in this learning activity. Many researchers have described the affordances and limitations of problem solving using physical manipulatives and computer simulations in science education research (de Jong and Van Joolingen, 1998); (Finkelstein, et al., 2005); (Triona, et al., 2005). Zacharia and Anderson (2003) investigated the effects of interactive computer-based simulations, presented prior to inquiry-based laboratory experiments, on students' conceptual understanding of mechanics. They found that the use of simulations improved students' ability to generate predictions and explanations of the phenomena in the experiments. Triona and colleagues (2005) investigated how physical and virtual manipulatives affected student learning about mousetrap cars. Students used either physical or virtual manipulatives to design their cars. The physical and virtual treatments showed the same effectiveness in helping students design cars. Finkelstein and co-workers (2005) looked at how students learned about electrical circuits differently with virtual or physical manipulatives. The simulations used by the students were similar to the physical materials, except that the simulations showed electron flow within the circuit, which the physical materials could not. They reported that the students who had used virtual manipulatives, i.e. the simulations, scored better on an exam and were able to build physical circuits more quickly than students who used physical manipulatives. Zacharia et al., (2008) looked at physical and virtual manipulatives in the context of heat and temperature. One group of students used physical manipulatives, while other group of student used physical manipulatives followed by virtual ones. Students who worked with physical followed by virtual manipulatives performed better on a conceptual test than students who only used the physical manipulatives. The authors' conclusion was that one reason for the addition of simulation increasing student learning was that simulations could be manipulated more quickly than physical setups.

Our research combines these two strands of tutoring and experimentation by designing and testing a system, ViPS, that has both intelligent tutoring and virtual experimentation capabilities. ViPS is able to provide guided tutoring to a student as he or she

solves physics problems involving pulleys. ViPS also allows the student to construct, run and collect data from complex as well as simple pulley setups.

The interfaces of ViPS have been designed in congruence with the Cognitive Theory of Multimedia Learning (Mayer, 2009), and its tutoring employs the instructional technique of Coached Problem Solving (Conati et al., 1997). Furthermore, ViPS is designed to detect and help address the following misconceptions regarding pulleys that students commonly exhibit (see Table 1).

Table 1: Different misconceptions tutored by ViPS.

	Definition
Misconception 1	The more pulleys there are in a setup, the easier it is to pull to lift a load.
Misconception 2	The longer the string in a pulley setup, the easier it is to pull to lift a load.
Misconception 3	Pulling upwards is harder than pulling downwards.
Misconception 4	Having more pulleys in a pulley setup reduces the amount of work.
Misconception 5	Size (radius) of pulleys in a pulley setup affects the amount of work.
Misconception 6	Improper understanding of force and work.

ViPS detects which of these misconceptions a student has by asking the student to solve a set of problems at the beginning. This involves answering questions about pulley setups after constructing and running them in the simulation environment. Based on this, ViPS constructs a student model. This model, which is continually updated throughout the tutoring session, is used for generating additional problems for the student to solve, and for providing hints and other kinds of feedback based on the students' knowledge state. As far as we know, ViPS is the first system to integrate a virtual experimentation environment with a tutoring component specifically tailored to address student misconceptions.

3 DESCRIPTION OF VIPS

ViPS provides a student with an interactive simulation and tutoring environment in which pulley setups can be created and simulated. Components required for pulley setups can be created and manipulated using a drag and drop interface. Students are asked by ViPS to solve problems in this environment by creating and running pulley simulations. As a student is working towards a solution, the system keeps track of his or her actions and provides feedback to help the student make progress.

The architecture of ViPS, implemented in Java, is shown in Figure 1. It consists of a graphical user interface that manages interaction with students, a simulation module that creates and simulates the pulley setups built by students, a feedback module that generates appropriate messages for the student, a knowledge evaluator that evaluates the knowledge of the student, a tutor module that tutors the student for misconceptions, a student model that includes the history of student interactions and various measures of student performance, a domain knowledge model that represents domain knowledge, a database of problems, and a procedural knowledge model that represents student solution paths within individual problems. We briefly describe these components below (more details may be found in Myneni, 2011).

