Supporting Mechanical Reasoning with a Representationally-Rich Learning Environment

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Abstract

A learning environment to support mechanical reasoning and understanding of simple machines for middle school and high school students is presented, along with results of an evaluation of its effectiveness in student learning. Based on recommendations from literature on instructional frameworks and cognitive aspects of mechanical reasoning, SIMALE (the Simple Machines Learning Environment) was designed to support reflection, collaboration, and presentation of concepts from multiple perspectives. SIMALE was implemented with a diverse population of middle and high school students with three treatment variations: (1) environment with focus on Lego exercises to engage in hands-on physical activities, (2) environment with focus on a Web-based computer module, and (3) environment with both the computer module and Lego exercises. Analyses of results show significant increases in post-test performance for all treatment variations within SIMALE. The results also revealed unexpected dramatic results in equalizing post-test scores along ethnic and gender dimensions, in spite of large population differences in pre-test scores.

Keywords: learning environment, mechanical reasoning, precollege education

I. Introduction

Several factors have motivated our development of a learning environment to support mechanical reasoning ability. For example, the National Academy Press recently published a report that defines technological literacy and how it can be achieved in K-12 classrooms [1]. Aspects of technological literacy include understanding basic engineering concepts, having hands-on skills, and the ability to identify and fix basic mechanical problems. "Exposure to technological concepts and hands-on, design related activities in the elementary and secondary grades are the most likely ways to help children acquire the kinds of knowledge, ways of thinking and acting, and capabilities consistent with technological literacy" [1, p. 57].

Earlier initiatives have also called for reform in science and technology education. Project 2061, an initiative through the American Association for the Advancement of Science, established benchmarks for science literacy [2]. Many of today's state and national standards documents have drawn their content from these benchmarks. In addition, at the national level, the National Science Education Standards also serve as a guide for developing appropriate curricula materials that advocate creative problem solving, thinking critically, using technology effectively, and valuing life-long learning [3]. Given these recommendations, SIMALE was designed to develop students' mechanical reasoning and critical technological literacies.

Furthermore, concepts of mechanical advantage, force and motion, and energy principles are common subject matter requirements listed in many state science standards. Several state standards explicitly mention concepts of simple and complex machines [4–7]. For example, the Virginia science standards mentions the following.

Virginia Physical Science Standard PS.10. The student will investigate and understand scientific principles and technological applications of work, force, and motion. Key concepts include: work, force, mechanical advantage…; and applications (simple machines, compound machines,…) [7].

Concepts of mechanical advantage, particularly force, motion, and energy, are also addressed in college physics and basic engineering mechanics classes [8, 9]. These basic concepts are used as a foundation to build more formal understanding and analysis of complex mechanisms. Since mechanical advantage and simple machines are common topics encountered in middle and secondary school classrooms, as well as in fundamental physics and engineering courses, our work provides a learning environment where students can explore, analyze, and integrate these concepts.

Drawing from the literature on instructional design, the simple machines learning environment was designed to support reflection and collaborative learning, and to engage students in generative learning through multiple representations of concepts and successive experimentation and design activities. Two key components of SIMALE are an original Web-based software tool and hands-on Lego activities. Students use the computer module and/or Legos to test their ideas and investigate simple machines concepts. Based on information obtained from the computer simulations and Lego experimentation students apply this knowledge to solve lever and pulley design problems.

Preliminary testing of the Simple Machines Web-based module showed mixed benefits and motivated the development of the SIMALE instructional design and the more extensive evaluation described here [10]. We designed a research study consisting of three treatment groups to investigate the differential benefits of variations within SIMALE—hands-on and Web-based computer activities—on students' analytic problem solving ability, drawing/modeling ability, and conceptual understanding. This paper provides an overview of SIMALE, describes the assessment study, and presents a summary of the results.

II. Overview of the Simple Machines Learning Environment

Two primary learning goals were established in developing SIMALE: (1) to foster development of simple machines concepts, and (2) to encourage students to make connections between abstract and more concrete forms of reasoning in order to effectively apply their knowledge to a range of problems. The learning environment provides different representations of the mechanisms to encourage students to make connections among the physical devices, the mathematical analyses, and appropriate applications.

