

Engineering for Middle School: A Web-based Module for Learning and Designing with Simple Machines

Ann McKenna and Alice Agogino[†]

Graduate Group in Science and Mathematics Education,

[†]Department of Mechanical Engineering, University of California at Berkeley, CA 94720

Abstract-The current work describes an instructional module which emphasizes integrative design using the six simple machines of the lever, the wheel and axle, the pulley, the inclined plane, the screw, and gear. The emphasis of this module is on having the students investigate the underlying scientific and mathematical properties of the 'machines', and then integrating this knowledge to design creative solutions to problems. This simple machines module makes use of an original web-based multimedia learning environment as well as off-line hands-on building activities with the LEGO® Technic 1 set.

Introduction

The current paper provides an overview of an instructional module that was developed for middle school students. Broadly, the module is intended to introduce students to the practice of engineering and, specifically, to have the students design and learn with simple machines. A web-based design was chosen in order to make the module widely accessible, as well as to make use of the Internet and advancing multimedia capabilities. The recent frenzy to get schools connected to the Internet has created a need for the development of effective and easy to use Internet-based instructional materials.

In addition, interest in pre-engineering curricula has become more widespread as evidenced by the amount of recent publications involving engineering curricula for K-12 [1, 2, 3]. The present work contributes to this expanding research community, but it also offers a unique perspective through its use of an interactive web-based instructional environment [4]. Features of the environment are programmed in Java [5] which allows for interactive computer simulations via the Internet. The module also includes hands-on building activities with LEGOS® [6]. The on-line computer simulations, combined with the hands-on design and building activities, encourage the students to make the connections between the more abstract principles and the actual physical system. This is a necessary connection that is often overlooked in engineering education.

This paper describes the cognitive goals and the design considerations that were outlined for this module. The cognitive goals were explicated in order to define the learning which should take place among the students. Since the module is web-based, it is also necessary to discuss the design guidelines which were followed in the development of the user-interface. For example, a main design guideline was to make the module gender equitable so many features of the user interface reflect this intention. Finally, the current paper illustrates and describes select features of the instructional environment.

The Engineering Design Process Defined for a K-12 Curriculum

In order to provide a framework for a pre-engineering curriculum, it is useful to discuss engineering design and its associated abilities and processes. The field of engineering is quite broad and the types of activities that individual engineers engage in can be quite diverse. Therefore, there is no one exact definition of engineering because it would be almost impossible to create a definition which applies to every engineer in every discipline. Consequently, the framework that is discussed here is not meant to be inclusive, or necessarily descriptive, of every engineering profession or job function. The present description of the engineering design process is intended to serve as a guideline for the development of the current pre-engineering instructional module.

The basic framework for the engineering design process is shown in Fig. 1. This figure illustrates a set of steps, or cognitive processes, that engineers generally complete while developing solutions to engineering design problems. The first step the engineer must do is to define the problem which needs to be solved. It is important to identify what the exact needs are for a particular problem so that the solution that gets developed matches the needs of the customer or end-user. The issues are not always obvious so careful attention is needed in defining the scope and parameters for each particular project.

After defining the problem the engineer moves into the stage of developing a solution. This solution-finding stage can consist of numerous skills and activities but they are summarized into three broad categories; research, simulate, and prototype. These three activities represent an iterative process that the engineer cycles through repeatedly to develop a solution. Researching involves investigating existing work and understanding the governing principles which apply to the particular problem. For example, if the project is to design a new commercial aircraft, it would be useful to understand how existing aircraft are designed and it would be essential to understand the laws of motion for flight.

Another step in the iterative process is to run simulations of possible solutions. The simulations are based on the underlying principles, such as the laws of motion for flight, and are a way to test and examine the engineer's predictions and hypotheses. The third category in the solution-finding process is prototyping. A prototype, or a physical working model (full size or scale), is typically built to investigate the actually functioning of the proposed idea. Prototyping is often done to test the functionality of the simulated design and to investigate manufacturing issues.