3.1 Graphical User Interface

The graphical user interface is responsible for all the interactions with the student. This interface is divided into two main parts: a tabbed work area for creating pulley setups and solving problems, and an object pallet for selecting the components required to create a pulley setup. A snapshot of the interface can be seen in Figure 2. Using this interface, students can create a pulley setup by dragging the required components from the object pallet on to the work area and clicking on the thread button. Students can also interactively manipulate various parameters of the components, like the size of a pulley, value of the load etc. A problem is given to the student in the form of textual and pictorial representations (see Figure 3). The student is asked to solve the problem by creating the setups required to answer the question, running the simulations and comparing the simulation outputs of the setups created. The problems in ViPS were designed and checked by experienced physics educators. Currently, ViPS contains ten problems per misconception (60 in total, with more to be added in future) in its database. A web-based interface is available to teachers and experts to add or modify the problems. The reason ViPS poses problems to a student is to first identify his/her misconceptions and then to address them through coached problem solving.

3.2 Knowledge Evaluator

When a student first initiates ViPS, a pre knowledge test, in the form of problems to solve (see Figure 2 for an example), is given. Once the student finishes the test, his/her answers are evaluated by the knowledge evaluator to estimate the student's initial
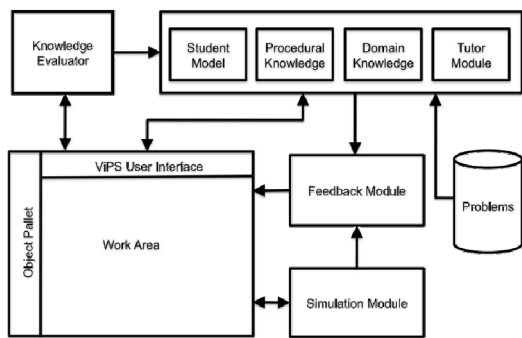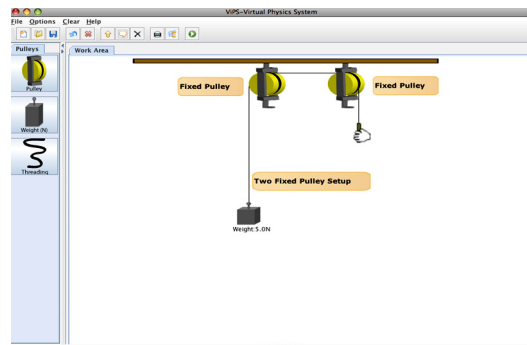
Figure 1: Architecture of ViPS.
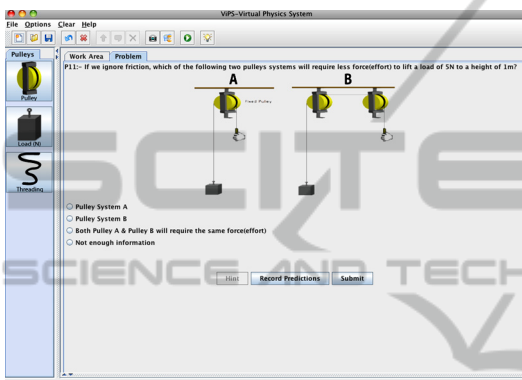

Figure 2: ViPS work area.
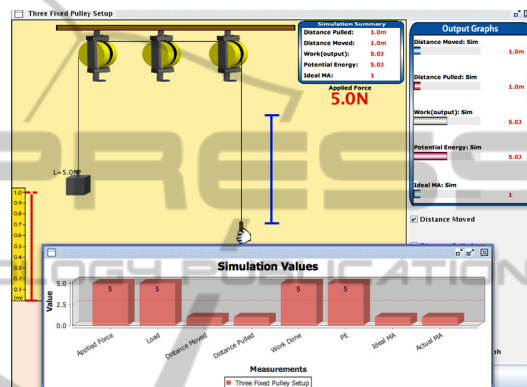

Figure 3: ViPS problem pane.

Figure 4: ViPS simulation window.

knowledge level and to identify the misconceptions he/she might have so that a subsequent sequence of problems can be generated for the student to solve in a tutoring session. Similarly, a post knowledge test is given to the student after the completion of a tutoring session, and the answers are evaluated by the knowledge evaluator to determine the student's post knowledge level and the status of each misconception identified from the pre-test.