The different representations range in their level of abstraction from concrete physical devices to abstract mathematical equations and graphs. Students engage in computer simulation activities and/or Lego building to illustrate the relationship between distance and effort. Results obtained from the simulations are used to make mathematical plots of the data in the computer module [10, 11]. The simulations and the mathematics provide different representations to illustrate how the concept of mechanical advantage is modeled by each of the devices. Through in-class discussions, students are introduced to force equations (an abstract representation) that define the relationship between force and distance for the lever and the pulley. Worksheets were constructed to focus students on connecting the ideas represented through the repertoire of models presented in the computer module, the Lego building, and the class discussions. The combination of these activities serves to provide multiple opportunities for students to connect the concepts to applications.

Four main findings from literature on learning theories guided the pedagogy of SIMALE. Specifically, the literature suggests that a learning environment should: 1) provide opportunities for students to actively participate, 2) support self-reflection, 3) provide multiple representations of concepts, and 4) cultivate generative learning. Each of these principles is described in more detail.

In the most general sense, the notion of an interactive environment implies that the learner plays an active role while working within the environment. In contrast to the idea of the learner as "passive recipient of knowledge," an interactive environment encourages students to actively participate in the learning process. Various features were included in SIMALE to promote active engagement of the learner. For example, the simulations and plotting applications in the simple machines Web module and the independent design activities foster cognitive initiative and promote active engagement.

Self-reflection and the development of metacognitive skills are common themes in many instructional frameworks. Many researchers have shown the benefits of self-reflection in order to make "thinking visible" as well as to create a sense of community [12–14]. Self-reflection activities are embedded in SIMALE in a variety of ways. The Web-based computer software contains a feature called the "share findings page" [10, 11]. This page provides an on-line space for students to share their discoveries with the class. Having students report their findings to the class accomplishes two main purposes: 1) it contributes to the collective knowledge of the class by making each student's thinking visible and, 2) it encourages students to self-reflect on their learning. Students are also encouraged to make their thinking and learning visible and self-reflect throughout the environment by engaging in collaborative activities, performing experiments and discussing results, and creating unique designs to open-ended problems.

Multiple representations are presented throughout SIMALE. For example, the simple machines Web-based module was designed to include simulations, animations, and feedback to input. The Lego building activities also provide an additional, more concrete, representation of the lever and pulley. Since students may have individual learning styles, the use of multiple representations increases the repertoire of models for students. According to Resnick and Ocko [15], the learning environment should offer multiple paths to learning that allow students the freedom to approach projects from different perspectives.

The application of the term "generative" to SIMALE is consistent with the basic definition of the word. Generative implies that something is created, revisited, and capable of being reproduced. In a learning environment, concepts should not be encountered just one time, but revisited and applied in multiple contexts. As Resnick and Resnick [16] note, "for concepts and organizing knowledge to be mastered, they must be used generatively—that is, they have to be called upon over and over again as ways to link, interpret, and explain new information."

As reported previously by McKenna and Agogino [10], the Web-based simple machines module provides multiple contexts in which students encounter the concepts. In addition, the learning environment presents problem-solving situations where the concepts can be applied. The environment provides multiple opportunities for students to revisit concepts and, more importantly, to use the concepts to solve real-life problems.

III. Experimental Design and Implementation

As discussed in the previous section, two primary resources were used within SIMALE to help students develop mechanical reasoning: (1) an original Web-based computer tool, and (2) Lego sets. In order to investigate the differential benefits of hands-on and Web-based computer activities on students' conceptual understanding and problem solving ability three treatment groups were created. One treatment group used just the physical objects, or Lego sets, as a resource to explore the principle of the lever and pulley. Another condition used just the simple machines Web-based computer module and the third condition used both the computer module and the Lego sets as resources. All three groups had the same instructional material about simple machines in either hard copy or electronic form, depending on the treatment. The three conditions will be referred to as the "Lego" group, the "Computer" group, and the "Both" group, respectively. Pre and post-tests were administered and compared among the three conditions.