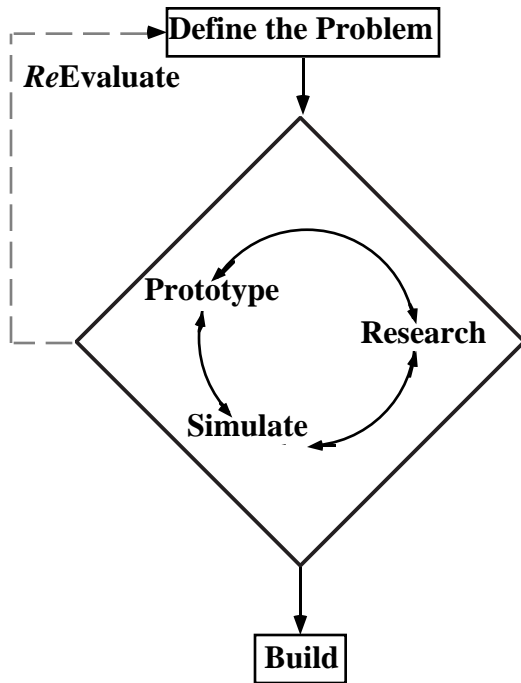


Figure 1. A basic framework for the engineering design process.

Finally, issues may arise during the solution process which may cause the engineer to re-evaluate the originally defined problem. It may be necessary to step out and evaluate the progress, possibly redefine the problem, adjust some initial conditions, or simply abort the mission. This is illustrated in Fig. 1 by a dashed line. These activities, skills, and processes serve as an outline for a pre-engineering curriculum which is intended to familiarize students with the engineering profession and to enable students to engage in and develop these skills.

Cognitive Goals

The cognitive goals were defined based on the overall purpose of this module which is to develop an understanding and spark an interest in how simple machines work and, to familiarize students with the practice of engineering. The four main cognitive goals are outlined below and the module contains various activities that the students will engage in which will contribute to the development of these goals.

- 1) To develop concepts about simple machines.
- 2) Develop and practice engineering problem solving skills. These skills entail using their concepts about mechanical devices to produce creative solutions to problems. Activities basically coincide with the iterative engineering design process of; research<-->simulate<-->prototype.
- 3) Enable students to make the connections between the physical devices, the mathematics, and the scientific principles.

- 4) Encourage students to self-reflect on their work, the activities, and hence their learning.

The first cognitive goal will be addressed throughout all of the activities contained in the module. During all of the activities the students will be working and designing with simple machines and all of these activities will contribute to their concept development. In this case, 'concept development' includes learning about the names and functions of each of the devices and their parts, and recognizing common uses for each of the simple machines. In addition, students should begin to recognize that simple machines are part of many common devices and this commonality increases the relevance of the learning [7, 8].

Middle school students are likely to have experience with 'simple machines' since they are ubiquitous in everyday life. Common everyday devices that are based on the fundamental principles of the six simple machines include; the wheelbarrow, the bicycle, a sliding board, a car, and many other objects too numerous to list. Students should have experience with all of these devices, at least to the extent of having seen or used them at least once. Therefore, this experiential knowledge is a basis upon which the students can build a more comprehensive and robust understanding of simple machines. This module builds on the existing experiential knowledge of the students in order to expand it to include the underlying principles behind the objects in their everyday lives. This 'principle' knowledge can then be used to design creative solutions to novel problems.

The second cognitive goal involves engaging the student in the 'engineering process'. The students will be solving design problems throughout the instructional module. The module is organized such that the students work through a set of activities for each of the simple machines. One of these activities is to use the particular machine to solve a given design problem. As the students work through the set of activities for each simple machine, they will also be working on a final project which makes use of two or more machines. Therefore the students will have multiple opportunities to solve design problems and engage in the engineering process as described in the previous section.

As the students work through their projects, they will be guided to use their developing knowledge to make predictions about possible solutions. The students will then test their predictions through modeling and prototyping. Part of the design activities include making sketches and calculations which describe and record the student's evolution of his or her design idea. This information will serve as a reference for the student which will be required if modifications need to be made. These records will also be part of a sharing activity so they serve as an opportunity for the student to make their thinking visible not only to themselves but to other class members as well. The combination of all of these activities model the engineering process described in Fig. 1.

The purpose of the third cognitive goal is to enable students to make the connections between the physical devices and their governing abstract principles. One of the basic principles behind all of the simple machines is that of mechanical advantage. Simple machines were developed to allow people to perform functions that are difficult to accomplish with individual strength alone. When machines allow us to perform these functions they provide us with mechanical advantage. For example, some of the simple

machines provide mechanical advantage by lifting very heavy objects with little effort. The principle of mechanical advantage is translated for each of the machines and the students are expected to make the connections between the principles and the machines.

To encourage making these connections the students engage in the dual activities of physical manipulation and abstract simulation. The physical manipulations are done using the Technic I set from LEGO® [6], and the abstract simulations are embedded in the technology component. Therefore the student will see the principles represented in two different ways, 1) the simulations will provide an abstract representation and 2) the LEGO® devices will provide a more concrete, physical representation. The students are then asked to compare these two results and draw conclusions about the functionality of each of the machines.