After helping students to clear a particular misconception that the system is currently addressing through problem solving or tutoring, a follow up test is given in order to estimate the knowledge acquired by the students from problem solving or tutoring. After the students exits the tutor module, a post knowledge test is also given to evaluate the status of all misconceptions detected from the pretest. Results from the post knowledge test are used to determine whether a student retained the acquired knowledge through the end of the session. The knowledge evaluator is responsible for evaluating the students' knowledge retention.

3.3 Simulation Module

The simulation module is responsible for creating and simulating the setups created by the student. In particular, it provides a platform for running simulations of setups that are difficult or impossible to create in the physical world, such as running a simulation with zero friction or running a simulation with quintuple pulleys. The outputs generated by the simulation include graphs and real time values of variables like force, work done, potential energy, friction and mechanical advantage (see Figure 4). The student uses the simulation module to run the different pulley setups he/she creates during problem solving. The domain knowledge of the simulation model regarding possible or valid pulley setups is represented in the form of a Bayesian Belief Network. This network is used by ViPS to 1) find all possible setups that can be created using components that an individual student has created on the work area, 2) find components for creating a valid setup that are missing from the work area, and 3) generate dynamic hints regarding pulley setups based on student actions. ViPS generates all possible setups that the student may possibly have in mind, based on the components that the student created in the work area. This setup inference process is illustrated by the example in Figure 5. Figure 5(a) shows the part of the network corresponding to a single compound
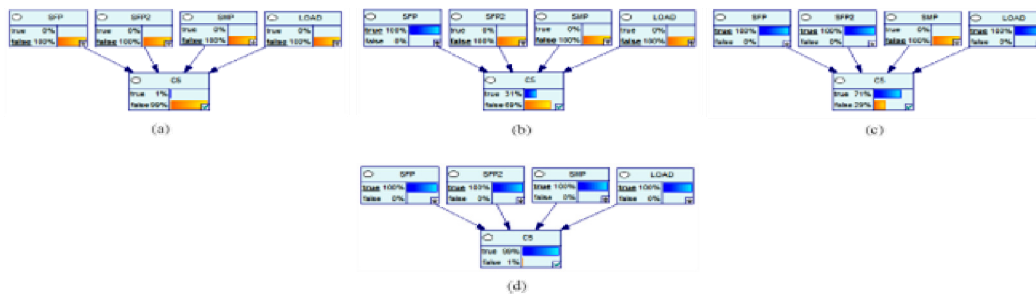
Figure 5: Setup inference using Bayesian Network.

pulley setup with extra pulley (C5). Initially the probability of this setup is zero or false (indicated by the orange bar in the figure). As the student creates a fixed pulley (SFP) in the work area, this evidence updates the network as shown in Figure 5(b). The probability of SFP is updated to 1 or true (indicated by the blue bar in the SFP box), and this results in an increase of the probability of C5. There is a further increase in the probability of the setup C5 when the student now adds a second pulley and a load (probability increases from 31% to 71%, indicated by the length of the blue bar in the C5 box) (Figure 5(c)). The probability for C5 increases to 99% upon the addition of a movable pulley to the existing setup (Figure 5(d)). This example shows how ViPS infers the intended setup if all the required components for that particular setup are present in the work area.

It is possible that the components assembled by a student do not lead to a unique pulley setup, and instead can be used to produce several possible setups. If this happens, ViPS infers and displays a list of possible setups based on the probabilities of creating each setup as determined by the Bayesian network, and ranked by an algorithm that we developed. This algorithm uses four attributes to rank order possible setups: (1) the number of components needed by a setup that are missing from the work area; (2) the number of grooves in each pulley in the setup; (3) the total number of components in the setup; and (4) the number of times this setup was created by the student previously. The rank of each setup is determined based on these attributes. For example, a possible setup with fewer number of components missing from the work area will have a higher rank than a setup with more missing components. In other words, higher the number of missing components, the lower the rank. Similarly, the algorithm ranks simpler setups containing fewer number of components and pulleys with fewer grooves higher than more complex setups, and also ranks setups that the student had previously created higher. Once the rank ordering is complete, the system displays the top five setups to the student. Then the

student is asked about which of these setups most closely match his or her intention. Based on the students' selection, the simulation module generates dynamic hints to guide the student towards the completion of the intended setup in the work area.

3.4 Student Model

The student model includes information about each individual student's interactions with the system, pre and post knowledge levels and misconceptions (as identified from the tests), and the past problem solving behavior of the student. A Bayesian inference network is used to update the student model (Mislevy and Gitomer, 1996); (Conati et al., 1997).