In order to eliminate possible confounding factors, the experimental design was structured to create as an equivalent learning experience as possible for each of the classes and conditions. Table 1 shows a comparison of various aspects of the study for each of the three conditions. The research site, class duration, pre and post-tests, teacher, in-class discussions and worksheets were consistent and the only variation among the different groups was the resource provided during the class.

One aspect of the study, the teacher, requires further elaboration. By having the same person teach all of the classes in the research study we avoid the issue of variation in teacher competence: since the teacher was the same in all groups, differences among the groups cannot be attributed to one group having a more effective teacher. In addition, several steps were taken to avoid teacher and instructional bias. First, the sequence and duration of the class activities was pre-determined so that each group received the same activities, in the same sequence, for an equivalent duration.

In addition the class discussions and lecture were carefully scripted. Since the lecture was the one activity where the teacher had the most interaction with the class as a whole, it was important to ensure that each class was presented with equivalent material. Therefore, the content of the lecture was scripted such that each class received the same presentation of material. By following such a rigid and equivalent structure, the research design isolates the effects that the different resources may have on student learning.

It is important to note that even though every effort was made to ensure equivalent treatment in each condition, the research study took place within an actual classroom setting. This follows in the tradition of design experiments where the aim is to examine cognitive phenomena in a complex setting because this is precisely how learning takes place in actuality [17]. The advantage and value of this work is that a rigorous experimental design was created *and* the study was implemented in a complex classroom environment. Every reasonable attempt was made to control for confounding factors without creating an artificial learning environment for students.

A. Student Populations

Participants for the research study were recruited from the Academic Talent Development Program (ATDP) and the Mathematics, Engineering, and Science Achievement (MESA) program. Both programs offer science, mathematics, and technology summer courses to middle and high school age students.

Thirty-seven students participated in the study from the MESA program. Students ranged in age from 12–17 years. Of the 37 students, 59 percent were male and 41 percent female. Since the MESA program is an outreach program that serves minorities and under represented groups in science and mathematics, the MESA participants formed a diverse group of students. Approximately 32 percent of the MESA participants were African-American, 32 percent Chicano/Latino, and 30 percent Asian-American.

Forty students participated in the study from the ATDP program. Students ranged in age from 13–15 years. Of the 40 students, 58 percent were male and 42 percent female. The ATDP program is an academically competitive program that serves students in the San Francisco Bay Area, Northern California and the California Central Valley. Approximately 5 percent of the ATDP participants were Native American, 8 percent African-American, 10 percent East Indian/Pakistani, 12 percent Chicano/Latino, 18 percent Caucasian, and 40 percent Asian-American.

Because the study was conducted in classes that were separate from the student's school curriculum, it is recognized that those who participated were a self-select group since they chose to participate. One could argue that these students are unique in terms of their motivation towards learning. This may be true but it should also be noted that the students who participated in this study formed a very diverse group with respect to gender, ethnicity, and academic achievement. Results and conclusions from the study are therefore presented with recognition that this sample of students is perhaps different in terms of motivation, but rich in diversity.

B. Lever and Pulley Assessments

Students in all three conditions were given paper-and-pencil pre and post-tests on the simple machines concepts addressed in the class. (See Appendix A and B in McKenna and Agogino [18] for a complete copy of the tests). Both the pre and post-tests were intentionally created to contain identical items. The strength of identical pre and post-tests is that the items are matched so that one can clearly measure improvement across items. Students are asked the same questions so we can assume equivalence in terms of interpretation and difficulty. The pre-test itself was also an important part of the learning environment in that it was intended to stimulate peer discussion, experimentation and self-reflection.