Finally, the fourth cognitive goal is assigned in order to encourage students to self-reflect on their work and activities. While self-reflection is embedded in many of the activities already described, another specific self-reflection activity included in the module is the sharing of ideas. Students will be expected to share their design ideas and any findings they made during the simulation and building process. The act of posting the results will require the students to reflect on what they have accomplished. In addition, the results will be posted via the Internet to a bulletin board which is viewable by everyone, and students will be able to make comments and suggestions about other students' work. Ultimately this questioning, and the resulting reflection required for responding, will lead to stronger student understanding [7, 8].

User Interface Design Considerations

The cognitive goals were only one piece of the puzzle for putting together this instructional module about simple machines. In addition to the cognitive goals there were other considerations which guided the development of this module. Since the module is a web-based design, many decisions had to be made regarding the user interface. While the user interface design is not part of the cognitive goals, it is still a critical component of the learning environment. Therefore a description of this module would not be complete without discussing the issues regarding the user interface design.

There were two main considerations that guided the design decisions for the module; 1) to develop an accessible and interactive instructional module and 2) to provide a gender equitable and enjoyable learning experience. The design of the user interface was directly tied to each of these guidelines and much time and effort was expended on meeting these two criteria.

The instructional module was designed to be web-based so that it would be widely accessible. Theoretically, anyone who has access to the Internet would have access to the module. The web document was written in HTML [9] and Java [5] which makes it platform independent. Therefore both Windows and Macintosh users can access the module. Many attempts were made to be sensitive to limited hardware capabilities. Since some users may not be directly connected to the network, and would be relying on modems, download times were kept to a minimum. Color tables were minimized and graphics were used sparingly. One of the features of the module included the use of video clips which require significant download time across a modem. Therefore the

clips were supplemented with text versions that could be quickly accessed.

Navigation issues were also considered as part of accessibility. A contents page was designed that allows the user to get to any page in the document from this page. Each subsequent page is then linked to the content page in case the user gets lost. There are two other main pages that the user may frequent while working through the module, the share findings page and the suggestion box, and these are also linked on every page for easy access.

A template was designed and included as a header for each of the pages. This enables the user to immediately recognize pages that are associated with this web document. Also the structure of the pages were consistent throughout. Each page has the same background, the same template, a title at the top, a description box with icon at the top, and consistent placement of navigation links. All of these features combine to create a user interface that is friendly, easy to use, and does not get in the way of the learning that should be taking place.

The module was also designed to be interactive and to make use of multimedia capabilities. The main feature that makes the module interactive is the use of web-based Java applets. The applets allow the user to run animated simulations based on the student's selection of parameters. The results of the simulations can then be entered into a plotting program which will mathematically display the results of the animated simulation.

The module was also designed with the intention of being a gender equitable learning experience. One of the obvious features that contribute to gender equity is the depiction of females as engineer/designer in the video clips. A more subtle feature of this module is the 'look and feel' of the interface. The interface was designed in an effort to be more friendly to female students. It is important to note that gender equitable does not translate into feminine. Instead, it is interpreted to mean designing an environment that is inclusive of issues regarding both *male and female* students.

Since simple machines can be very easily associated with 'male stuff', effort was made to make the topic more attractive to the female students. One of the first decisions made concerned how to represent the actual devices. Actual machine-shop like pictures of pulleys, gears, etc. tended to look rusty, metallic, and oily and, for sure, would alienate most female students. As a result hand drawings were made of each of the machines and included in the document because they were accurate representations of the devices and, theoretically, they would be more acceptable to all of the students.

In order to be consistent with the hand-drawings, a notebook paper background was chosen as well as a pencil for the template. In fact, some of the module activities include having the students make sketches of their ideas and designs so the interface is also consistent with the cognitive goals and activities. The background, the template, and hand drawings all contribute to a 'look and feel' of a learning environment which is intended to be gender equitable.

Features of the Web-Based Environment

The current instructional module consists of many different design features and some of these features will be described and pictured in this section. Five of the features, and corresponding computer screens, that will be shown and

described are 1) the *Home Page*, 2) the *Computer Simulation Page* for the lever, 3) the *Plotting Page* for the lever 4) the *Share Findings Page* and, 5) the *Video Page*.

The *Home Page* is shown in Fig. 2. This page illustrates the basic look and feel of the environment; all of the subsequent pages have the same background, the same header, the same footer, and titles with red text. All of this was done in order to provide consistency among the pages. Consistency is an important factor since it orients the user to the web site and connects all of the pages with a single theme.