A classical approach on how people forget is based on research conducted by Herman Ebbinghaus, and appears in reprinted form in (Ebbinghaus, 1998). Ebbinghaus' empirical research led him to create a mathematical formula that calculates an approximation of how much may be remembered by an individual sometime after he or she stops a learning activity (equation 1).

$$b = 100 * k / (\log t)^c + k \qquad (1)$$

Where:

- t is the time in minutes counting from one minute before the end of the learning activity,
- b is an estimate of the amount remembered from the learning activity after time t, and
- c and k are two constants with predetermined values k=1.84 and c=1.25.

In the student model of ViPS, the Ebbinghaus calculations have been used as the basis for finding out how much tutoring content or content learned from problem solving is retained by the student. After solving problems related to each misconception or after tutoring the student for a particular misconception, a follow-up test with three questions is given to the student and based on the responses, the students' initial memory state is calculated using equation 2.

$$X\% = b/100 * RQ \qquad (2)$$

Here b is Ebbinghaus' power function result calculated using equation 1 with t=0. However, equation 2 has a new factor, called the Response Quality (RQ). This is used to individualize equation 1 to the particular circumstances of each student by taking into account his or her answers to the follow-up questions. RQ is the number of correct responses to the follow-up questions asked after the completion of problem solving or tutoring for a particular misconception.

Once the tutoring for all the misconceptions a student might have is completed, or after all the problems have been solved, the student is given a post knowledge test that is used to estimate the status of each misconception detected by ViPS from the pre knowledge test. This test is also used to calculate the knowledge retained by the student, using equations 1 and 2. The difference between the initial (immediately after a problem solving or tutoring session for a misconception) and final (after all misconceptions have been addressed) retention levels gives us an estimate of content that is not retained by the student. This information is used by the system to decide whether to re-tutor the student.

3.5 Tutor Module

The Tutor module of ViPS is based on the Cognitive Theory of Multimedia Learning (Mayer, 2009) and Vygotsky's theory of learning. The tutor module is responsible for overseeing the process of tutoring the student for the misconceptions he/she might have, and it is also responsible for overseeing the process of problem solving by using the information generated by the student model to select and present appropriate problems. It uses a decision algorithm to determine the level of coaching to provide, and interacts with the feedback module to generate appropriate hints. The design of tutoring content, text and pictures, adhered to the principles stated in the Cognitive Theory of Multimedia Learning, and the feedback generated by the tutor module is based on the Zone of Proximal Development (ZPD) component of Vygotsky's theory of learning.

The tutor's decision to tutor or not depends on the student's response to the problems he or she has been given to solve. For every problem, the student has to enter his prediction (P), actual answer (A) and answer to a follow-up (FU) question. Based on these answers (correct answer: T and wrong answer: F) the problem is classified into one of the categories as shown in Table 2.

Table 2: Students' problem solving classification truth table.

(P)	(A)	(FU)	Classification
T	T	T	R+
T	T	F	R-
T	F	T	W+
T	F	F	W
F	T	T	R-
F	T	F	R
F	F	T	W+
F	F	F	W-

The problem is classified as successfully solved (true), if the outcomes are R+, R-, and R or else it is classified as incorrectly solved (false) (W+, W-, W). The tutor module presents two or three problems per misconception to determine whether a student has that misconception or not. It uses these problem outcomes to decide whether to tutor the student for the current misconception or move on to evaluate the next misconception using another set of three problems. Table 3 shows the tutor action truth table. For example, if the student solves the first two problems correctly, he or she is determined not to have the corresponding misconception, so the tutor will move on to the next misconception (Table 3, row 1). If the student solves the first problem correctly but errs in the second one, the tutor will present a third problem and depending on its outcome will either move to the next misconception (Table 3, row 2) or start tutoring actions to clear the current misconception (Table 3, row 3). Tables 2 and 3 together illustrate the tutor module decision tree. The student is given up to four attempts to solve a given problem. Figure 6 shows the flowchart of the tutoring process.

3.6 Feedback Module

The feedback module is responsible for generating feedback messages for the students. This module produces the following four types of feedback:

1. The student creates a setup by dragging components onto the work area and clicking the thread button. If any constraint violations that can lead to impossible or invalid pulley setups are detected, ViPS generates a feedback known as *setup feedback*.