Aspect of Study	***Lego Group***	***Computer Group***	***Both Group***	***Same***
Research Site	UC Berkeley	UC Berkeley	UC Berkeley	Yes
Class Duration	5 1/2 hours	5 1/2 hours	5 1/2 hours	Yes
Pre and Post-Tests	Same	Same	Same	Yes
Teacher	AM	AM	AM	Yes
Class Discussions	2 per class	2 per class	2 per class	Yes
Sequence and duration of activities	Same	Same	Same	Yes
Focusing Task	Worksheets	Worksheets	Worksheets	Yes
Hands-on Activity	Lego sets	None	Lego sets	No
Computer Activity	None	Simple Machines Module	Simple Machines Module	No
Resource	Lego sets	Simple Machines Module	Lego sets and simple machines module	No

Table 1. A comparison of study aspects among the three conditions.

Questions on the lever and pulley tests were based on items from the Test of Mechanical Comprehension [19], literature on mechanical reasoning [20], state standards on simple machines, and the objectives of the curriculum. An example of a pulley question is given in Figure 1. Each item on the test also asks students to provide an explanation for his or her answer. Conceptual understanding is gauged by the quality of explanation students provide to each question. We used a blind scoring process such that the researcher did not know to which group the test belonged.

To compare the effectiveness of the resources provided in the three different treatment groups t-tests and analyses of variance (ANOVA) were used. The t-tests allow us to test for any significant differences among the three treatment groups, both before and after the intervention. The ANOVA were performed to test for effect on post-test scores due to treatment group controlling for three between subject factors: pre-test scores, condition, and gender. The following section presents the results from the lever and pulley tests for each condition.

Two additional measures are also reported: normalized gain scores and effect sizes. Normalized gain scores compare the actual gain to the potential gain. This measure takes into account pre-test performance such that learning is measured as a ratio of how much was learned to how much could potentially be learned. Effect sizes reveal the magnitude of the experimental effect in consistent units of standard deviation. In this study, effect size is an appropriate measure to understand gains in performance due to small sample sizes in the experimental conditions.

IV. Results

Results from the MESA and ATDP populations are presented for the lever and pulley tests. The pre and post-test consisted of eight questions each for the lever and the pulley. Each item was given one point for a correct answer or no point for an incorrect response. The range of scores therefore varied from zero to eight.

A. Pulley Results: MESA Students

Unpaired sample t-tests were performed to test for differences between the three groups prior to the intervention. All three groups performed equally well on the pulley pre-test and no significant differences were found between the Lego and Computer group, $t(22) = 1.066$, $p = 0.14$, the Lego and Both group, $t(17) = 1.18$, $p = 0.10$, or the Computer and Both group, $t(25) = 0.119$, $p = 0.83$. Table 2 shows the comparison of pre and post-test pulley scores. The data indicate significant gains in post-test performance for all three treatment variations with the MESA student population.

ANOVA was then performed to test for interactions between performance on the pulley post-test and three between-subject factors: treatment, gender, and pre-test. The ANOVA on pulley post-test scores revealed no effect of type of treatment within the environment ($F = 0.267$, $p = 0.76$), gender ($F = 0.02$, $p = 0.88$), or pulley pre-test ($F = 1.2$, $p = 0.28$), and no interactions were found.

B. Lever Results: MESA Students

Unpaired sample t-tests show all three groups performed equally well on the lever pre-test and no significant differences were found between the Lego and Computer group, $t(22) = 0.037$, $p = 0.97$, the Lego and Both group, $t(18) = 1.007$, $p = 0.33$, or the Computer and Both group, $t(22) = 1.14$, $p = 0.27$. Table 3 shows the comparison of pre and post-test lever scores. Similar to the pulley analyses, the data indicate significant gains in post-test performance for all three treatment variations with the MESA student population.

The ANOVA on lever post-test scores also revealed no effect of type of treatment within the environment ($F = 0.061$, $p = 0.94$), gender ($F = 0.182$, $p = 0.67$), or lever pre-test ($F = 0.42$, $p = 0.52$), and no interactions were found. The ANOVA data indicate there is no effect (on lever and pulley post scores) due to type of