Figure 2. The home page for the instructional module.

The computer simulation Java applet for the lever is shown in Fig. 3. The user has a choice of four loads with different weights; a suitcase, a sofa, a refrigerator, and a car. There is also a choice of three different fulcrum positions. The initial position of the lever is with the load resting on the floor and the opposite end of the lever in the air. The idea is to add weight to the end of the lever until the lever rotates about the fulcrum position and lifts the load. As the fulcrum position changes and moves further away from the load, the more weight it will take for the lever to rotate. The student will do simulations for each weight in the three different fulcrum positions and record the results. These simulations demonstrate the principle of mechanical advantage.

After the students collect their data from the simulation page they then enter their results in the plotting page. The plotting applet for the lever is shown in Fig. 4. The graph which is plotted also illustrates the principle of mechanical advantage for the lever; the further the fulcrum position is from the load, the more weight is needed to lift the load. Both the computer simulation and plotting programs for the lever, Fig. 3 and 4, were written in Java and are embedded in the web document. They can be run in any Java enabled web browser, independent of the hardware platform [10].

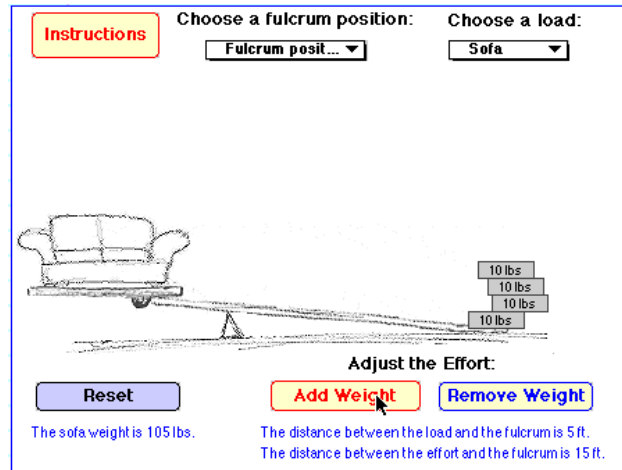


Figure 3. The computer simulation applet for the lever.

The students will also be doing off-line hands on activities with LEGOS®. The LEGO activity page for the lever provides a list of activities which the students are expected to complete. The hands-on activities serve to familiarize the students with the physical devices and provide an opportunity for them to make the connections between the simulation results and the actual 'machine'. Therefore the students are provided with multiple representations of the

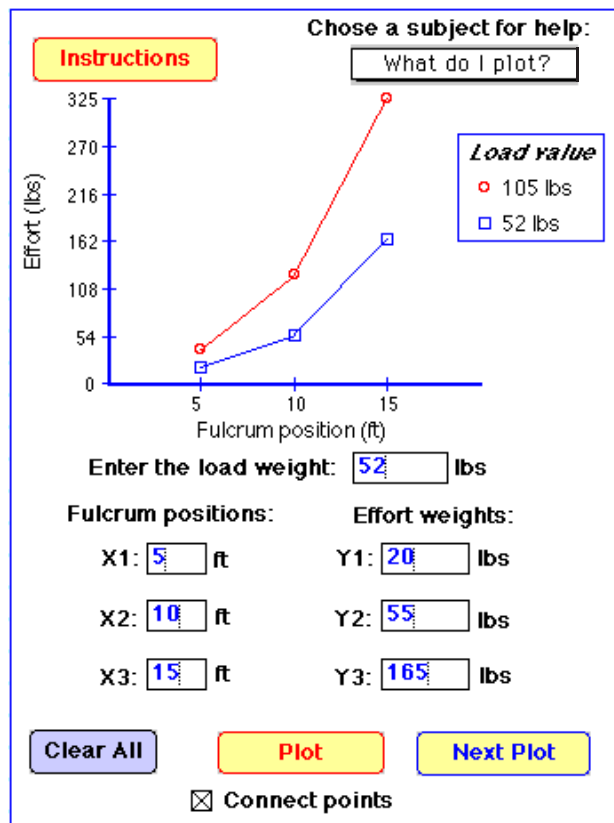


Figure 4. The plotting applet for the lever.

same principle; the physical device, the simulations, and the graphs.

The order in which the students engage in the activities is not prescribed. For example, the student can choose to do the LEGOS® building first then the simulating, and vice versa. This flexibility exists because students have a variety of different learning styles [11] and some may benefit from performing the concrete examples first, or some may prefer to see the graphs and simulations.