2. The student creates a set of valid components in the work area, but has no idea of what to do next, i.e., how to thread a string through the pulleys to complete the setup construction. In these circumstances, ViPS can deliver feedback about the next moves the student has to make. This is known as *threading hint feedback*.

Table 3: Tutor action truth table.

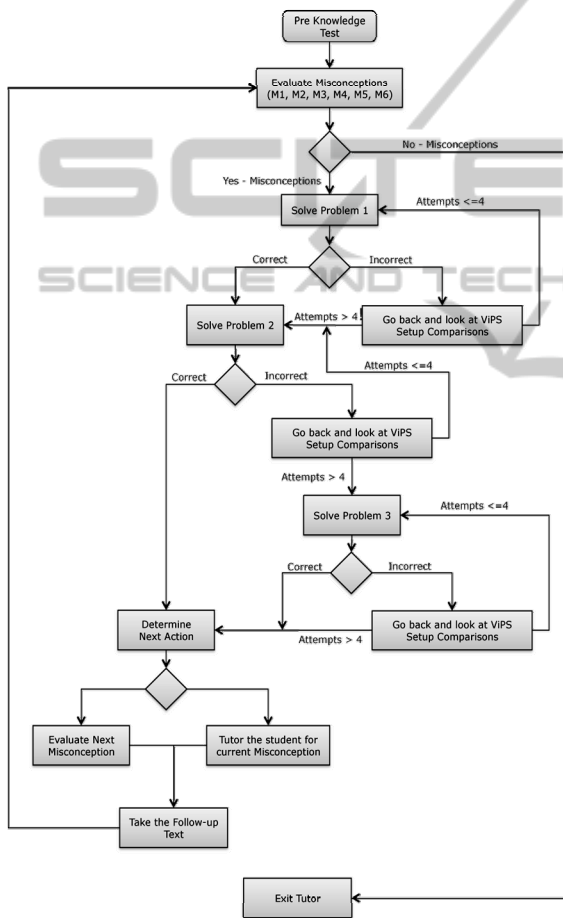| Problem 1	Problem 2	Problem 3	Tutor Action
T(R+, R-, R)	T(R+, R-, R)	N/A	Next Misc
T(R+, R-, R)	F(W+,W-,W)	T(R+, R-, R)	Next Misc
T(R+, R-, R)	F(W+,W-,W)	F(W+,W-,W)	Tutor Action
F(W+,W-,W)	T(R+, R-, R)	T(R+, R-, R)	Next Misc
F(W+,W-,W)	T(R+, R-, R)	F(W+,W-,W)	Tutor Action
F(W+,W-,W)	F(W+,W-,W)	N/A	Tutor Action

Figure 6: ViPS tutoring process flowchart.

3. After creating and simulating one or more setups, the student submits his/her problem solutions. The system evaluates this and generates messages known as *problem feedback*.

4. ViPS can coach students when needed during the process of problem solving, and this is known as *problem hint feedback*.

4 EVALUATION OF VIPS

We conducted evaluation studies of ViPS at one university with 12 engineering majors enrolled in their first physics course, and at another university with 210 pre-service elementary teachers enrolled in a physics course. Since ViPS is intended for eventual middle school use, our iterative design approach to ViPS involves the following stages: (1) initial design; (2) usability test of the initial design with the target middle school population; (3) redesign; (4) evaluation with more advanced (i.e. college) students regarding the usefulness and usability of the system; (5) redesign; and (6) deployment in middle schools for final evaluations. Myneni (2011) provides details of the initial design (stage 1) and usability testing with middle school students (stage 2), which showed that the interface was usable, but also revealed problem areas that were then corrected in redesign (stage 3). Myneni (2011) also describes the evaluation studies (stage 4). The analysis of data generated from these studies revealed that ViPS is effective in helping students learn and is also well perceived by students. Below, we present just a summary of this evaluation.

