

Better Learning of Mechanics through Information Technology

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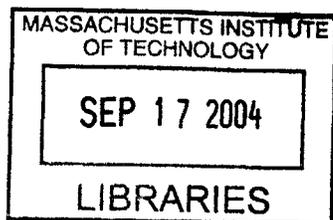
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BARKER

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Submitted to the Department of Civil and Environmental Engineering
on August 27, 2004 in Partial Fulfillment of the Requirements for the Degree of
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in the Field of Geotechnical and Geoenvironmental Engineering

Abstract

The use of Information Technology (IT) in engineering education offers the opportunity to teach concepts more effectively than the methods of instruction most commonly used. IT can assist students in making abstractions and improve their understanding of more complicated concepts starting from simple principles and/or real-world physical phenomena. This thesis presents two interactive computer-aided learning tools. For their development, educational theory is first reviewed from which important learning concepts are extracted. These concepts are proposed as essential elements to be incorporated in computer-assisted learning tools. The thesis also reviews the history of technology in education since the 1600's, including the major contributions, challenges, and reactions encountered during years of technological change.

The first tool addresses the teaching of basic solid mechanics. The tool uses simulations and animations in multimedia interactive exercises. Formative testing was conducted during its development, and its effectiveness was assessed through a summative evaluation involving 38 students. Two important conclusions can be drawn from this research. First, a clear overall improvement trend was observed for the students who used the basic mechanics tool. Second, the students who benefited the most from the use of the tool were those who were particularly weak in the subject after having been instructed through conventional teaching methods.

The second tool covers the principles and applications of stereographic projections and their application to rock wedge stability analyses. It benefits from the findings of the development, implementation, and assessment process of the first tool. This module uses three-dimensional imagery which helps visualize complex geometric arrangements.

Finally, the tools developed represent an alternative to what learning technology has always done; transmit academic knowledge to the student. These tools are an example of how IT can be used to go beyond the traditional forms of academic teaching by using technology with an approach that is not attached to this transmission model. They also show how to exploit the adaptive potential of IT to serve a different, more effective kind of learning.

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Chapter 1 Introduction

Information Technology promises to transform virtually every human endeavor. Organizations are learning how this technology streamlines processes, facilitates real-time information transactions, expands markets beyond geographic areas, and customizes service offerings to the needs of customers. These new capabilities have made organizations more efficient – they have forced leaders to rethink markets and reengineer structures and processes that led to dramatic improvement in quality. This technology can also be harnessed to transform education and training in ways previously unimaginable. Rapid advancements in the years ahead will produce new learning environments using simulations, networks of learners, tools of adaptable content, and more. The technology as it is can create rich and compelling learning opportunities that meet all learners' needs, and provide knowledge and training when and where it is needed, while boosting the productivity of learning.

However to a large extent, schools have been an exception to this information revolution (Paige, 2002). Teaching methods have not evolved sufficiently to keep pace with what is needed. The dominant model is still the transmission model, with the prevailing learning technologies still being those it has spawned: the lecture, the book, the graded assignment. Academics have been unable to go beyond the traditional forms of academic teaching. Teachers have begun to play with digital technologies as a way of

meeting the demands of the digital age, but with an approach attached to the transmission model. The academic community has not defined how to teach how to come to know rather than teaching what is known, and therefore cannot draft the specification as to how the new technology should do anything other than what learning technology has always done – transmit the academic’s knowledge to the student. With each new technological device – word processing, interactive video, hypertext, multimedia, the Web, etc. - the academic world has called each one into the service of the transmission model of learning. The adaptive potential of the technology to serve a different kind of learning cannot be exploited by an academic community that sticks only to what it knows. The academy does not adapt itself to new technologies. Therefore, there is no progress in how we teach, despite what might be possible with the currently available technology (Laurillard, 2001).

Paige (2002) also mentions, “the problem is not that we have expected too much from technology in education – it is that we have settled for too little. Many schools have simply applied technology on top of traditional teaching practices rather than reinventing themselves around the possibilities technology allows.”

The availability of inexpensive and powerful computers and the worldwide web have the potential to become one of the primary technologies for distance education (Punambekar, 1999). Theoretically, through a web-based learning system, students can perform various learning activities in a virtual classroom. This facilitates the development of web-learning spaces that maximize educational benefits.

The potential for the development of interactive tools that engage a two-way communication with students exists today. The tools are available for such development, but few efforts have been made to build these tools with full implementation of active learning, especially in the mechanics area. Many of the available teaching tools fail to achieve communication with the student and are limited to provide browsing capabilities by using navigational elements located on the screen.

The students are presented the material by advancing through the contents of these modules. This model does not provide much of an improvement with respect to textbooks.

In order to develop effective teaching tools that implement the advantages offered by Information Technology, technical standards must be established to help guide the development of education and training content that are to be drawn from countless sources throughout the world. Also, the technology community must form stronger partnerships with the education community. The education and training institutions need to prepare for rapid technological change.

The following chapters describe the development of a series of interactive teaching tools in the area of mechanics and geometry. This presentation is divided into three main parts related to the tools: background, development, and evaluation.

The first part provides a historical background of how technology has influenced education through the years since the American colonial period to current times. This presentation is considered to be of importance to the context of this work since it provides clear examples of various attempts made throughout history to implement technology in the educational process; attempts that were not always successful. Very importantly, this part of the work describes a set of educational theories in an attempt to extract important elements from each theory. This is done to provide a basis for producing a more effective use of Information Technology in engineering education. The result of this effort was the realization that no one theory fully describes the learning processes considered important for engineering education. Instead, components of many educational theories were found to enrich the content of the new tools making them more effective. These theories are discussed and their components and their use are described in detail.

The second part of this thesis focuses on the description of the tools developed within this research project. The tools developed are three modules in basic solid mechanics and one module on the use of stereographic projections for stability analysis of rock masses. These self-paced modules use simulations and animations to present fundamental engineering concepts. The development process of each set of modules is fully described, as well as their content, objectives, application scenarios, and the technology used in their implementation.

The modules are designed as a supplement to the currently used lecture-type instruction and intend to challenge students of varying abilities and diverse backgrounds. They are especially appropriate for developing a student's ability to visualize systems, and to gain a qualitative sense of the behavior of those systems.

The idea of presenting concepts using the proposed methods is based on the hypothesis that knowledge in mechanics is not adequately presented through propositional statements. Instead, knowledge should be presented as a sequence of representations of concepts or analogies. Most importantly, these methods should assist the student to make abstractions on his or her own and therefore develop understanding of more complicated concepts departing from known, simple principles and/or real-world physical phenomena. They should also inherently teach students how to come to know, rather than teach what is known. All this, implemented through Information Technology, should contribute to the improvement of engineering education.

The third and last part of the thesis presents the evaluation of the developed modules. This exercise should produce conclusions about the hypothesis set out in the previous paragraph; it should serve as a measure of how much improvement, if any, these modules are capable of bringing into the engineering education curriculum.

The evaluation part of the thesis includes an extensive description of the methodology used in the assessment of teaching tools developed in this research project. This section

was deemed necessary since it provides the necessary guidelines to plan and undertake an evaluation process. These guidelines are then implemented to evaluate the developed modules. The chosen evaluation methodology is presented along with a description of its implementation process and the results obtained from it. The conclusions reached in this process encourage the development of other Information Technology based teaching tools in the field of engineering.

Chapter 2 Technology in Education - History

Technology has always been linked to education. Throughout history, technology has changed the way students learn and the way educators approach the main objective of instruction; the acquisition of knowledge. This chapter attempts to inform the reader on how technological innovations were introduced into the classroom since the 17th century and what reactions these innovations sparked among educators. The main objective of this chapter is to show that the introduction of technology in instruction has not always been an easy task for education reformers; however, it has brought benefits to the system and to its ultimate goal of educating students.

This chapter is divided in three sections, which correspond to three important periods of the use of technology in the classroom. Although these periods are defined by events related to American history, an attempt is made to describe technological developments made in the United States as well as in Europe. The first period comprises the American colonial and early republican years of the United States until the American civil war, the second period covers from the civil war to the year 1900, and the third period discusses technological innovation in what is considered modern times until the appearance of the computer and its introduction into the classrooms. The difference in technological development between the United States and Europe is more evident during the first

period. As can be expected, the technological gap between the two regions starts to vanish from the second half of the 19th century. It is considered that by the beginning of the 20th century to our days, the last of the three periods in which this chapter is divided, the technological innovations, and their applications to education take place in a more synchronized manner.

2.1 From the Colony to the American Civil War (1600 – 1865)

During the colonial period, educational technology was in a pre-industrial state. Only artesian apparatuses manufactured by hand such as quill, ink, and the hornbook were used.

Colonial schools in the United States did not have blackboards, slates or maps. Almost all school supplies for students were homemade. The pens were goose-quills and each family supplied their children with homemade ink. The paper was rough and dark and came in foolscap size (approximately 13" by 17") and was unruled (Anderson, 1962).



Figure 2.1 The hornbook (Source www.folger.edu/institute)

The hornbook is an apparatus that is particular to the colonial period. Its use in the United States was a direct import from the English educational system where it had been used since the 1400's. Hornbooks were never manufactured in the United States; they were always imported from England. The hornbook was the first book used to teach children to read, and was their first introduction to formal education (Anderson, 1962). The hornbook, shown in Figure 2.1, was a leaf of paper printed with the alphabet, the ten numerals, some elements of spelling, and the Lord's Prayer. Hornbooks were printed in black-letter type, which in the early modern period was believed to be easier to read. The printed sheet of paper was then protected by a thin plate of translucent horn and mounted on a tablet of wood with a projecting piece for a handle. The hornbook was modified during the years; later, hornbooks were built such that different lessons could be slipped under the horn.

The next big step towards the modern textbook was the spelling book, which preceded primers by a number of years. The first spelling book in English language was *The English Schoolmaster*, published in England in 1596 (Anderson, 1962).

One of the first notable textbooks was *Orbis Pictus* written by John Amos Comenius, published in Germany in 1657. This textbook was translated into fourteen languages and became the standard text for German schools for 200 years. It also enjoyed great popularity in England and the American colonies (Anderson, 1962)

As paper became cheaper in the United States and easier to manufacture, the textbook was introduced into the American school system. Stephen Daye assembled the first printing press in the colonial United States in 1639; it printed a spelling book between 1641 and 1643 (American Textbook Publishers Institute, 1949). This textbook, a spelling book, however, did not have much influence on the American textbook movement. The first American textbook of any importance, *The New England Primer*, was published

around 1690. It was a book bound by hand with covers made from thin oak that cracked and splintered badly (Anderson, 1962).

The text on the books during the American colony was concentrated more on moral teaching than actual factual teaching. As an example the following problem found in the arithmetic section of *Dillworth's Schoolmaster's Assistant* is presented.

Three jealous husbands, each with a wife, met on a river bank. How are they to cross so that none of the wives is left in the company of one or two men unless her husband is also present?

(Pulsifer, 1921, p. 6)

Illustrations in early textbooks were of very poor quality. Illustrations were presented in wood or copper engravings. These were technically challenging to reproduce, making the appearance of illustration scarce.

The American Revolution forced the United States to be self sufficient. The period between 1791 and 1861 was one of rapid growth for the country. During this period, important teaching implements such as the blackboard and slate towards the beginning of the 1800's, and maps in the 1830's were introduced into the American school system (Anderson, 1962).

From around 1830, educators started to accept the fact that new teaching apparatuses could make invaluable contributions to the field of education. Education reformers began to require their schools to report on new apparatuses acquired and their use. William J. Adams (1830) said at a teacher's convention:

Sensible objects, judiciously selected, and properly exhibited to the young student, are found to contribute wonderfully to his advancement in all good learning. In fact, books and lecture, without these means of illustration, are precept without example; theory without practice; uninteresting, hard to

understand, and soon forgotten... The world is full of apparatus, but the teacher, in times past, has been slothful, or too dogmatical, even to point it.

(pp. 344-345)

In another meeting, in Hanover, Massachusetts, Daniel Webster said:

We teach too much by manuals, too little by direct intercourse with the pupil's mind; we have too much of words, too little of things. Take any of the common departments, how little do we know of the practical detail, say geology. It is taught by books. It should be taught by excursions in the field. So of other things.

(*American Journal*, 1856, p. 590)

But at the same time there were critics of the innovations being introduced into the school system. Some people felt technology was being introduced at the wrong pace and criticized advocates of a "teaching machine".

"Observe" says a third, "the spirit of the age? In these mechanical labor-saving times, we must have a mill in which to grind scholars; - something in which the moving power is no longer the unfailing stream of patient, sound instruction; - a Machine, in fact, which steam may turn, and a child direct?"