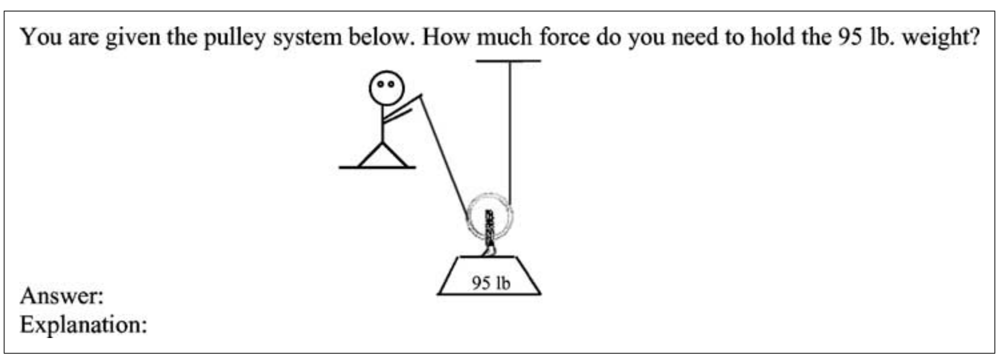

Figure 1. Example of a pulley question.

Condition	Pre (SD)	Post (SD)	Actual Gain (%)	Normalized Gain (%)	Effect Size	N	t-value	p-value
Lego	2.0(1.8)	6.2(1.7)	52.5	70	2.4	8	5.19	<0.01
Computer	3.1(1.5)	6.2(.78)	38.75	63	2.1	16	7.96	<0.01
Both	3.2(1.2)	6.1(1.1)	36.2	60	2.5	11	7.02	<0.01
Total	2.8(1.5)	6.2(1.1)	42.5	65.3	2.2	35	11.31	<0.01

Table 2. Comparison of pre and post-test pulley scores (max score = 8): MESA.

treatment within the environment. This suggests that the students who used just the computer module did as well as students who received both Legos and the computer, or just Lego materials within SIMALE. The fact that there is no effect of pre-test scores suggests that the simple machines environment, with each treatment group, is similarly beneficial to students regardless of prior knowledge.

C. Pulley Results: ATDP Students

Unpaired sample t-tests were performed to test for differences between the three ATDP groups prior to the intervention. All three groups performed equally well on the pulley pre-test and no significant differences were found between the Lego and Computer group, $t(23) = -0.842$, $p = 0.408$, the Lego and Both group, $t(29) = 0.469$, $p = 0.64$, or the Computer and Both group, $t(22) = 1.187$, $p = 0.249$. Table 4 shows the comparison of pre and post-test pulley scores. These data indicate significant gains in post-test performance for all three groups. These results are consistent with the MESA data as shown in Table 2.

The ANOVA on ATDP pulley post-test scores revealed no effect of treatment ($F = 1.19$, $p = 0.318$) or gender ($F = 0.087$, $p = 0.77$) and no interactions were found.

D. Lever Results: ATDP Students

Unpaired sample t-tests were performed to test for differences on the lever pre-test. All three groups performed equally well on the lever pre-test and no significant differences were found between the Lego and Computer group, $t(22) = 0.777$, $p = 0.44$, the Lego and Both group, $t(29) = -0.208$, $p = 0.83$, or the Computer and Both group, $t(21) = -0.902$, $p = 0.37$. Table 5 shows the comparison of pre and post-test lever scores. Using a significance level of $p < 0.05$, the data indicate statistically significant gains in post-test performance for all three groups. These results are consistent with the MESA data given in Table 3.

An analysis of variance was then performed and similar to the analyses of the MESA data, the ANOVA on lever post-test scores revealed no effect of treatment ($F = 2.336$, $p = 0.12$), or gender ($F = 2.113$, $p = 0.157$), and no interactions were found.

E. MESA vs. ATDP Comparison

Student performance between the MESA and ATDP populations was compared for both the lever and pulley pre and post-tests. MESA students scored consistently lower on the lever and pulley pre-test than ATDP students (e.g., see Figure 2 for a comparison using the Lego treatment groups). T-tests revealed a statistically significant difference between MESA and ATDP students on the lever pre-test, $t(71) = -3.98$, $p < 0.01$ and pulley pre-test, $t(73) = -2.39$, $p = 0.02$. However, post-test scores for the MESA and ATDP students were similar and t-tests revealed no significant differences in student lever post-test performance, $t(71) = -1.3$, $p = 0.19$ or pulley post-test, $t(73) = -1.66$, $p = 0.10$.