4.1 Experimental Procedure

A total of 220 students, 12 engineering majors from one university and 208 pre-service elementary teachers from another university, took part in the evaluation studies. Experimental subjects with differing backgrounds were recruited so that we could explore the extent to which ViPS would help both students with more advanced physics knowledge (engineering majors) and those who have less expertise (elementary teachers). Twelve participants from the first university and 50 from the second were assigned to one experimental condition: the Virtual-Only condition in which participants constructed pulley systems using ViPS and solved problems

related to misconceptions. However, data from two participants at the first and 3 participants at the second university could not be used for analysis because of gaps in collected data. Hundred and fifty eight participants from the second university were randomly assigned to two experimental conditions: (1) the Physical-Virtual condition (PV) in which participants worked in groups of two, first with physical pulleys and next with ViPS, to solve problems related to one misconception, and (2) the Virtual-Physical condition (VP) in which participants worked in groups of two, first with ViPS and then with physical pulleys, to solve problems related to the same misconception. There was no Physical-Only condition because learning data for physical pulleys could be obtained from the PV and VP groups. All students answered a usability questionnaire at the end of their sessions, which was used to assess user satisfaction with the system.

Study Procedure for Virtual-Only Condition

• *Pre-Test*: In a pre-test, the participants were asked to individually answer 18 questions related to pulley systems in ViPS in order to measure their prior knowledge.

• *Problem Solving*: The participants individually solved problems related to the misconceptions that were identified from the pre-test, and underwent tutoring as needed using ViPS.

• *Post-Test*: In a post-test, the participants were asked to individually answer 18 questions (same questions as pre-test, but displayed in different order) related to pulley systems in ViPS in order to measure their knowledge. ViPS used this test to detect any remaining misconceptions.

• *Usability Survey*: All participants were asked to fill out a usability survey to measure their overall satisfaction in using ViPS.

Study Procedure for Physical-Virtual and Virtual-Physical Conditions

• *Pre-Test*: In a pre-test, the participants were asked to individually answer 18 questions related to pulley systems on paper in order to measure their prior knowledge.

• *Group Assignment*: Participants were paired and pairs were randomly assigned to either the PV Group or the VP Group.

• *Problem Solving*: Each group solved problems related to one misconception ("the more pulleys there are in a setup, the easier it is to pull to lift a load") using either actual pulleys or ViPS depending on their assignment to the PV or VP condition.

• *Mid-Test*: In a mid-test, the participants were asked to individually answer 18 questions related to

pulley systems (same questions as pre-test, but presented in different order) on paper in order to measure their knowledge after solving problems using either actual pulleys or ViPS.

• *Problem Solving*: Each group then solved problems related to the same misconception using either ViPS or actual pulleys depending on their assignment to the PV or VP condition.

• *Post-Test:* In a post-test, all the participants were asked to individually answer 18 questions related to pulley systems (same questions as pre-test and mid-test, but presented in different order) on paper in order to measure their knowledge after solving problems using actual pulleys and then ViPS or vice versa.

• *Usability Survey:* All participants were asked to fill out a usability survey to measure their overall satisfaction in using ViPS.

4.2 Log Analysis

The interactions between ViPS and the students have been comprehensively logged. From these log files, several features have been extracted and compared using linear regression.

4.2.1 Pre-test Scores

Linear regression found a significant negative correlation (see Table 4) between pre-test score and learning gain in Virtual Only, Virtual (VP), and Physical (PV) groups. It is not surprising that these correlations are strong as many of the students have low pre-test scores.

Table 4: Correlation between pre-test score and learning gain.

	N	R	p	Std Beta
Virtual Only	57	0.66	0.001	-0.664
Virtual (VP)	80	0.66	0.001	-0.633
Physical (PV)	78	0.62	0.001	-0.620

4.2.2 Problems Solved

Linear regression found a significant positive correlation (N=57, R=0.756, R^2=0.571, p=0.03, Standardized Beta=0.792) between learning gain and number of problems solved in the Virtual Only group. On average, each student solved 8 problems while working with the ViPS tutor. The other two groups (PV and VP) were excluded from this analysis as they solved problems related to only one misconception.

4.2.3 Number of Simulations Created

Linear regression found a positive correlation between learning gain and number of simulations created, but the value of p was not statistically significant ($N=57$, $R=0.039$, $R^2=0.002$, $p=0.830$). On average, each student created 14 simulations.