(Anderson, 1962, p. 10)

The goose-quill pen was around until the late 1830's when the steel pen made its appearance. In 1830 the essential educational apparatuses included a time-piece, maps and globes, the blackboard, and the abacus or numeral frame (Anderson, 1962).

The blackboard was slowly introduced in the United States. Anderson (1962) mentions the first reference to a blackboard made in an arithmetic publication in 1809 in Philadelphia, where a footnote explained that "the Black Board should be about 3 feet square, painted or stained with ink, and hung against the wall in a convenient place for

a classroom to assemble around it". Samuel J. May, an educational reformer in Boston schools, reports his first experience with a blackboard as follows:

*... in the winter of 1813-1814... I attended a mathematical school kept in Boston
... on entering this room, we were struck at the appearance of an ample
Blackboard suspended on the wall, with lumps of chalk on a ledge below, and
cloths hanging at either side. I had never heard of such a thing before ...*

(*American Journal* , 1886, pp. 140-141)

By the late 1830's, teachers were now considering the blackboard as essential to teaching. In the late 1840's texts for teachers on the use of the blackboard began to circulate. One of these books quotes:

*The inventor or introducer of the blackboard system deserves to be ranked among
the best contributors to learning and science, if not among the greatest
benefactors of mankind.*

(Bumstead, 1841, p. 8)

The use of slates reaches back into antiquity. Its predecessors were the wax tablets used by the Greeks and Romans and the black wax tablet used by the Hindus around 1000 A.D. The use of the modern slate was common in Europe by the 1400's. It made its appearance in America only in the 1800's. Anderson (1962) quotes an article in the *Connecticut School Journal* of 1939 on "The use of slates" which advises, "We can hardly recommend any experiments or methods more likely to succeed, than slate exercises".

Globes were in use in the classroom in the United States as early as 1830. It was one of the apparatuses considered essential for instruction which helped explain the phenomena of the earth. It helped solve the problem of children understanding the globe as a disc, and not as a sphere (Anderson, 1962).

The textbook movement in the United States between the American Revolution and the Civil War saw an improvement in the printing process. The type moved from movable type, set by hand, which sometimes proved to be difficult to read, to the appearance of stereotyping¹ introduced in 1840, allowing books to be printed from plates. In the 1860's, the book adopted the new electrotyping² process of printing (Anderson, 1962).

During the mid 1800's the art of photography was reaching an advanced state of development. Educators then began to use photographs to illustrate texts. Various methods of printing photographs onto text sheets were used, while others chose to attach the photograph directly. In 1856 the first serious attempt to illustrate a text with extensive use of photographs was made by John W. Draper in *Human Physiology, Statical and Dynamical*. Illustrations were printed from copper plates, prepared from photographs (Anderson, 1962).

Anderson (1962) also mentions the criticism that the now abundance of textbooks received among educators. A critic wrote:

The houses of many of us are overflowing with the result of this misdirected industry and mercantile enterprise, so that not a few of us are obliged to refuse the admission to any further specimens of school literature...

(p. 25)

2.2 From Civil War to 1900 (1865 – 1900)

This period saw a significant evolution in attitude towards technology in education. The new educational apparatuses introduced in the previous period were not regarded as novelties anymore; instead, they were now seen as necessary educational elements. Also, during this period, the International Exhibitions did much to disseminate knowledge on more than just local basis. It became the standard practice after the

¹ Stereotype: A metal printing plate cast from a matrix molded from a raised printing surface.

² Electrotype: A metal plate made by electroplating a lead mold of the page to be printed.

World's Fair in London in 1851 to include educational exhibits representing the latest in educational technology and methods from the different nations (Anderson, 1962).

As an example of this dissemination, the Centennial Exhibition in Philadelphia in 1876 the then president of MIT was so impressed by the exhibits from the technical schools of Moscow and Petersburg, that he obtained the exhibits and used them as the basis for the first laboratory system in the United States schools (Waterman, 1894)

This period, and the advances in educational technology, however, had its own critics. Many felt that the new educational apparatuses were complicated, beyond the ability of the teacher. Anderson (1962) quotes the following criticism to the innovation of using object as visual aid for teaching:

A practical objection will occur to everyone – the disqualification of the majority of teachers to use the system. It is above them. It is too high a kind of instruction. It requires more available knowledge, tact, and experience than most teachers can command.

(p. 28)

Others saw school being converted into educational factories, where the role of the teacher would be relegated to the manipulation of educational apparatuses, Anderson (1962) quotes an opinion in this regard, voiced in 1870:

The old-time schoolhouse ... is giving place to finer buildings ... we have improved desks and settees, improved maps and charts, improved slates and globes, and improved textbooks ... We are certainly far in advance of anything in our past, and are to be far in advance of other nations.

But just here, it seems to me, in the line of our greatest excellence, lies our greatest defect and our greatest danger. In looking so closely after the mechanism of education, we have lost something of the life and spirit of our teaching. Our

methods are ... mechanical and superficial ... So long as people like showy mechanism in our schools, so long they will have it.

(p. 28)

The blackboard continued to be a popular implement used in schools during this period. A school catalog of 1881 described its importance in these terms:

No one article of apparatus for the schoolroom is more indispensable than the blackboard. ... It is the tablet for recording mental processes of the pupil. ... It is the mirror reflecting the workings, character and quality of the individual mind. It is the chief auxiliary of the teacher; the aid-de-camp, the monitor, the guide.

(Illustrated catalog, 1881, p. 73)

In this period, however, blackboards were improved. They were now framed, put on rollers, or would even rotate within the frame. Some were made of paper that could be rolled up after use. The blackboard industry began to use complicated methods of pressing boards together and slate applications. Near the turn of the century, the natural slate began to replace the wooden blackboards.

The slates continued their popularity in schools, especially in rural areas where paper was difficult to obtain. By 1900, slates disappeared from nearly all schools except from those in the most remote rural areas (Anderson, 1962).

Technological advances in paper manufacturing during this period brought better and cheaper writing paper to schoolrooms. The pencil had been in use in England since 1564, was then refined in France in the 1700's and then became a big industry in Germany since 1761 under the Faber family (Godbole, 1953). In 1861, Eberhard Faber introduced the pencil industry in the United States. Steel (fountain) pens became now a practical writing instrument, although they were not yet widely used in this period (Anderson, 1962).

American maps, which were the standard in the world at the time, saw big technological advances during this period. In 1872, Rand McNally & Co. introduced a new relief line engraving process for making maps. This revolutionary method cut the cost of production significantly.

Instructional devices for arithmetic and geometry were abundant during this period. As early as 1867, a device was introduced which enabled the teacher to flash arithmetic problems to the class with little effort. The apparatus consisted of a number of slots holding number sequences. By manipulating knobs, the teacher could change number combinations and set up problems in “addition, subtraction, multiplication, division, decimals, federal money, and reduction” (American School Apparatus Company, 1867). Simple machines such as mechanical calculators were being devised and used in universities in the United States as early as 1873 (Anderson, 1962).

The textbooks saw improvements during this period with the appearance of the rotary self-feeding printing press. This technique reduced printing time by ten in comparison to the flat press. Illustrations in textbooks also improved, photography was now more influential with the introduction of the half-tone process in the 1880's (Anderson, 1962).

The developments in photography, together with projection principles, produced a visual aid for education – the stereoscope. Utilizing two photographs and a simple optical apparatus, the stereoscope permitted the user to see a third dimension. Sir David Brewster, who pioneered certain fields of stereoscopic research, wrote a book urging educators to adopt the stereoscope in education. Referring to the old system of education he wrote:

... the existing system is utterly inefficient. The teacher ... may pour it in the ear, or extract it from the printed page, or exhibit it in caricature in the miserable embellishments of the schoolbook, but unless he teaches through the eye ... no satisfactory instruction can be conveyed.

(Brewster, 1856, pp. 195)

The increased interest in photography germinated the next logical step in visual education; the projection of these photographs. This gave way to the magic lantern or stereopticon, shown in Figure 2.2. This apparatus was sought by the most progressive schools. It required a much higher investment compared to any other educational instruments. Not only were they expensive to acquire, but also their operation was expensive since it required a bright light for the projection process. Regardless of this, the magic lanterns were immediately recognized as the vanguard of a new field of visual aids. This is illustrated in this comment from the turn of the 19th century:

The age of illustration is now with us and illustrate we must if we expect to gain and to hold the attention of young and old ... No one can predict the limits of education through this wonderful advance in photography, and no one can deny the immediate expediency of adopting such an auxiliary in the schools.

(Morsell, 1893, pp. 558-559)

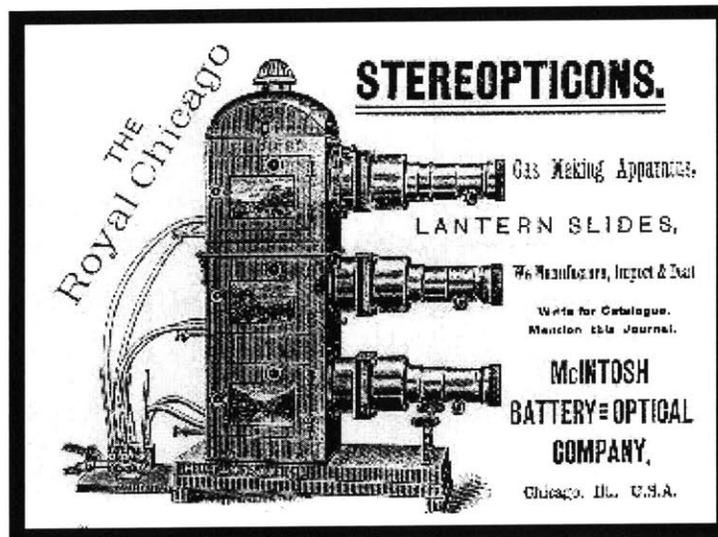


Figure 2.2 Magic lantern advertisement in 1884 (Source: www.magiclanterns.org)

2.3 From 1900 to our Days

By 1900 classrooms were equipped with desks bolted to the floor facing a blackboard and the teacher's desk. Report cards, homework, textbooks, teacher lectures, and student recitation were standard features of urban classrooms (Cuban, 1986).

The use of the magic lantern, introduced into classrooms in the late 1800's, evolved into film projectors. Thomas Edison was one of the enthusiasts of this technology. In 1912 he said:

Books will soon be obsolete in the schools, scholars will soon be instructed through the eye. It is possible to touch every branch of human knowledge with the motion picture.

(Seattler, 1968, p. 98)

In 1922 Edison added:

I believe that the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks.

I should say that on the average we get about two percent efficiency out of schoolbooks as they are written today. The education of the future, as I see it, will be conducted through the medium of the motion picture ... where it should be possible to obtain one hundred percent efficiency.

(Cuban, 1986, p. 9)

The motion picture was first introduced by the Lumiere brothers in France in 1895. The first school use of the motion pictures in the United States was in 1910 by the Rochester,

New York public schools. By 1931, 25 states had departments dedicated to films and related media. Early textbooks in the use of motion pictures furthered the influence of the film, as did film-oriented college courses for teachers, which appeared in the 1920's (Cuban, 1986).

Almost at the same time as the film was introduced into the classrooms, radio made its appearance in schools. In the United States, the Radio Division of the Department of Commerce began licensing commercial and educational stations in 1920. The first lessons broadcasted in school began as early as 1923. In that same year an enthusiast of this new technology implemented to education remarked:

The central and dominant aim of education by radio is to bring the world to the classroom, to make universally available the services of the finest teachers, the inspiration of the greatest leaders ... and unfolding world events which through the radio may come as a vibrant and challenging textbook of the air.

(Darrow, 1932, p. 79)

By 1942, an incomplete survey of school districts across the country found 29 systems in 17 states that provided broadcasts at one time or another. By 1945, many commercial stations, school districts, state departments of education and universities produced and aired programs for teachers to use in their classrooms. The usage of this technology, however, did not reach the anticipated levels, where it had been predicted that every classroom would have a radio receiver. Nevertheless, it proved to be more accessible than film. The nature of radio educational programs, being half-hour long to hour-long broadcasts once a day or a few times a week, destined the radio usage to be viewed as a supplement to teacher instruction (Cuban, 1986).

In the 1950's radio sets had failed to become "as common in the classroom as is the blackboard". By this time, the enthusiasm for television promoted the dreams of yet a new generation of school reformers. Research and journal articles on radio in the

classroom have now virtually disappeared. The promise of radio as a teaching tool, where “the roof of the classroom has been blown off and the walls have been set on the circumference of the globe” failed to materialize by the time instructional television appeared (Cuban, 1986).