The data from the lever and pulley analyses indicate that MESA students entered with less prior knowledge about simple machines but achieved equivalent or greater gains in performance compared to ATDP students.

F. Gender Effects

In addition to comparing the two populations (MESA and ATDP) of students we also evaluated our results with repect to gender. We examined the perfomance of male and female students on pre-test and post-test measures. In both populations we found

Condition	*Pre (SD)*	*Post (SD)*	*Actual Gain (%)*	*Normalized Gain (%)*	*Effect Size*	*N*	*t-value*	*p-value*
Lego	4.3(.95)	6.7(1.2)	30	65	2.5	10	5.31	<0.01
Computer	4.3(.91)	6.8(1.1)	31.2	67.6	2.7	14	7.27	<0.01
Both	4.7(.82)	6.3(1.2)	20	48.5	1.9	10	4.00	<0.01
Total	4.4(.89)	6.6(1.2)	27.5	61.1	2.5	34	9.57	<0.01

Table 3. Comparison of pre and post-test lever scores (max score = 8): MESA.

Condition	*Pre (SD)*	*Post (SD)*	*Actual Gain (%)*	*Normalized Gain (%)*	*Effect Size*	*N*	*t-value*	*p-value*
Lego	3.8(1.9)	6.6(1.7)	35	66.7	1.5	16	5.12	<0.01
Computer	4.4(1.5)	6.5(1.7)	26.25	58.3	1.4	9	4.36	<0.01
Both	3.5(2.2)	6.9(1.1)	42.5	75.5	1.6	15	5.59	<0.01
Total	3.8(1.9)	6.7(1.4)	36.25	69	1.5	40	8.55	<0.01

Table 4. Comparison of pulley pre and post-test scores (max score = 8): ATDP.

Condition	*Pre (SD)*	*Post (SD)*	*Actual Gain (%)*	*Normalized Gain (%)*	*Effect Size*	*N*	*t-value*	*p-value*
Lego	5.6(1.4)	7.1(1.0)	18.75	62.5	1.1	16	3.98	<0.01
Computer	5.1(1.6)	6.6(1.4)	18.75	51.7	0.9	8	2.81	0.026
Both	5.7(1.5)	7.0(1.2)	16.25	56.5	0.9	15	4.75	<0.01
Total	5.6(1.5)	7.0(1.2)	17.5	60	1.0	39	6.71	<0.01

Table 5. Comparison of lever pre and post-test scores (max score = 8): ATDP.