4.2.4 Problem Time

Figure 7 shows the average time taken to solve the three problems in each misconception category (see Table 1). Repeated measures ANOVA revealed an overall significant difference in the average time taken to solve the three problems while working with ViPS ($F(1,140)=9.1$, $p<0.02$). The time required to solve a problem decreased significantly as students moved to subsequent problems in the same misconception category. This suggests that students took more time to solve the first problem in a misconception category as they were seeing a problem related to that misconception for the first time, but that they were faster at solving subsequent problems.
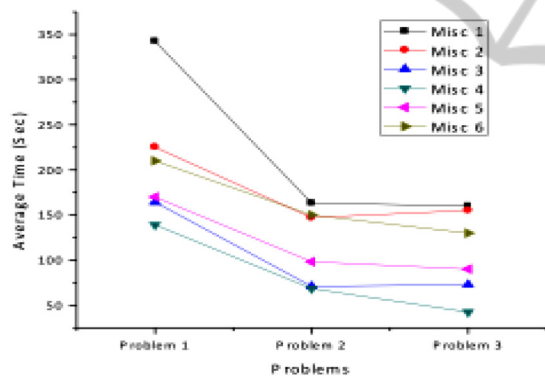

Figure 7: Average time taken to solve three problems in each misconception category.

4.2.5 Misconceptions

Figure 8 shows the detected frequency of each misconception. The most common misconception among all the students who participated in the evaluation experiments is Misconception 2 (see Table 1) followed by Misconception 1 and Misconception 4. Out of all the students, 60 exhibited all the six misconceptions. That such misconceptions persist in college students is an interesting finding. A paired-sample t-test comparing the number of misconceptions identified in the pre-test and post-test in the Virtual-Only group found a significant reduction in number of misconceptions ($t(54)=16.6$, $p=0.001$). On average, each student exhibited five misconceptions after pre-test and two misconceptions after post-test. The number of misconceptions decreased significantly after working with ViPS.
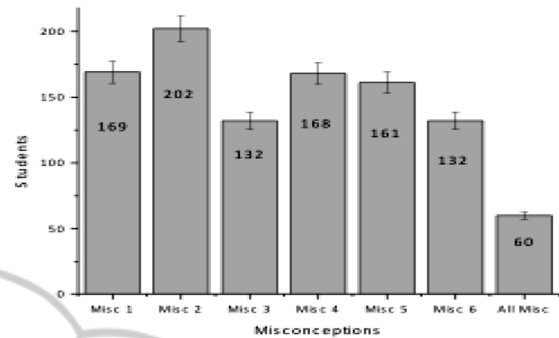

Figure 8: Frequency of misconceptions.

5 CONCLUSIONS

In this paper, we presented an intelligent simulation and tutoring system called ViPS for learning physics concepts through exploring a class of simple machines. ViPS is innovative in several ways. First, ViPS employs the Coached Problem Solving approach (Conati et al, 1997) to detect and effectively tutor for common student misconceptions regarding physics concepts exemplified in pulley systems. ViPS is able to dynamically infer valid pulley setups from the components that a student selects and places on the workspace, and to adaptively generate hints based on student actions. Second, ViPS is a new tool for virtually experimenting with – creating, exploring and simulating – pulley setups, which are hard to build and manipulate in the physical world. Third, the graphical interface of ViPS is designed according to the Cognitive Theory of Multimedia Learning (Mayer, 2009) in order to help students connect abstract and difficult concepts of physics with representations at a more tangible level. Fourth, ViPS brings together the concepts of virtual experimentation and intelligent tutoring in one platform.

Data analyses from ViPS evaluations support these conclusions: (1) the less prior knowledge a student has, the more he or she learns from ViPS; (2) amount of learning is directly related to the number of problems a student solves and the number of simulations he or she runs; (3) the more a student works with ViPS, the faster he or she is able to solve problems; and (4) ViPS is able to reduce the number of misconceptions students commonly exhibit.

One limitation of this work is that the system is yet to be field-tested with the target population of middle school students. An early study did show that

middle school students found the system to be usable (Myneni, 2011). Results from evaluation with college students also give us confidence that the system will be effective in middle schools. It is interesting to note that we identified an average of five misconceptions in college students, even though middle school curricula in physics are generally thought to address and remedy such misconceptions. ViPS was indeed successful in remedying many of these misconceptions in college students. Nevertheless, this finding needs to be re-evaluated in middle schools. Therefore, our future work is on fielding ViPS in middle schools and evaluating it further.

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