By the mid 1950's, a number of school districts using support provided by the Fund for the Advancement of Education of the Ford Foundation, local funds, and corporate equipment got involved in television instruction. In the first decade of its adoption there were three commonly implemented uses of the television in classrooms (Cuban, 1986):

1. Total instructional program presented by television teacher: where lessons were presented in a television set in front of the classroom with no teacher present
2. Supplemented television instruction: where the teacher used the televised lesson as the main means of instruction
3. Television as a teaching aid: where the teacher used televised material as a supplement to class instruction

During 1950 the introduction of the television as a teaching aid provided a clever solution to a shortage of teachers in the school system in the United States. During its implementation, the technology and its initial applications to the classroom were conceived, planned, and adopted by nonteachers. School boards and superintendents initiated efforts for using the new technology; only later were teachers involved in discussions of how to install it into the classroom. During its early stages of implementation, while much was said to quiet teacher fears of being replaced by technology, a concerted push by reformers, amplified loudly by the media, sold the new technology as doing many of the things that teachers did and what teachers could not do (Cuban, 1986).

In the 1960' teacher shortage eased and most districts embraced the pattern of television as a supplement to rather than the primary vehicle of instruction. This is in part due to results of early research on the effectiveness of the methodology which showed that there was no substantial difference between the amount of information learned from televised lessons and information conveyed through conventional instructional approaches (Cuban, 1986).

The use of television as an instructional aid has been and continues to be used as an accessory rather than the primary vehicle for basic instruction in schools. Only a small portion of teachers use the medium willingly, consistently, and with enthusiasm.

The personal computer comes as the last technological innovation introduced as a teaching aid. The appearance of these machines during the 1980's has, yet again, prompted opinions such as the following:

There won't be schools in the future ... I think the computer will blow up the school. That is, the school defined as something where there are classes, teachers running exams, people structured in groups by age, following a curriculum – all of that. The whole system is based on a set of structural concepts that are incompatible with the presence of the computer ... But this will happen only in communities of children who have access to computers on a sufficient scale.

Seymour Papert, 1984

Educational computing, like the Force, is with us. Microcomputers are proliferating in our schools and unless a lot of people are wrong they're here to stay. But the \$64 question is whether these computers will make any difference in the education of our children. When my daughter graduates from high school in the year 2000, will she have received a better education with the help of computers than I did without them?

Dale Peterson, 1984

These points of view remain yet to be proven. The development of computers since they first appeared as an alternative in education has been large, so has been the quality of the instruction provided by these machines. It is definitely an ongoing process that remains to be defined in history.

2.4 Summary

This chapter attempts to bring to the attention of the reader the role that technology has played in the classroom throughout history. It mentions the most important technological advances introduced to education during three periods:

- **From the colony to the civil war**, when the development of the schoolroom takes place. Students in this period of time move from using quill-goose pens and homemade ink to the introduction of the hornbook, which was later replaced by early textbooks. Teaching apparatuses such as globes and maps made their appearance into classrooms after the Revolutionary War. The blackboard was another important technological innovation brought to the school system, while the end of the period saw the introduction of photography as a visual aid included now in textbooks.
- **From the Civil War to the year 1900**. This period saw significant evolution in education. Technological innovations introduced in the previous period were improved and now considered basic elements for classroom instruction. The blackboards were improved, maps were introduced, and printing processes were enhanced, allowing for mass production of textbooks. The end of the period saw the introduction of the magic lantern, recognized as the vanguard of a new field of visual aids.

- **From the year 1900 to our days.** This period has seen the most important technological innovations introduced into the classroom. The magic lanterns introduced in the late 1800's evolved into the animated film during the beginning of the 1900's, the radio then made its appearance into the classrooms in the 1920's. The Television was the next innovation brought to educational instruction in 1950, while the personal computer made its appearance as the latest technological innovation in the 1980's.

Throughout history, technological advances have improved education in different ways. The early years saw technology innovations leading to improvement of school equipment; elemental implements such as paper, ink, notebooks, etc. became of better quality and more affordable thanks to technology. Advances then shifted their field of application. Technology started to provide better means for teaching; the introduction of apparatuses to improve visualization of phenomena, maps, textbooks, and the blackboard among others, were all technological innovations that improved the learning environment in classrooms.

The latest stage of technological innovations came with the sophistication of the inventions being introduced into education. Apparatus such as the magic lantern, the film, the radio, the television, and ultimately, the computer have all come during a period of nearly one hundred years. Some of these have been more successful than others. It can be affirmed, that all of them have contributed to the improvement of education in general, despite the fact that some of them have not met the high expectations with which they were introduced.

Although technology has definitely brought advances and improvements to instruction through the years, the teacher has remained as an important element of the education system in the classrooms, despite all predictions about their disappearance, especially in the later years.

Chapter 3 Educational Theory in IT-based Teaching Tools

As was discussed before, teaching methods have not evolved sufficiently to keep pace with the evolution of Information Technology (IT). Teachers have begun to play with digital technologies; however, such attempts represent a way of teachers meeting the demands of the digital age, but with an approach attached to the transmission model predominantly used in the classroom before the appearance of IT. The academic community so far has not drafted specifications as to how the new technology should do anything other than what learning technology has always done; transmit academic knowledge to the student. With each new technological device – word processing, interactive video, hypertext, multimedia, the Web, etc. - the academic world has called each one into the service of the transmission model of learning. The adaptive potential of the technology to serve a different kind of learning cannot be exploited by an academic community that sticks only to what it knows.

The development of teaching tools for the improvement of engineering education, presented in this thesis, recognized the problem discussed above and provided evidence of the need to explore methods of instruction that departed from the transmission model while making use of the advantages of IT. In order to identify these new instructional models, a review of educational theory and pedagogy was undertaken. This exercise allowed one to identify a set of educational theories, where each theory contributes

important aspects and explanations of how learning occurs in students. The relevance of each one of these aspects was considered from the point of view of their potential application in a computer-based teaching tool. In addition to reviewing learning theories, a review of pedagogy in education led to the identification of pedagogical models that are enhanced through the tools under development.

As a result, the evaluation of educational theories and pedagogical models allowed one to formulate a series of learning concepts applicable to IT. These concepts should be contained in computer-based teaching tools that attempt to move away from the transmission model taking advantage of the adaptive potential of IT and form the basis of the conceptual development of the tools presented in this research.

Section 3.1 presents the set of educational theories considered most relevant to the development of teaching tools while section 3.2 presents a set of pedagogical models facilitated through IT. The learning concepts mentioned above are presented in section 3.3.

3.1 Learning Theories

The theories presented in this section have been chosen through a review of many learning theories proposed in the educational literature. The following subsections present a brief description of each of these learning theories. They also should provide the essential information showing what makes computer assisted learning different than learning without computers. This will provide the basis for section 3.3 in which specific aspects of the learning theories will be used in developing concepts of IT-based learning.

3.1.1 Constructivism

Constructivism is a philosophy of learning founded on the premise that, by reflecting on experiences, students construct their own understanding of the world they live in. Each individual generates his own “rules” and “mental models”, which he uses to make sense

of experiences. Learning, therefore, is simply the process of adjusting mental models to accommodate new experiences (Bruner, 1966).

There are several guiding principles of constructivism:

1. Learning is a search for meaning. Therefore, learning must start with the issues around which students are actively trying to construct meaning.
2. Meaning requires understanding wholes as well as parts. And parts must be understood in the context of wholes. Therefore, the learning process focuses on primary concepts, not isolated facts.
3. In order to teach well, the mental models that students use to perceive the world and the assumptions they make to support those models must be understood.
4. The purpose of learning is for an individual to construct his or her own meaning, not just memorize the right answers and recite someone else's meaning.

3.1.2 Behaviorism

Behaviorism is a theory of animal and human learning that only focuses on objectively observable behaviors and discounts mental activities. Behavior theorists define learning as nothing more than the acquisition of new behavior.

Experiments by behaviorists identify conditioning as a universal learning process. There are two different types of conditioning, each yielding a different behavioral pattern:

1. Classic conditioning occurs when a natural reflex responds to a stimulus. The most popular example is the observation that dogs salivate when they eat or even see food. Essentially, animals and people are biologically wired so that a certain stimulus will produce a specific response.

2. Behavioral or operant conditioning occurs when a response to a stimulus is reinforced. Basically, operant conditioning is a simple feedback system: If a reward or reinforcement follows the response to a stimulus, then the response becomes more probable in the future. For example, leading behaviorist B.F. Skinner used reinforcement techniques to teach pigeons to dance and bowl a ball in a mini-alley.

There have been many criticisms of behaviorism, including the following:

- Behaviorism does not account for all kinds of learning, since it disregards the activities of the mind.
- Behaviorism does not explain some learning--such as the recognition of new language patterns by young children--for which there is no reinforcement mechanism.
- Research has shown that animals adapt their reinforced patterns to new information. For instance, a rat can shift its behavior to respond to changes in the layout of a maze it had previously mastered through reinforcements.

3.1.3 Piaget's Theory

Swiss biologist and psychologist Jean Piaget (1896-1980) is renowned for constructing a highly influential model of child development and learning. Piaget's theory is based on the idea that the developing child builds cognitive structures, in other words, mental maps, schemes, or networked concepts for understanding and responding to physical experiences within his or her environment. Piaget further attested that a child's cognitive structure increases in sophistication with development, moving from a few innate reflexes such as crying and sucking to highly complex mental activities.

Piaget's theory identifies four developmental stages and the processes by which children progress through them. The four stages are (Piaget 1969):

1. *Sensorimotor stage (birth - 2 years old)* - The child, through physical interaction with his or her environment, builds a set of concepts about reality and how it works. This is the stage where a child does not know that physical objects remain in existence even when out of sight (object permanence).
2. *Preoperational stage (ages 2-7)* - The child is not yet able to conceptualize abstractly and needs concrete physical situations.
3. *Concrete operations (ages 7-11)* - As physical experience accumulates, the child starts to conceptualize, creating logical structures that explain his or her physical experiences. Abstract problem solving is also possible at this stage. For example, arithmetic equations can be solved with numbers, not just with objects.
4. *Formal operations (beginning at ages 11-15)* - By this point, the child's cognitive structures are like those of an adult and include conceptual reasoning.

Piaget outlined several principles for building cognitive structures. During all development stages, the child experiences his or her environment using whatever mental maps he or she has constructed so far. If the experience is a repeated one, it fits easily, or is assimilated, into the child's cognitive structure so that he or she maintains mental equilibrium. If the experience is different or new, the child loses equilibrium, and alters his or her cognitive structure to accommodate the new conditions. This way, the child erects more and more adequate cognitive structures.

3.1.4 Brain-based Learning

This learning theory is based on the structure and function of the brain. As long as the brain is not prohibited from fulfilling its normal processes, learning will occur.

Every person is born with a brain that functions as an immensely powerful processor. Traditional schooling, however, often inhibits learning by discouraging, ignoring, or punishing the brain's natural learning processes (Caine & Caine, 2001).

The core principles of brain-based learning state that (Caine & Caine, 2001):

1. The brain is a parallel processor, meaning it can perform several activities at once, like tasting and smelling.
2. Learning engages the whole physiology.
3. The search for meaning is innate.
4. The search for meaning comes through patterning.
5. Emotions are critical to patterning.
6. The brain processes wholes and parts simultaneously.
7. Learning involves both focused attention and peripheral perception.
8. Learning involves both conscious and unconscious processes.
9. We have two types of memory: spatial and rote.
10. We understand best when facts are embedded in natural, spatial memory.
11. Learning is enhanced by challenge and inhibited by threat.
12. Each brain is unique.

The three instructional techniques associated with brain-based learning are (Caine & Caine, 2001):

1. **Orchestrated immersion**--Creating learning environments that fully immerse students in an educational experience
2. **Relaxed alertness**--Trying to eliminate fear in learners, while maintaining a highly challenging environment
3. **Active processing**--Allowing the learner to consolidate and internalize information by actively processing it

3.1.5 Learning Styles

This approach to learning emphasizes the fact that individuals perceive and process information in very different ways. The learning styles theory implies that how much individuals learn has more to do with whether the educational experience is geared toward their particular style of learning than whether or not they are smart (Kolb, 1984).

The concept of learning styles is rooted in the classification of psychological types. The learning styles theory is based on research demonstrating that, as the result of heredity, upbringing, and current environmental demands, different individuals have a tendency to both perceive and process information differently. The different ways of doing so are generally classified as (Kolb, 1984):

1. **Concrete and abstract perceivers**: Concrete perceivers absorb information through direct experience, by doing, acting, sensing, and feeling. Abstract perceivers, however, take in information through analysis, observation, and thinking.
2. **Active and reflective processors**: Active processors make sense of an experience by immediately using the new information. Reflective processors make sense of an experience by reflecting on and thinking about it.