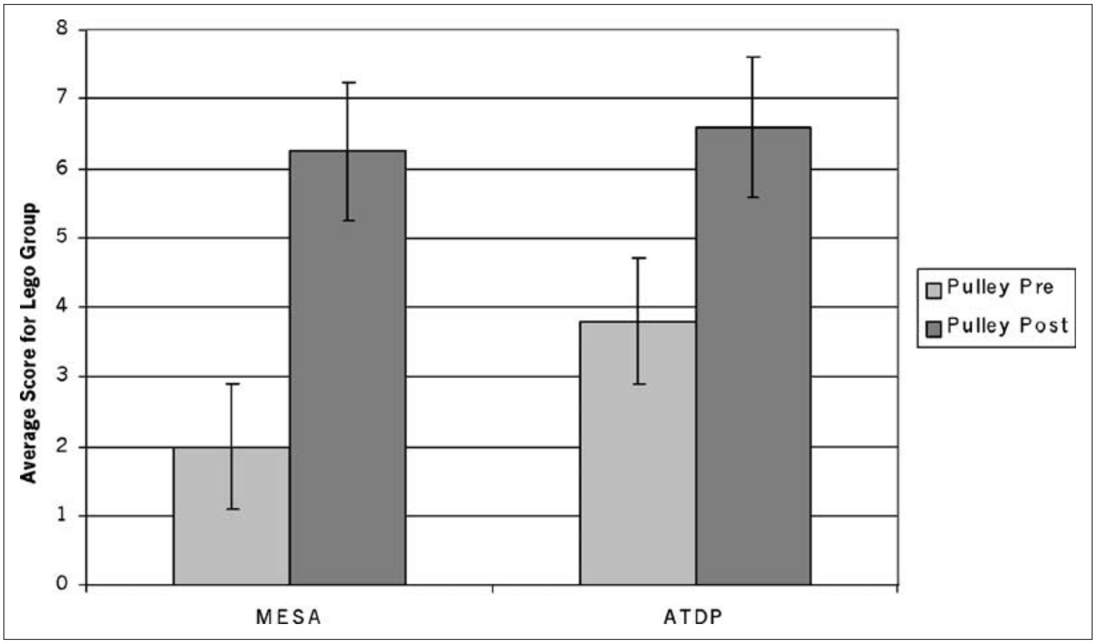

Figure 2. Plot of pulley pre and post-tests for the Lego treatment group.

Pulley	*Male Mean (SD)*	*N*	*Female Mean (SD)*	*N*	*t-value*	*p-value*
Pre	4.0 (1.8)	43	2.6 (1.6)	32	3.4	<0.01
Post	6.6 (1.2)	43	6.3 (1.4)	32	.872	0.39

Table 6. Comparison of pulley pre and post scores by gender.

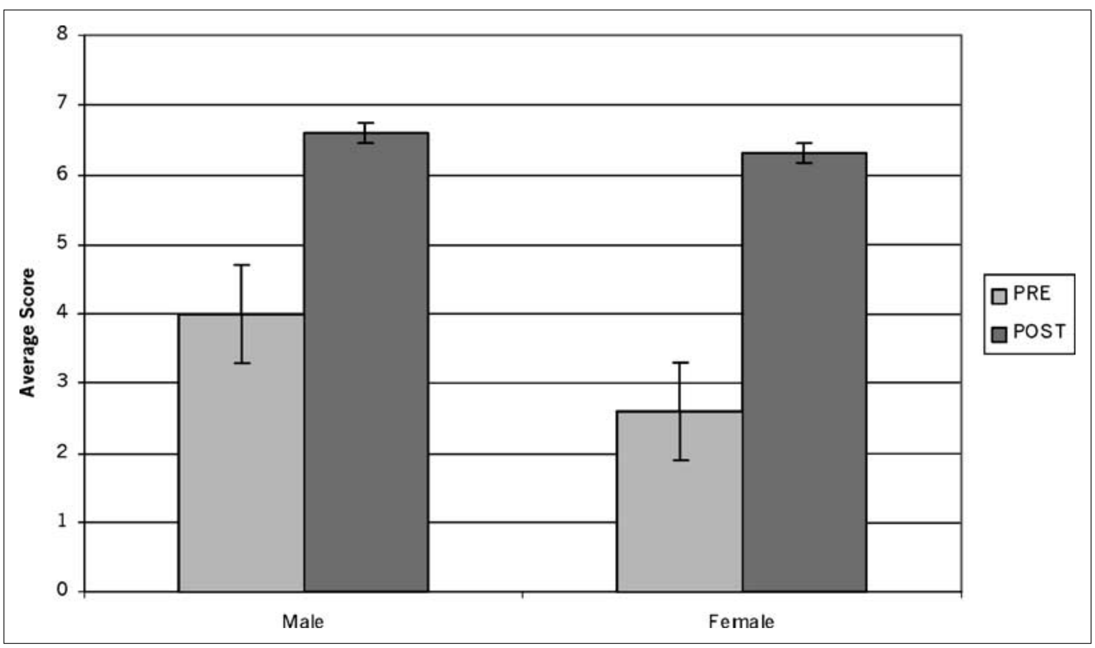

Figure 3. Plot of pre and post pulley scores by gender.

significant differences between male and female students on pre-test performance but no significant gender differences were found on post-test performance. For example, the statistics for the combined MESA and ATDP pulley pre and post-tests are given in Table 6 and the average scores are displayed in Figure 3.