Figure 5. The share your findings page.

The *Share Your Findings Page* is shown in Fig. 5. This page was included to provide a space for the students to share their discoveries with the class. Having the 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 the students to self-reflect on their learning. Making thinking visible refers to revealing one's tacit cognitive processes and ideas in order to give them form and substance on the page. Both of these activities, making thinking visible and self-reflection, encourage the student to become self-sufficient learners as well as contribute to a more robust understanding [7, 12]. A set of prompts are provided to scaffold the students in formulating responses. Using a cgi script [9], all of the comments that are submitted are sent and saved to a separate web page that can be referenced by the students. In addition, the students will be encouraged to question others' findings

and to engage in a dialogue which requires students to defend and explain their positions.

Finally, the *Video Clip Page* is shown in Fig. 6. Presently the page includes four different people describing their suggestions about the design process. Each person offers a different perspective about, and/or a useful technique for, working on design problems. The videos were used in order to personalize engineering and the design process and to represent the multiple opinions regarding doing design. There is no one definition of design and it can be interpreted to mean many different things to different people. Rather than making a static list of all these perspectives, 'real-life' designers are presented to represent each of the various perspectives. Ultimately three or four additional videos will be included in order to broaden the 'definition' of design and to include a wider variety of ethnicities.

An assessment feature has also been built into the on-line activities via 'the suggestion box page'. This page is where students can submit any comments about the assignments, the LEGO activities, the computer simulations, the projects, etc. The students will be encouraged to explain what they did or did not like about the simple machines module. This page will serve as mechanism for obtaining feedback which will be used for continuous improvement of the design features of the module.



Figure 6. The video clip page for introducing design.

Summary and Future Work

The basic structure of the on-line instructional environment has been established, and the cognitive goals have been explicated. However, more work needs to be done in completing the sections for each of the machines. At present almost all of the web pages for the lever are complete and the format for the other machines has been set. Additional pages for the gear, the pulley, the inclined plane, and the wheel and axle still need to be designed.

The module will be used in a pilot study in the summer of 1997 in an Introduction to Engineering class for 7th, 8th and 9th grade students. This study will provide the data and feedback necessary for continuous improvement and refinement of the module.

Acknowledgments

We would like to gratefully acknowledge Mark Jeffery for his help with writing the code for the Java applets and the cgi scripts. His contribution was critical in meeting the guideline for making an interactive module. The authors would also like to thank the members of the EMST291B class, Spring 1997 for their comments about this instructional module. They helped to clarify the cognitive and design issues regarding this instructional module.

References

- [1] Crawford, Richard H., et al., An Engineering Design Curriculum for the Elementary Grades, *Journal of Engineering Education*, April 1994, pp. 174-181.
- [2] Muller, Carol B., "Engineering Concepts in the High School Classroom: The Dartmouth/Thayer Problem-Solving Methods," Proceedings from FIE 95, *Frontiers in Engineering Education*, Atlanta, Nov. 1-4. 1995, pp. 4b1.15-4b1.18.
- [3] Wilson, Denise, et al., "Establishing the Foundations for Engineering Education in K-5," Proceedings from FIE 95, *Frontiers in Engineering Education*, Atlanta, Nov. 1-4. 1995, pp. 3b2.5-3b2.9.
- [4] URL for the simple machines module:
http://socrates.berkeley.edu:7009/simple_machines
- [5] Java Development Kit and documentation: see the Sun Microsystems Web page at <http://java.sun.com>
- [6] LEGO® Dacta, 555 Taylor Road, Enfield, CT 06083-1600, <http://www.lego.com>
- [7] Linn, M.C., & Muilenberg, L. (1996). Creating Lifelong Science Learners: What Models Form a Firm Foundation? *Educational Researcher*, 25 (5), 18-24.
- [8] Linn, M.C., Bell, P., & Hsi, S. (in press). Using the Internet to enhance student understanding of science: The Knowledge Integration Environment. *Interactive Learning Environments*.
- [9] Lemay, L., "Teach Yourself Web Publishing with HTML," Sams.net Publishing, Indianapolis IN, 1995. Chapters 1-8.
- [10] Presently, on a Macintosh, the Java applets only run in Internet Explorer 3.0.1

- [11] Felder, R., Matters of Style, *ASEE Prism*, pp. 18-23, Dec. 1996.
- [12] Collins, A., Brown, J.S., & Holum, A. Cognitive Apprenticeship: Making Thinking Visible. *American Educator*, 6 (11), 38-46, 1991.