Traditional teaching tends to favor abstract perceiving and reflective processing.

3.1.6 Multiple Intelligences

This theory of human intelligence, developed by psychologist Howard Gardner (1983), suggests that there are at least seven ways in which people perceive and understand the world. Gardner labels each of these ways a distinct intelligence, in other words, a set of skills allowing individuals to find and resolve genuine problems they face.

Gardner defines an intelligence as a group of abilities that:

- Is somewhat autonomous from other human capacities
- Has a core set of information-processing operations
- Has a distinct history in the stages of development we each pass through
- Has plausible roots in evolutionary history

While Gardner suggests his list of intelligences may not be exhaustive, he identifies the following seven:

1. *Verbal-Linguistic* - The ability to use words and language
2. *Logical-Mathematical* - The capacity for inductive and deductive thinking and reasoning, as well as the use of numbers and the recognition of abstract patterns
3. *Visual-Spatial* - The ability to visualize objects and spatial dimensions, and create internal images and pictures
4. *Body-Kinesthetic* - The wisdom of the body and the ability to control physical motion
5. *Musical-Rhythmic* - The ability to recognize tonal patterns and sounds, as well as a sensitivity to rhythms and beats

- 6. *Interpersonal* - The capacity for person-to-person communications and relationships
- 7. *Intrapersonal* - The spiritual, inner states of being, self-reflection, and awareness

3.1.7 Right Brain vs. Left Brain

This theory of the structure and functions of the mind suggests that the two different sides of the brain control two different modes of thinking. It also suggests that each of us prefers one mode over the other (McCarthy, 1987).

Experimentation has shown that the two different sides, or hemispheres, of the brain are responsible for different manners of thinking. Table 3.1 illustrates the differences between left-brain and right-brain thinking.

Most individuals have a distinct preference for one of these styles of thinking. Some, however, are more whole-brained and equally adept at both modes. In general, teaching tends to favor left-brain modes of thinking, while downplaying the right-brain ones. Left-brain scholastic subjects focus on logical thinking, analysis, and accuracy. Right-brained subjects, on the other hand, focus on aesthetics, feeling, and creativity.

Table 3.1 Left-brain vs. right-brain thinking

Left Brain	Right Brain
Logical	Random
Sequential	Intuitive
Rational	Holistic
Analytical	Synthesizing
Objective	Subjective
Looks at parts	Looks at wholes

3.1.8 Vygotsky and Social Cognition

The social cognition learning theory (Vygotsky, 1978) asserts that culture is the prime determinant of individual development. Humans are the only species to have created culture, and every human develops in the context of a culture. Therefore, the learning development of a student is affected in ways large and small by the culture in which he or she is included.

The core principles of social cognition state that:

1. Culture makes two sorts of contributions to the intellectual development of a child. *First*, through culture children acquire much of the content of their thinking, that is, their knowledge. *Second*, the surrounding culture provides a child with the processes or means of their thinking, what Vygotskians call the tools of intellectual adaptation. In short, according to the social cognition learning model, culture teaches children both what to think and how to think.
2. Cognitive development results from a dialectical process whereby a child learns through problem-solving experiences shared with someone else, usually a parent or teacher but sometimes a sibling or peer.
3. Initially, the person interacting with the child assumes most of the responsibility for guiding the problem solving, but gradually this responsibility transfers to the child.
4. Language is a primary form of interaction through which adults transmit to the child the rich body of knowledge that exists in the culture.
5. As learning progresses, the child's own language comes to serve as his primary tool of intellectual adaptation. Eventually, children can use internal language to direct their own behavior.

6. Internalization refers to the process of learning a rich body of knowledge and tools of thought that first exist outside the child. This happens primarily through language.
7. A difference exists between what a child can do on his/her own and what the child can do with help. Vygotskians call this difference the zone of proximal development.
8. Since much of what a child learns comes from the culture around him/her and much of the child's problem solving is mediated through an adult's help, it is wrong to focus on a child in isolation. Such focus does not reveal the processes by which children acquire new skills.
9. Interactions with surrounding culture and social agents, such as parents and more competent peers, contribute significantly to the intellectual development of a child.

3.1.9 Situated Learning

This learning theory was originated by Jean Lave (Lave & Wenger, 1989) who argues that learning, as it normally occurs, is a function of the activity, context, and culture in which it occurs (i.e. it is situated). This contrasts with traditional classroom learning activities which involve knowledge that is often presented in an abstract form and out of context. Social interaction is a critical component of situated learning; learners become involved in a community of practice which embodies certain beliefs and behaviors to be acquired. As the beginner or newcomer moves from the periphery of this community to its center, they become more active and engaged within the culture and hence assume the role of experts.

Collins (1989) describes situated learning as “the notion of learning knowledge and skills in contexts that reflect the way the knowledge will be useful in real life”. In the

same context, Collins, Brown and Newman (1987) argue strongly for the effectiveness of what they call cognitive apprenticeship models of pedagogy, where, it is suggested, “teaching methods should be designed to give students the opportunity to observe, engage in, and invent or discover expert strategies in context” (Collins, Brown, & Newman, 1987).

Cognitive apprenticeship supports learning in a domain by enabling students to acquire, develop and use cognitive tools in authentic domain activity. Learning, both outside and inside school, advances through collaborative social interaction and the social construction of knowledge.

Principles of Situated Learning:

1. Knowledge needs to be presented and learned in an authentic context, i.e. settings and applications that would normally involve that knowledge.
2. Learning requires social interaction and collaboration.

3.1.10 Information Processing Theory

George A. Miller (1956) has provided two theoretical ideas that are fundamental to the information processing framework and cognitive psychology. The first concept is “chunking” and the capacity of short term (working) memory. Miller presented the idea that short-term memory could only hold 5-9 chunks of information (seven plus or minus two) where a chunk is any meaningful unit. A chunk could refer to digits, words, chess positions, or people's faces.

Information processing corresponds to the second concept; it uses the computer as a model for human learning. Like the computer, the human mind takes in information, performs operations on it to change its form and content, stores and locates it, and generates responses to it. Thus, processing involves gathering and representing information, or encoding; holding information or retention; and getting at the

information when needed, or retrieval. Information processing theorists approach learning primarily through a study of memory.

Information processing theory has become a general theory of human cognition; the phenomenon of chunking has been generally verified for all levels of cognitive processing. Cognitive psychologists have begun to consider how the limitations of working memory are not usually taken into account in designing computer assisted instruction, and they have begun to design cognitively robust instructional software that enhances the learning process.

The approaches to learning of information processing find expression in other cognitive theories of learning, but in general they can be applied to instruction by following these guidelines:

1. Help students make connections between new information and what they already know;
2. Provide for repetition and review of information;
3. Focus on meaning, not memorization, of information.

3.2 Pedagogy

There are a number of pedagogies that involve different uses of the computer as a teaching instrument. Pedagogy plays a very important role in providing learning to students; it effectively supplements computer based teaching tools. Without an appropriate pedagogy, computer use cannot provide for any planned, significant learning outcomes in students. A range of pedagogies are explored below.

3.2.1 Rotational use of computers

An instructional system where a limited number of computers are situated in a single learning area or classroom. All learners are rotated around the computer. Often this

rotation is guided by the use of a roster, controlled by a strict timetable or directly by the teacher, or sometimes with learners themselves determining the length of time they each spend at the computer.

3.2.2 The computer station

This is a strategy used most often in primary schools, where the computer becomes a station alongside a number of other stations (e.g. a reading station, writing station, resource station, painting station). It differs from the rotational use of computers in that students might rotate or not around these stations or choose a station to work at according to their needs. This strategy is often used to make effective use of scant resources, as well as to provide students with choice and decision making about learning activities.

3.2.3 Needs-only basis

This planning strategy sees the use of a computer primarily as a support resource in the classroom. Students are encouraged to use the computer according to need. As a planning strategy, deploying one or more classroom computers on a needs-only basis often leads to a small number of students making exclusive use of the computer (i.e. those with the appropriate skills and confidence).

3.2.4 Computer as electronic blackboard

The classroom computer is often employed as an electronic blackboard. That is, it is used to demonstrate a concept, event or phenomenon by illustration or description. Different types of software can be used in this context, since the pedagogy for this use of the computer centers on the dominant and mediating role of the teacher in motivating, questioning, explaining to and reinforcing students, the computer is simply employed to demonstrate, illustrate and describe. This mode of computer use is best employed when using software that demonstrates a concept, event or phenomenon that is difficult to reproduce by other means.

3.2.5 Computer as surrogate teacher

As a surrogate teacher, the computer is used to set tasks for a student, as well as monitor and evaluate a student's performance in that task. In this sense, the computer carries out a number of roles commonly assumed by a human teacher.

3.2.6 Computer as cognitive tool

A cognitive tool is usually characterized by a generic item of software, such as a spreadsheet, which provides for knowledge construction and modeling. They are content-free and therefore appropriate to a range of subject or domain areas. Cognitive tools are defined as mental and/or technological devices which support, guide and extend the thinking processes of their users. The computer, in the shape of a cognitive tool, allows the learner to externalize their thinking, to enrich it, manipulate it and change it, all by interacting with one or more conceptual models. The nature and use of cognitive tools is closely aligned with the concept of cognition as mental models.

3.2.7 The computer in a collaborative environment

With the appearance and development of the Internet, the last ten years have brought a new dimension to the limits of computer use in a teaching environment. The capability to link various computers in real-time have allowed the appearance of teaching tools that implement multi-user networked three-dimensional environments, also called virtual worlds. These worlds are capable of drawing experiences from physical worlds and mimic many of the forms and activities from the real world. In the work presented by Maher and Gu (2002), architectural metaphors in a virtual world provide a sense of place while its multi-user capability brings awareness of others, allowing users to communicate through a chat room or even by expressing emotions through avatars. This environment facilitates a true collaborative workspace for students.

3.3 Learning Concepts

This section presents a number of learning concepts considered to be essential during the development and implementation of a computer based instructional tool. These concepts emerge in part from the learning theories presented in section 3.1. The concepts, as implemented in teaching tools, should be supplemented by different pedagogies, as outlined also in this chapter, in order to achieve a maximum learning experience through the use of computer based teaching tools. Table 3.2 shows the connection between each learning concept and its associated learning theory or theories. It also shows the supplemental pedagogical model in which each concept is to be applied.

As was shown in section 3.1, there are many theories concerned with the way in which students learn. However, in much of the current debate about the role of educational and learning theory in instructional technologies (especially multimedia), there seems to be a tendency to polarize behaviorism and constructivism, and, further, to present the former as grossly deficient and the latter as the only credible explanation of student learning.

The polarization is not helpful in determining effective instructional design. For example, the principles of contiguity, repetition, reinforcement through feedback and motivation contained in behaviorism are still recognized as important in processes of learning. In fact, there are various dimensions in different theories of learning, and not all fit an imaginary continuum connecting two supposed extremes.

The overriding point is that all theories or explanations of learning are credible in helping to understand certain kinds of learning; but that each theory is also partial in that it refers to a limited range of learning situations.

In the following description of learning concepts a short paragraph at the end of each section mentions which learning theories and which pedagogical models are associated with the particular concept.

Table 3.2 Learning concept relationship to learning theories and pedagogical models

Learning Concept	Associated Learning Theories	Supplemental pedagogical model
Context and situation	Situated learning	The computer as a cognitive tool
Feedback and reinforcement	Behaviorism	The computer as a surrogate teacher The computer as a cognitive tool
Imagery	Learning styles Multiple intelligences Brain-based	The computer as electronic blackboard The computer as cognitive tool
Learning strategies	Learning styles Multiple intelligences Right brain vs. left brain	The computer as electronic blackboard The computer as cognitive tool
Mastery	Learning styles	The computer as surrogate teacher
Memory	Behaviorism Constructivism Information processing	The computer as electronic blackboard The computer as cognitive tool
Mental models	Constructivism Piaget's theory	The computer as a cognitive tool
Motivation	All theories	
Problem-solving	Constructivism Social cognition	The computer as a cognitive tool The computer in a collaborative environment
Scaffolding	Social cognition Behaviorism	The computer as surrogate teacher The computer in a collaborative environment

3.3.1 Context and situation

Cognitive apprenticeship models of instruction, introduced in section 3.1.9, are current in much multimedia software development for schools. Such software builds easily onto the demonstrated effectiveness of experiential and activity-based education found in subjects such as science.

It is not clear, however, that the concept of situated learning accommodates the levels of abstraction required for understanding in many domains of knowledge, particularly

those studied by older students. For example, Laurillard (1993) argues that learning in situated contexts does not, by itself, allow a learner to make abstractions from the particular context and therefore be able to generalize or even be able to apply what is learnt to new situations or contexts.