Based on our analyes of the data by population and gender we found that SIMALE was beneficial in supporting a diverse range of students. Specifically, SIMALE has significant impact on developing mechanical reasoning ability for all students, regardless of gender, ethnicity, or prior academic achievement.

V. Discussion

A review of the data from the MESA and ATDP lever and pulley pre and post-tests show a consistent trend. Students performed significantly better on post-test measures, regardless of treatment group. Given these overwhelming positive findings it is useful to reexamine the features of SIMALE that may have contributed to these results. During the implementation of SIMALE, regardless of treatment group, students engaged in collaborative and reflective learning and were provided multiple opportunities to interact with concepts. Students encountered simple machines concepts through multiple representations and perspectives and engaged in iterative experiments to test ideas. Based on the results from the study the combination of these activities led to significant improvement in performance in mechanical reasoning and problem solving ability. The improvements, regardless of treatment group and focus (computer simulation, Legos, both), show the strength of the environment and the associated instructional design.

One might argue that there may be a "test effect" due to repeated exposure to the same test material. In Summer 2002, we implemented an additional study with MESA students to test for this effect and found no effect due to repeated testing. Students were given the pulley pre-test, then engaged in lever computer simulations and class discussion for approximately one hour, then were given the pulley test again. We found no significant differences between pre and post-test performance, female: $t(8) = 0.229$, $p = 0.82$, male: $t(6) = -0.548$, $p = 0.60$. In fact, the average scores on the pre and post-tests were exactly the same so there were no gains between test time one and two. This result indicates that students do not benefit from just observing and taking the test. In this sense we attribute gains in post-test performance to interaction with SIMALE learning materials.

The mechanism by which students refine their understanding and develop a more robust understanding of the concepts is what we seek to explore. Based on the instructional framework developed for SIMALE we can extract general principles that foster a productive learning experience. Within SIMALE, collaborative activities served multiple purposes. Students worked with partners to share and test ideas, clarify perspectives, and discuss points of confusion. This process encouraged students to reflect on their understanding and enabled them to make their thinking explicit. Students revealed their thinking through verbal discussions, graphical representations, and written explanations. These tangible expressions of tacit understanding were visible products that could be debated and refined within SIMALE.

VI. Summary and Future Work

This paper provided an overview of SIMALE by describing the learning goals of the environment and discussing the theoretical principles that guided the design of the pedagogy. SIMALE was designed to help students develop concepts about simple machines and make connections among the physical devices, the mathematical analyses, and appropriate applications. The environment included activities to provide opportunities for students to actively participate, support self-reflection, provide multiple representations of concepts, and cultivate generative learning. These four principles, taken from instructional and learning theory, embody the pedagogy of SIMALE.

SIMALE included two primary resources for students to investigate the lever and pulley, the simple machines Web-based module and Lego sets. A study was conducted to investigate the benefits of these two resources in supporting students' mechanical reasoning. Three treatment groups were created, one used just the computer module, one used just the Lego sets, and one used both resources within the simple machines environment. Students were recruited from two outreach programs at the University of California at Berkeley. The students in this study formed a diverse population with respect to gender, ethnicity, and academic achievement.

Statistical analyses showed significant gains in lever and pulley post-test performance for both the MESA and ATDP populations, in spite of major differences in pre-test scores. ANOVA revealed no effect of type of treatment within SIMALE for both tests (lever and pulley) and both populations (MESA and ATDP). That is, students who used the computer module within SIMALE performed as well as those that received hands-on activities or both resources within SIMALE. SIMALE, therefore, clearly contributes to students' mechanical reasoning and understanding of simple machines concepts for a diverse population of students. The results are quite promising in terms of showing the strength of the environment and the associated instructional design, which leaves much flexibility for the instructor in its implementation depending on teaching preferences and classroom infrastructure. As a consequence, SIMALE has been used effectively in a range of instructional settings with a diversity of instructional styles.

The paper discussed the successful results from the pre and post lever and pulley tests of the simple machines learning environment when used with diverse student populations. Future work will address analyses along different categories of learning: conceptual change and drawing/modeling ability.

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