This concept is associated with the situated learning theory and the use of the computer as a cognitive tool pedagogical model where the computer allows the learner to externalize his/her thinking, to enrich it, manipulate it and change it, all by interacting with one or more conceptual models located in a situated context.

3.3.2 Feedback and reinforcement

Feedback and reinforcement are two of the most pivotal concepts in learning. These two components play an important role in behaviorism theory. Feedback involves providing learners with information about their responses whereas reinforcement affects the tendency to make a specific response again. Feedback can be positive, negative or neutral; reinforcement is either positive (increases the response) or negative (decreases the response).

Feedback is almost always considered external while reinforcement can be external (extrinsic) or intrinsic (i.e. generated by the individual). Information processing theories tend to emphasize the importance of feedback to learning since knowledge of results is necessary to correct mistakes and develop new plans. On the other hand, behavioral theories focus on the role of reinforcement in motivating the individual to behave in certain ways. One of the critical variables in both cases is the length of time between the response and the feedback or reinforcement. In general, the more immediate the feedback or reinforcement, the more learning is facilitated. The nature of the feedback or reinforcement provided is the basis for many instructional principles. For example, the use of "prompting" (i.e. providing hints) is recommended in order to "shape" (i.e. selectively reinforce) the correct responses. Other principles concern the choice of an

appropriate “step size” (i.e. how much information to present at once) and how often feedback or reinforcement should be provided.

Computer based teaching tools can be very effective in implementing this concept. Feedback and reinforcement can be immediately given to a student from a prompt evaluation of the student response to a question or his interaction with a simulated exercise. The immediate nature of this response generates true interactivity and therefore, facilitates learning.

Two pedagogical models are associated with this learning concept; the computer as a surrogate teacher and the computer as a cognitive tool. As discussed above, this concept is mainly extracted from the behaviorism learning theory.

3.3.3 Imagery

Learning styles and multiple intelligences learning theories propose that students learn in different ways; concrete perceivers and active processors will absorb or understand through experience, whereas abstract perceivers and reflective processors understand through thinking and reflecting on information received. Based on this, it is considered that learners are much more likely to learn effectively if information is presented both verbally (or in written form), for the reflective thinker, and visually, for the experience oriented, at the same time. This concept also fits within the brain-based learning theory, which considers that learning takes place when all senses are involved.

Current computer based teaching tools often provide for the representation of images but usually only as an illustrative medium, and not as an implementation of this concept. It is only with the application of interactive multimedia that the power of sophisticated and realistic images is being exploited. But even with the advent of this new technology, very few multimedia software products deliberately apply this concept. Thus, even with today's more sophisticated software, the role of images in the cognitive processes in learning, are often not exploited.

Learning theories associated with this concept are the learning styles, multiple intelligences, and brain based learning theory. Pedagogical models such as the use of the computer as an electronic blackboard and as a cognitive tool are also favored by the implementation of interactive imagery.

3.3.4 Learning strategies

Learning strategies refer to methods that students use to learn and range from techniques for improved memory to better studying or test-taking strategies. For example, the *loci method* is a classic memory improvement technique; it involves making associations between facts to be remembered and particular locations (usually familiar ones). To remember something, one simply visualizes places and the associated facts. Such systematic procedures or strategies for improving memory are called *mnemonics* and include keyword mnemonics, pegword mnemonics, and chainword or linking mnemonics.

The keyword strategy is based on linking new information to keywords that are already encoded to memory. A teacher might teach a new vocabulary word by first identifying a keyword that sounds similar to the word being taught and easily represented by a picture or drawing. Then the teacher generates a picture that connects the word to be learned with its definition.

The pegword strategy uses rhyming words to represent numbers or order. The rhyming words or “peg words” provide visual images that can be associated with facts or events and can help students associate the events with the number that rhymes with the pegword.

The chainword strategy involves the use of acronyms and acrostics. Acronyms are words whose individual letters can represent elements in lists of information; while acrostics are sentences whose first letters represent to-be-remembered information.

Some learning strategies involve specific changes to how instruction should be designed. For example, the use of questions before, during or after instruction has been shown to increase the degree of learning (Ausubel, 1963; 1968). The use of analogies and real world pictures also help students understand physical processes better.

The development of a computer based teaching tool should consider this concept when envisioning how to present different concepts to students. The use of imagery, true interactivity, what-if simulations, and analytical derivations, among other, are strategies that should be contained, in the case of engineering education, all at the same time within a teaching tool. This also true when considering the learning styles, multiple intelligences, and right brain vs. left brain learning theories, which implicitly call for a wider spectrum of learning strategies. The computer as electronic blackboard and the computer as cognitive tool are pedagogical models applicable to this concept.

3.3.5 Mastery

In an individualistic goal structure (rather than cooperative goal structure), students work independently and are evaluated only on their own achievements, regardless of how others do in the learning task. One popular teaching method consistent with individualistic goal structures is *mastery learning*, a concept that is based on the assumption that given enough time and appropriate instruction, most students can master the learning objectives.

John B. Carroll (1963) first argued for the concept of mastery learning suggesting that the focus of instruction should be the time required for different students to learn the same material. This contrasted with the then-classic model, in which all students are given the same amount of time to learn and the instructional focus is on who learned the material and who did not.

The idea of mastery learning amounts to a radical shift in responsibility for teachers: the blame for a student's failure rests with the instruction not a lack of ability on the part of

the student. In a mastery learning environment, the challenge becomes providing enough time and employing instructional strategies so that all students can achieve the same level of learning.

The concept and elements of mastery learning are reflected in many computer based teaching tools, since educational programs, whatever type of software they belong to, usually help individual students to learn at their own pace providing feedback and reinforcement.

The theory associated with this concept is the learning styles theory while the use of the computer as a surrogate teacher helps in the implementation of the mastery learning concept.

3.3.6 Memory

Memory is one of the most important concepts in learning; if things are not remembered, learning cannot take place. Furthermore, memory serves as a battleground for opposing theories and models of learning. According to behaviorism, remembering is a function of Stimulus-Response pairings which acquire strength due to contiguity or reinforcement. On the other hand, cognitive theories of learning insist that *meaning* plays an important role in remembering. In particular, the information processing theory suggests that information is organized in memory into meaningful “chunks”. For working memory, this is important, since working memory is limited to the number of bits of information it can hold, rather than the size of each bit. By deliberately chunking information committed to memory it is possible to manipulate more information in working memory.

This concept is sustained by the behaviorism, constructivism, and information processing theories of learning. Although all of these theories approach the memorization process differently, they all provide important guidelines regarding memory that need to be taken into account for development of computer-based teaching

tools. The implementation of this concept is also related to the use of the computer as electronic blackboard and the computer as cognitive tool.

3.3.7 Mental models

Mental models, such as the models proposed in Piaget's theory or constructivism, are representations of reality that people use to understand specific phenomena. Norman (in Gentner & Stevens, 1983) describes them as follows:

In interacting with the environment, with others, and with the artifacts of technology, people form internal, mental models of themselves and of the things with which they are interacting. These models provide predictive and explanatory power for understanding the interaction.

Some authors suggest that mental models are the basic structure of cognition and the basis for all reasoning processes.

Some of the characteristics of mental models are:

- They are incomplete and constantly evolving.
- They are usually not accurate representations of a phenomenon; they typically contain errors and contradictions.
- They are parsimonious and provide simplified explanations of complex phenomena.
- They often contain measures of uncertainty about their validity that allow them to be used even if incorrect.
- They can be represented by sets of condition-action rules.

Mental models can be closely aligned with computer-based models or simulations, in that the latter possess some of the same characteristics as the former such as the ability

to adjust the outcome of the model to new input. In fact, taking a mental models view of cognition, gives credibility to the concept of the computer as a cognitive tool, in this concept, the computer is seen as a modeling device and, as such, an *extension* of the human (mental) modeling system (Wild, 1996).

3.3.8 Motivation

Motivation is a pivotal concept in most theories of learning. For example, a person needs to be motivated enough to pay attention while learning; anxiety can decrease our motivation to learn. Receiving a reward or feedback for an action usually increases the likelihood that the action will be repeated. Behavioral theories tend to focus on extrinsic motivation or rewards while cognitive theories deal with intrinsic motivation or goals. The degree of the learning achieved can be manipulated by its underlying motivation.

Malone (1981) presented a theoretical framework for intrinsic motivation in the context of designing computer games for instruction. Malone argues that intrinsic motivation is created by three qualities: challenge, fantasy, and curiosity. Challenge depends upon activities that involve uncertain outcomes due to variable levels, hidden information or randomness. Fantasy should depend upon skills required for the instruction. Curiosity can be aroused when learners believe their knowledge structures are incomplete or inconsistent. Intrinsically motivating activities provide learners with a broad range of challenge, concrete feedback, and clear-cut criteria for performance.

3.3.9 Problem-solving

Problem solving is usually defined as formulating new answers, going beyond the simple application of previously learned rules to create a solution; it is what happens when routine or automatic responses do not fit the current situation. The nature and degree of metacognitive (thinking about thinking) skills possessed are also related to levels of success in problem-solving. Teaching both thinking skills and metacognitive skills are considered by some to be of paramount importance at all levels of education;

many suggest the computer can play a central role in teaching metacognitive and other thinking strategies.

From case-study evidence alone, many teachers appear to agree that computers can play a vital role in developing both problem-solving and thinking skills applied in facilitated collaborative environments as stated by the social cognition theory.

The problem solving concept is also related to the constructivism theory where learning takes place by formulating new answers through reflection. The pedagogical models that facilitate this concept are the use of the computer as a cognitive tool and the use of the computer in a collaborative environment.

3.3.10 Scaffolding

Scaffolding is a term that is most often applied to Vygotsky's theory of learning, in which it is believed that cognitive development in children occurs through the interaction of a child with more capable members of the same culture; adults or more able peers. These people serve as guides and teachers for the child, providing information and support necessary for the child to grow intellectually. This type of assistance is often called scaffolding. However, in many cases, scaffolds are also used to refer to support materials and support processes, particularly in the case of computer based teaching tools. Based on this definition, scaffolding is associated to the concept of feedback and reinforcement previously discussed.

According to Vygotsky (1978), at any given point in cognitive development there are certain problems that children are on the verge of being able to solve. While some of these can be solved independently by a learner, others are outside the learner's capabilities and can only be solved under teacher guidance or in collaboration with a more advanced peer.

The scaffolding concept can be implemented through teaching tools that are designed to use the computer as a surrogate teacher or the computer in a collaborative environment.

3.4 Summary

This chapter presents a brief description of various learning theories and pedagogical models. The intention is not to present all trends proposed by educational theory, instead, only the theories and models that are relevant to the subject of this research are presented here. Based on these theories and models, a set of learning concepts are discussed and presented as essential elements to be implemented in the development of computer based teaching tools.

The pedagogical models of implementation of the teaching tools are presented as evidence that a particular tool can be implemented in class in different ways. This fact should be kept in mind by developers who should then be aware that the success of a certain teaching tool may lay in its flexibility to be used within different pedagogical models in the class. It should be kept in mind that the teacher is the ultimate user of the product and that its use and implementation in the classroom depends on the teacher's like or dislike towards the tools.

Chapter 4 will present the contents of the modules developed in this research project. These modules were conceived and prepared with the intention to implement the learning concepts just presented.

Chapter 4 Modules

The research work presented in this thesis includes the development and evaluation of a set of computer based teaching modules to help students at the university level learn mechanical and geometric concepts. The development of these modules was initially undertaken following the methodology proposed by Shepherdson (2001), within the context of the learning concepts presented in Chapter 3. Figure 4.1 summarizes the main components of Shepherdson's methodology.

The modules were developed with various goals in mind; first, the creation of a set of modules for basic mechanics and for three-dimensional geometry to be used as a free resource available to everyone through the World Wide Web (WWW), second, the implementation and evaluation of the proposed methodology for the development of such tools, and third, the assessment of the tools within the context of the classroom. This chapter describes each of the modules developed. This description is made stepping through the methodology proposed by Shepherdson (2001).

The development of these modules was undertaken as part of the iCampus project at the Civil and Environmental Engineering Department at MIT. This project focuses on the enhancement of university education through information technology and is the result of an alliance between Microsoft Research and MIT.

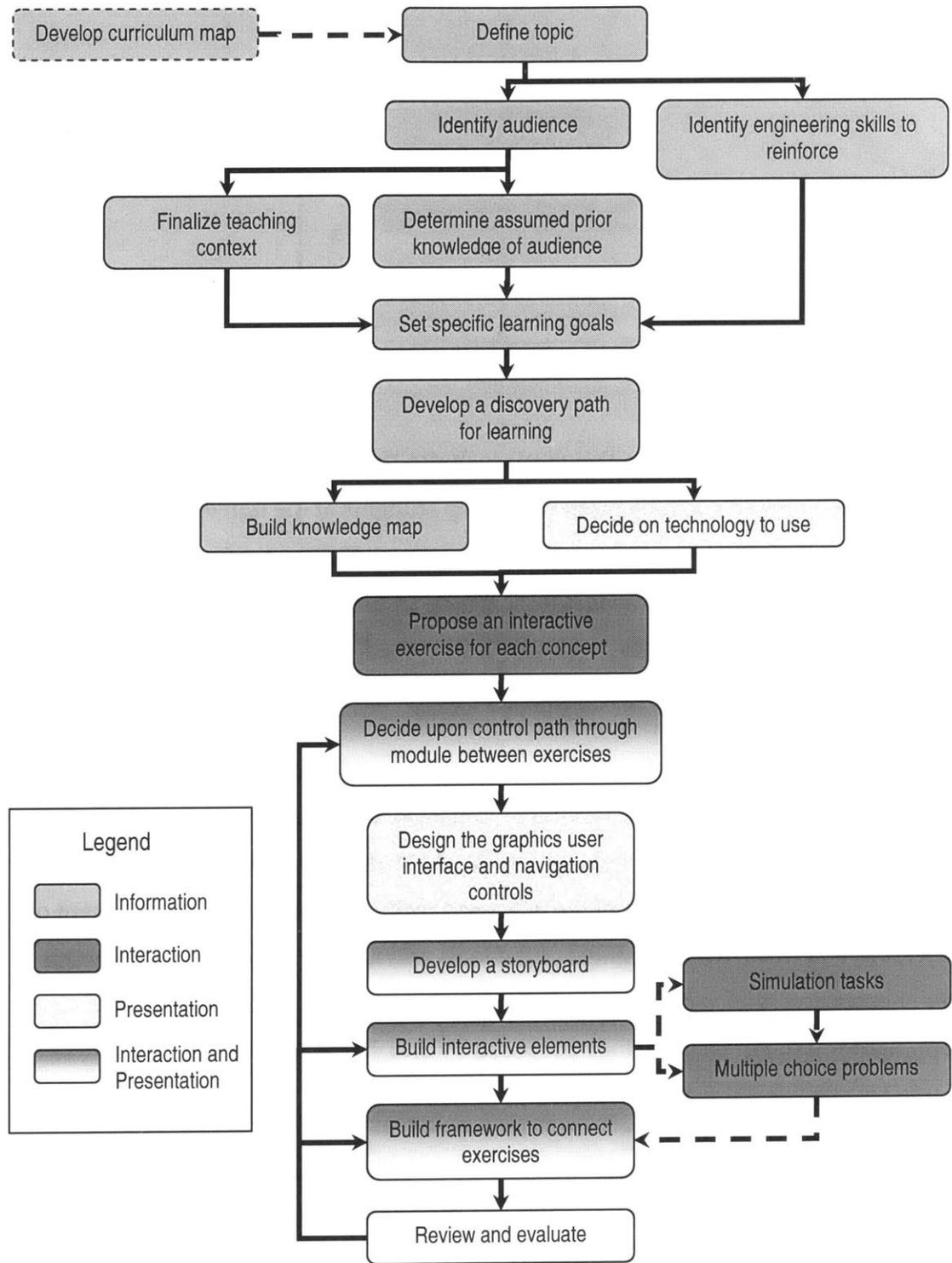


Figure 4.1 Flowchart representation of development methodology (Shepherdson, 2001)

4.1 Solid Mechanics Modules

The solid mechanics modules consist of three modules. These modules represent the evolution of a solid mechanics module developed by Michalis Aftias during his work towards the degree of Master of Science in the CEE Department at MIT.

The objective of the modules is to introduce undergraduate students to basic principles of structural engineering. The development of the early module explored “new ways of teaching structural engineering concepts by building *Solid Mechanics Learning Modules* that will hopefully be more attractive and instructive to the students and therefore, educationally more effective” (Aftias, 2001).

The modules presented below represent an improved version of the early module. This improvement consisted of the addition of interactive capabilities, an enhanced graphic user interface, and the extension of the material covered. These additions resulted in a much bigger module that was then sectioned into three parts, giving each section a length that was suitable for a student to follow in a continuous session. Each of those sections will be referred to as a module.

4.1.1 Definition of topic

As mentioned before, the main topic of the modules is basic principles of solid mechanics. It encompasses the definition of a beam as the most elemental structural element, the definition of a point load versus a distributed load, the concept of equilibrium and equilibrium equations, and the concept of internal forces, and the methodology for their representation in a simply-supported beam.

This definition of the topic was considered within the context of a library of modules being developed in the Department of CEE at MIT, mostly under the iCampus project. This library of modules includes simulations to solve for forces in structural frames and trusses (Sthapit, 2002), a steel profile database (Nguyen, 2003) and a simulation of beams that makes use of intelligent agents that provide feedback to the student on proposed

exercises (Viteri, 2003). All these other modules are located steps ahead in the knowledge map with respect to the material covered by the modules presented in this thesis. Within this context, there existed a constraint on how much material could be covered by the modules. They are clearly seen as the introductory teaching tools to be used on the subject. Figure 4.2 shows a schematic flow chart for the suggested use of the modules developed within this effort. When a student reaches the end of Mechanics Module 3 the flow divides into four potential paths to follow indicated by the black arrows. The light gray lines connecting the FrameWorks and TrussWorks modules (Sthapit, 2002) mean that an internal use of the profile database is made from within each of the modules. In other words, Sthapit's modules are designed to access the profile database.

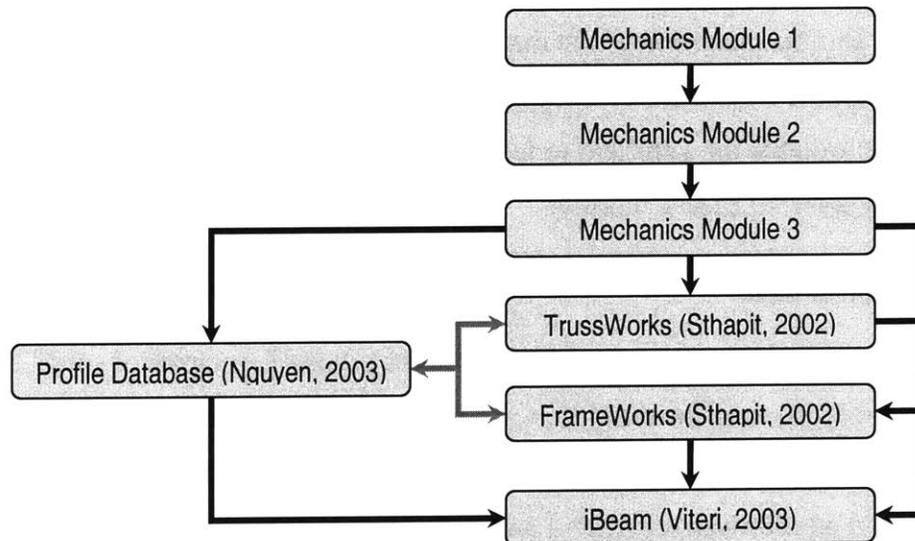


Figure 4.2 Schematic flow chart of modules library

4.1.2 Audience

Students in their first structural analysis course at an undergraduate level are the target audience of the solid mechanics modules. Students most likely to make use of the

modules are those involved in Civil Engineering, Architecture, or Mechanical Engineering programs, although there is potential for other users as well.

4.1.3 Assumed prior knowledge of the audience

The material covered by the modules sits in the early stages of the knowledge map for Structural Engineering instruction as shown in Appendix A of Shepherdson's work (Shepherdson 2001). This fact implies that the use of the modules require very little knowledge of the topic. What is considered to be necessary is an elementary understanding of vectors, forces and loads, and the ability to solve a system of equations with up to three unknowns.

As a general philosophy for the development of the modules it was assumed that the knowledge necessary to progress through the material presented was minimal. The path followed in the modules always builds on what has been covered, in this way it is ensured that students using the mechanics modules will not face a roadblock when a new concept is presented that had not been covered before.

4.1.4 Teaching context

The modules are conceived as a supplement to what is taught in a more analytical context in the classroom by the teacher of the course. However, their use depends on the instructor. It could be used as homework for students to go through the modules or simply suggested as an additional tool for students who feel the need for some reinforcement after in-class instruction of the material.

The modes presented in the pedagogy section of Chapter 3 are also relevant here. The simulations designed within the modules serve well the purpose of using the computer as an electronic blackboard and, to some extent, as a cognitive tool. The narrative style and the order of presentation of concepts also fit well a model of using the computer as surrogate teacher.

The technology with which the modules have been developed ensures that the modules are available over the Internet. It should take between 35 and 40 minutes for a student to go through the contents of each of the three modules, this was one of the main criteria considered for the division of the original mechanics module.

Although the concept of a library of modules, shown schematically in Figure 4.2, as mentioned before exists, the solid mechanics modules do not provide links or connections to these other modules; this is due to the fact that it was preferred to keep the flow of information to the students within the solid mechanics modules themselves.

The mechanics modules are designed so that navigation has to take place from start to finish. There is no option to fast-forward nor is a contents menu provided to go directly to certain frame within a module. This proved to be one of the complaints when receiving feedback from users who participated in the evaluation of the solid mechanics modules. It will be treated in the next chapter.

4.1.5 Engineering skills to reinforce

The engineering skills to learn and reinforce through the use of the modules are:

- Predict the deflected shape of a beam based on its loading conditions and its supports
- Predict the reactions of any type of statically determinate structure
- Predict the bending moment and shear force diagrams of a beam

4.1.6 Specific learning goals

As can be expected, the engineering skills to learn and reinforce will be a part of the specific learning goals of the modules. Following is the complete list of specific learning goals:

- Predict the deflected shape of a beam based on its loading conditions and its supports
- Predict the reactions of any type of statically determinate structure
- Predict the bending moment and shear force diagrams of a beam
- Understand the reactions and displacements allowed by each type of support used in structural elements
- Understand moments
- Understand the equilibrium concept in a two-dimensional system
- Identify determinate and indeterminate structures
- Enhance learning by focusing on conceptual understanding
- See the connection between real life elements and their analytical representation

The first three goals are the same as the engineering skills mentioned in section 4.1.5; the last two learning goals are facilitated through the use of IT and represent the enhancement in student learning with respect to the typical classroom instruction. Finally, the goals in between these two groups represent goals specific to the material covered by the modules and are the means for achieving the engineering skills.

4.1.7 Discovery path for learning

The linear approach of the modules requires a narrative format. The basic design philosophy of the modules is to build on what has been presented, that is, the first module starts by explaining the most basic structural element; the beam. It then adds on supports and equilibrium equations, until the concept of internal forces is reached in the third module. Each step uses what was shown in the preceding one. Each component is

presented by an animation or a simulation that tries to spark the understanding of the behavior of what is being treated rather than relying on showing analytical derivations, as can be the case for concepts that involve mostly mathematical derivations.

The content of the three modules perfectly match each other, in other words, modules two and three start where the previous modules are finished, there is no overlapping nor noticeable jumps in the content presented.

4.1.8 Knowledge map

The concepts taught are directly connected to the goals presented in section 4.1.6. These are the concepts that, once understood, will eventually achieve the student's learning of the material covered by the modules, and, ultimately, the reinforcement of the engineering skills outlined in section 4.1.5.

Figure 4.3 shows the knowledge map specific to the solid mechanics modules.

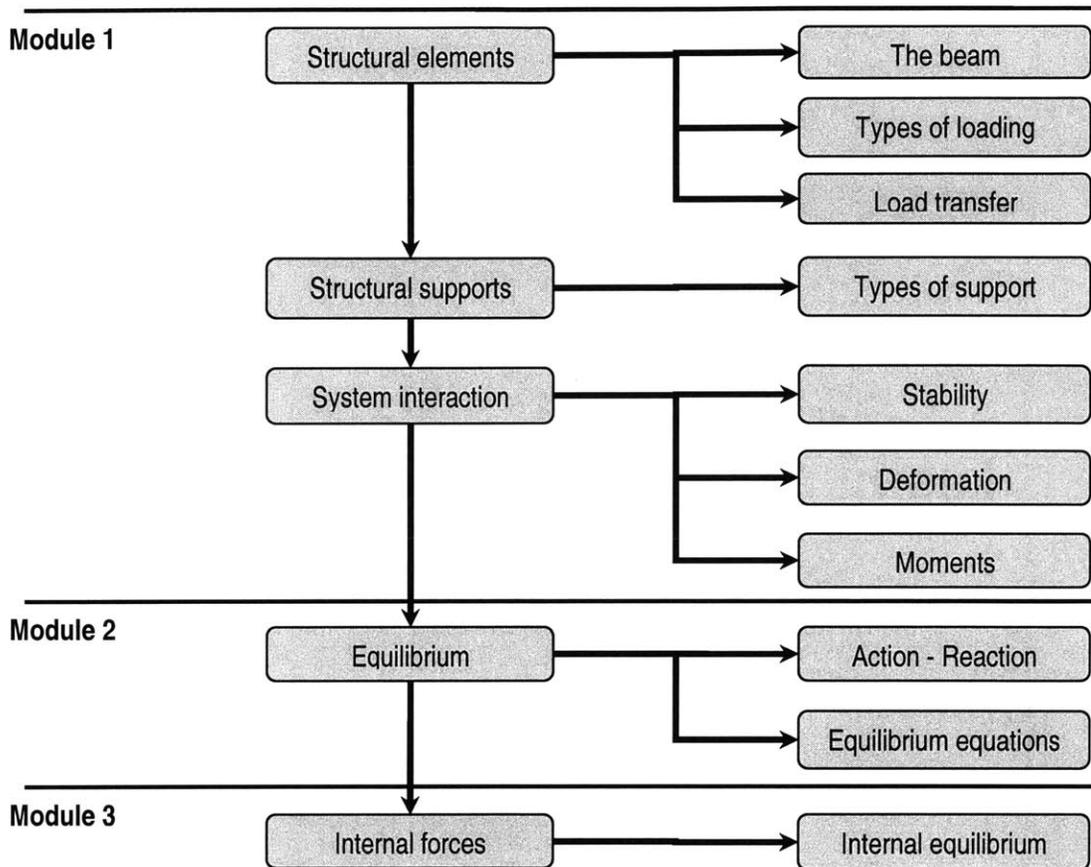


Figure 4.3 Knowledge map specific to the solid mechanics modules

4.1.9 Technology used

The modules were developed using the Macromedia Director (Macromedia, 2001) platform and are compiled as Shockwave (Macromedia, 2004) movies, a format developed by Macromedia which allows one to deploy the movies through the World Wide Web (WWW).

A web page has been set up in the WWW which provides links to access the three modules; this page is shown in Figure 4.4. By clicking on the hyperlinks, the corresponding module is deployed in a web page. What the user sees is the playback of

a Shockwave movie, provided the adequate plug-in is installed on the browser. It should be said that this plug-in is one of the most popular ones on the WWW and is available free of charge also through the Internet.

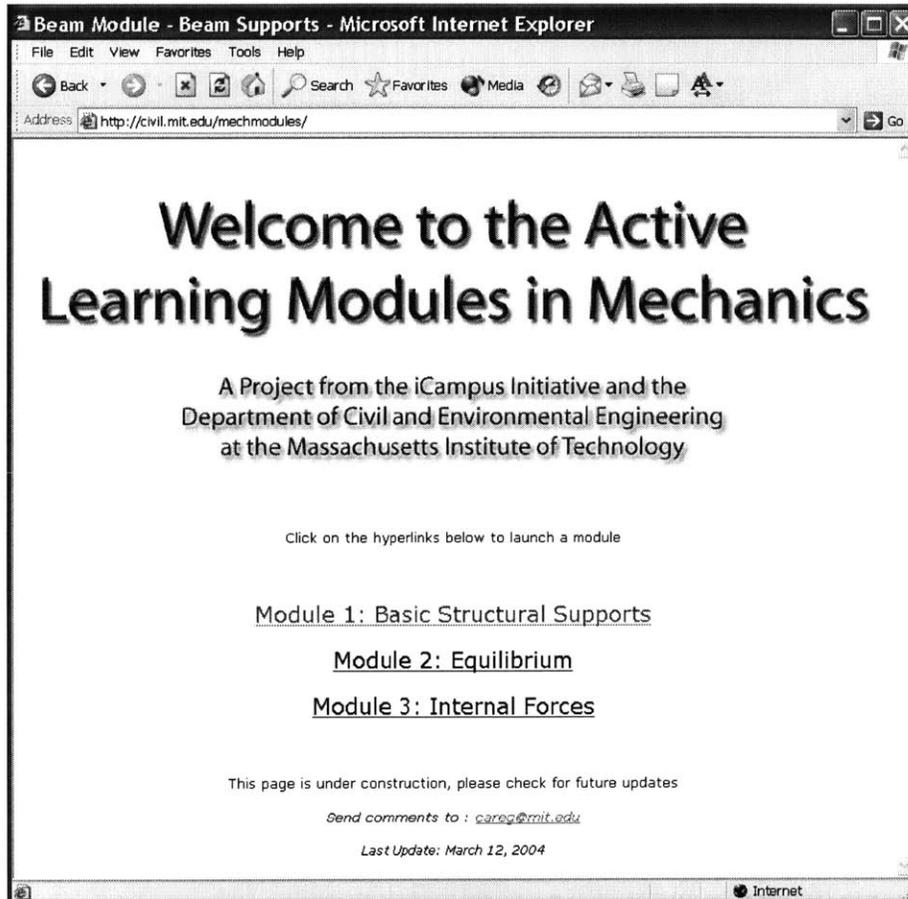


Figure 4.4 Access screen for solid mechanics modules

The Shockwave format was chosen for its capability of displaying text, graphics, video, and sound, among other media, with the capability of featuring animated graphics. All this goes hand in hand with the intention to develop an interactive teaching tool that implements the learning concepts outlined in Chapter 3. Moreover, the format also fits into the spirit of making this tool available to all students around the world free of charge as part of the content of the OpenCourseWare (OCW) MIT initiative, a free and open educational resource for faculty, students, and self-learners around the world.

The size of each module is about 2.6 MB. The download time for each module should be around 6' 29" for a user with a 56Kb modem and about 2' 40" for a user with a DSL connection¹. Although these times seem to be long, the advantage of the technology chosen is that once the initial download has been completed, the movie plays without interruption for the rest of the session. Faster connections, often found in universities and other educational institutions, yield a download time of less than 10 seconds per module.

4.1.10 Interactive exercises

The set of interactive exercises included in the finished modules is presented in section 4.1.14. The initial planning of the modules called for emphasis on animation of graphics to show processes of deformation in beams and interactions in structural systems, all this supported by rich graphics representing structural elements. This was later enhanced by the implementation of simulations, written in Lingo, Macromedia Director's built in object-oriented programming language, which provides a much richer experience to the user, adding to the interactive nature of the contents of the module.

4.1.11 Control path through module and between exercises

As was mentioned before, the control path chosen for the modules is a single path through them, with each module directly connecting to the next. Each concept is presented and then either multiple choice or open-ended questions or simulations are given to the student. Some concepts allow the student to obtain additional information if deemed necessary by clicking on a hyperlink. Specialized feedback, based on the student response, is provided after the student has answered any questions. All open-ended simulations are repeatable, encouraging play and what-if experimentation. Open-ended questions will offer the disclosure of the correct answer if a student has answered incorrectly the first time. A sample scheme of this control path is shown in Figure 4.5.

¹ Source: www.onlineconversion.com

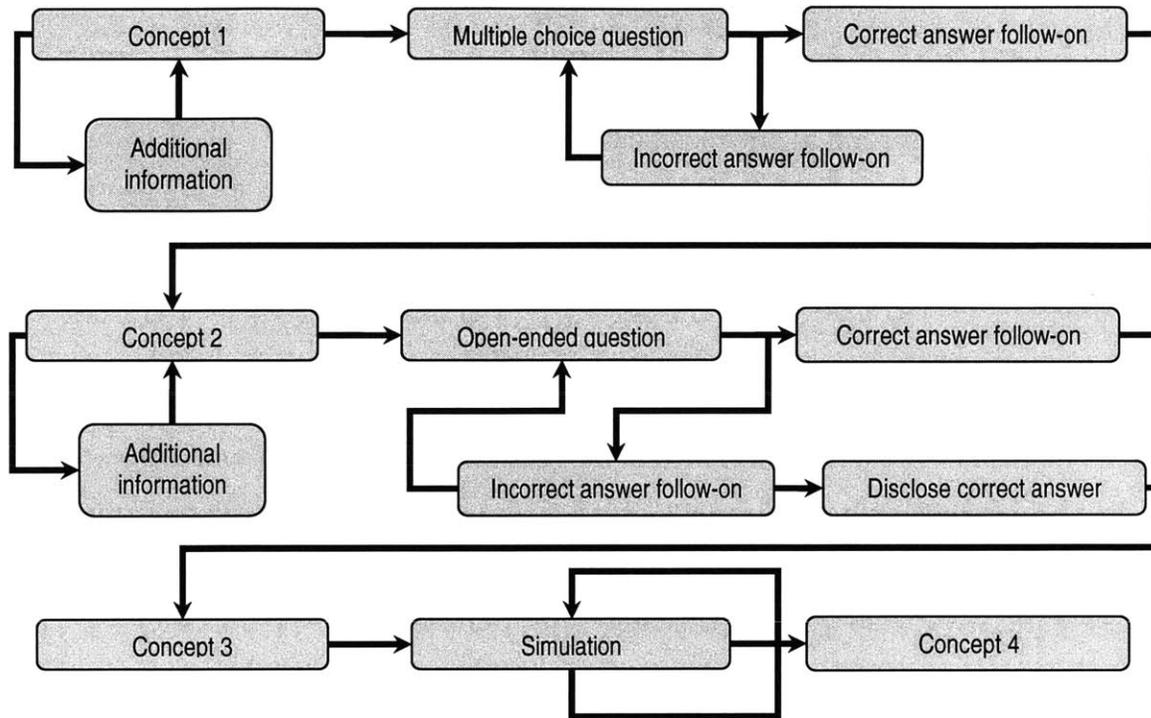


Figure 4.5 Control path for solid mechanics modules

4.1.12 Graphical user interface and navigation controls

The graphical user interface chosen for the modules is a split-screen design. The right part of the contents window is used to display the text and the navigation controls, while the left part of the window is used for the display of animations and simulations, text was used on this side only when strictly necessary. A third element, in the form of a balloon, was deployed sometimes when the user chose to display additional information that generally added to already explained concepts. Figure 4.6 shows a typical screen shot with the two sides and the additional information balloon.

Supports

Observe the distance r between the rotation point and the traction point. This causes the cylinder to translate a distance Δx which is proportional to the angle of rotation ($\Delta x = \Delta\phi \cdot 180 \cdot \pi \cdot r$). Note that if the point of rotation is the same as the point of traction (say a cylinder supported at its axis) then r is zero and therefore Δx is always zero (no translation despite rotation). [Click here to see that again...](#)

We observe the following:

1. The weight of the car is supported by the rollers, which provide only one reaction each. In this case, these are vertical reactions R_{YA} and R_{YB} .
2. The weight of the car bends the beam. As the beam bends, its ends A and B try (i) to get closer, and (ii) to rotate.
3. Because of the rollers, the reaction points translate horizontally a distance Δx . The amount of rotation of the rollers ($\Delta\phi$) is related to the translation distance by $\Delta x = (\Delta\phi/180) \pi r$. (r =radius of the roller). [Click here](#) to observe this in detail.
4. The deformed shape of the beam is like a very wide, elongated U.

[Click to see what happens when the car is running on the beam and suddenly brakes....](#)

[Click here](#) to see the beam deforming again... or

[Click here](#) to see pictures of real rollers.

Figure 4.6 Typical graphical user interface

The main controls to advance through the modules are located in the lower right corner of the module window. A closer look at these controls is shown in Figure 4.7. The upper four controls are mouse-activated; the mouse pointer changes to a finger shape when it is rolled over these controls. This is shown in the figure, where the mouse pointer is rolled over the second upper control, from left to right. The leftmost control restarts the module from the beginning; the two controls in the middle take the user backward and forward within the storyline of the module, and the fourth control exits the module. The lower control is a progress bar that informs the user about his/her location within the full content of the module.

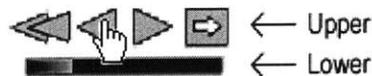


Figure 4.7 Navigation controls of solid mechanics modules

In addition to these controls, navigation is sometimes possible by pressing on hyperlinks. These are clearly marked in the text region and are generally used to advance to the next screen within the normal flow of the module (the same function as the forward arrow in the navigation control elements) or to provide additional information not normally supplied in the regular flow of information.

4.1.13 Storyboard

The storyboard of Module 1, Module 2, and Module 3 are presented in Figures 4.7, 4.8, and 4.9, respectively. These storyboards should match the knowledge map presented in Figure 4.3 and portray the single path approach chosen as control path through the modules. Each storyboard depicts the major module components. Each one of those components is represented by a box in the figure. Within each box, the main topics covered by each component are outlined. These topics are usually accompanied by elements, indicated between parenthesis, such as narrative, animations, or interactive simulations, among others, that are implemented in the modules and are aimed at facilitating understanding in students.

Section 4.1.14 will explain in detail each of the interactive elements, animations, and simulations included in the modules.

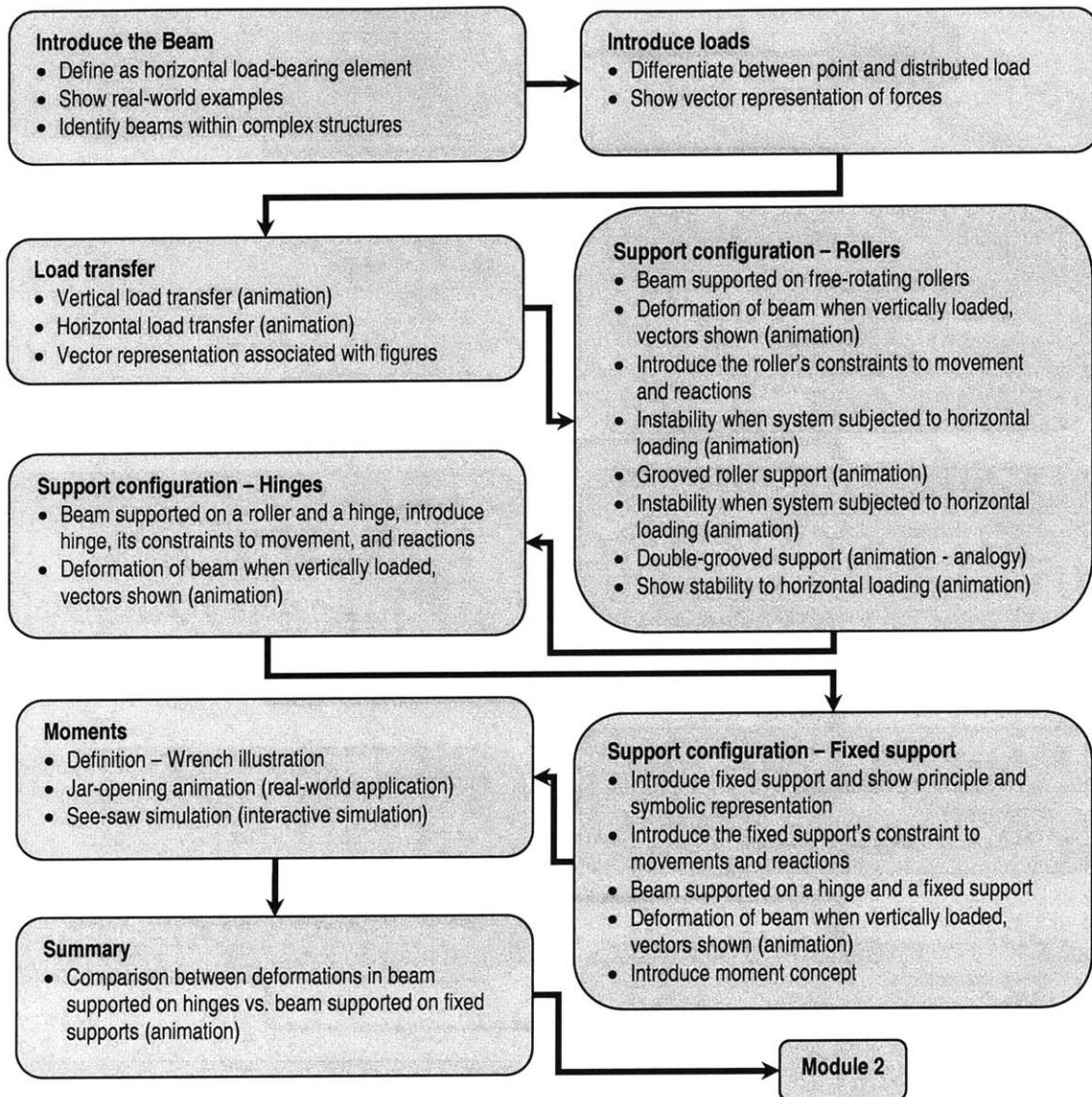


Figure 4.8 Storyboard Module 1

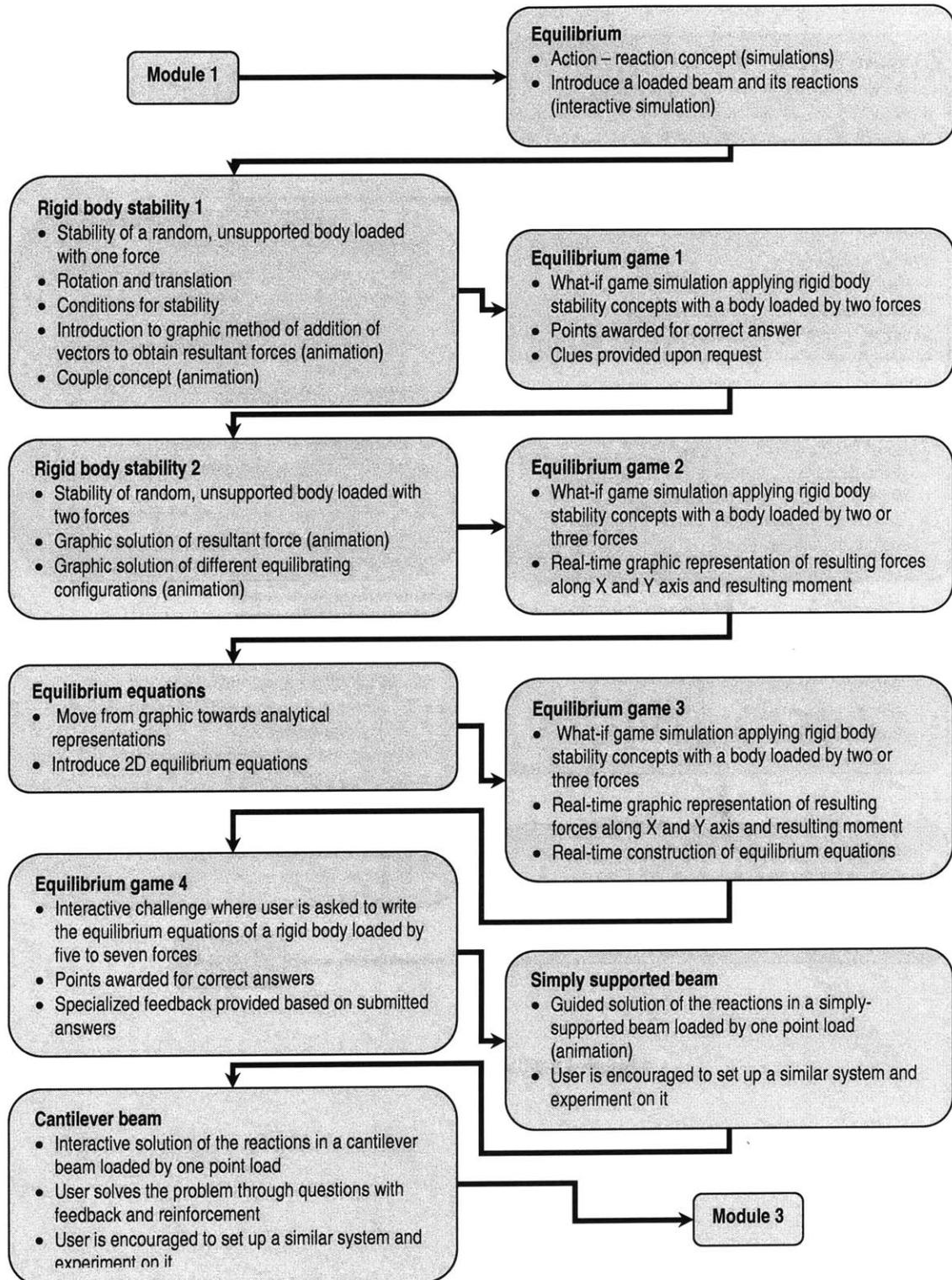


Figure 4.9 Storyboard Module 2

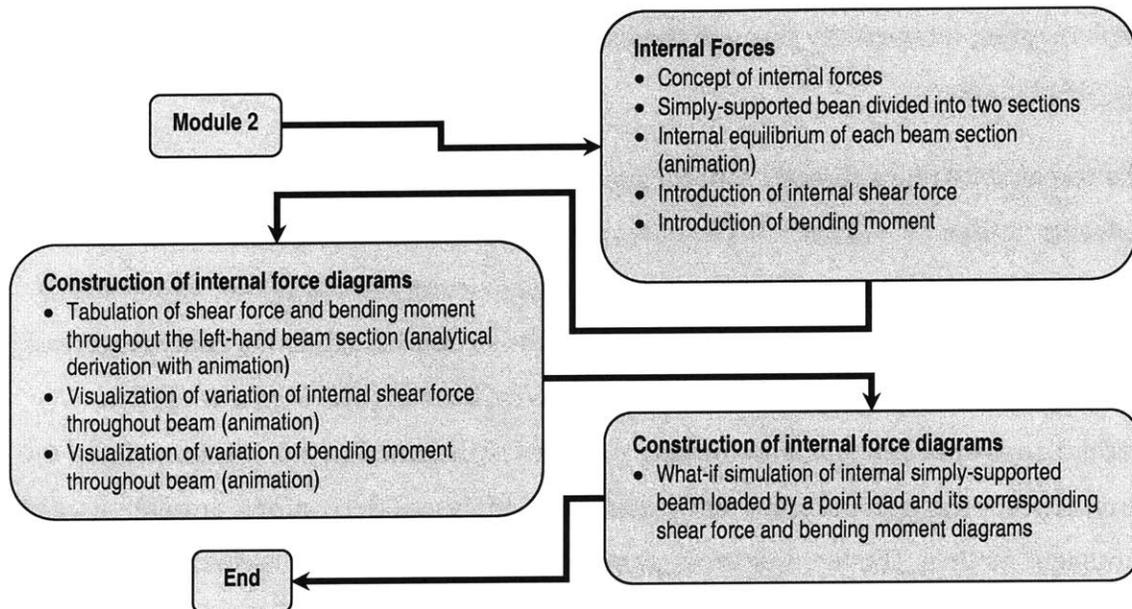


Figure 4.10 Storyboard Module 3

4.1.14 Interactive elements and animations

The interactive elements and animations included in the final version of the modules are the product of an iterative process. A formative testing process during the development of the modules helped optimize the teaching concepts included in the modules. This process is discussed in section 4.1.16. This yielded what is considered an optimal use of the benefits of IT to facilitate understanding by students using the tool.

The target during the preparation of the modules was to make them as engaging as possible by providing an environment appealing to the student. The result of this effort produced a series of simulations, games, and animations that use rich graphics and provide as much interactivity as deemed possible, and, at the same time, implement the learning concepts outlined in Chapter 3.

The implementation of each element (i.e. simulation, games, and animations) was facilitated by the technology chosen for the authoring of the modules. Macromedia's

Director allowed for the creation of animations, easily converted into rich simulations implementing interactivity through the use of the built-in object-oriented computer language Lingo.

The use of animations directly reflects the implementation of *imagery*, one of the learning concepts outlined in Chapter 3. The other major element used in the modules, the simulated interactive games, portrays an attempt to foster the creation of *mental models* in the students using the tools. In addition, and as a complement to the concepts already mentioned, the modules utilize concepts such as *feedback and reinforcement* used in student answer evaluation, and *learning strategies* represented by the presentation of the same concept through different methods such as analytical derivations, animations, and simulated models. The learning concept of *mastery* is implied in the technology used to develop the modules since it allows the user to access them as many times as desired, while the *motivation* concept is one that is also kept in mind by providing the student an appealing set of exercises and animations for the presentation of mechanics concepts. The *problem-solving* concept also plays an important role in the modules, especially in the presentation of the concept of equilibrium. The relation of each of these concepts to learning theories is discussed in Chapter 3.

The following subsections explain major components of the modules separately, highlighting the elements used to enforce the outlined learning concepts.

4.1.14.1 Introduction of the beam

The beam is introduced as the simplest structural element. The student is shown a schematic representation of the beam, which will be the same used throughout the modules. Figure 4.11 shows a screen shot of the module where the beam is introduced. Below the beam representation, to the left, the student is shown the location of beams within more complex structures. This is done by animating colored arrows that travel to highlight the objects.

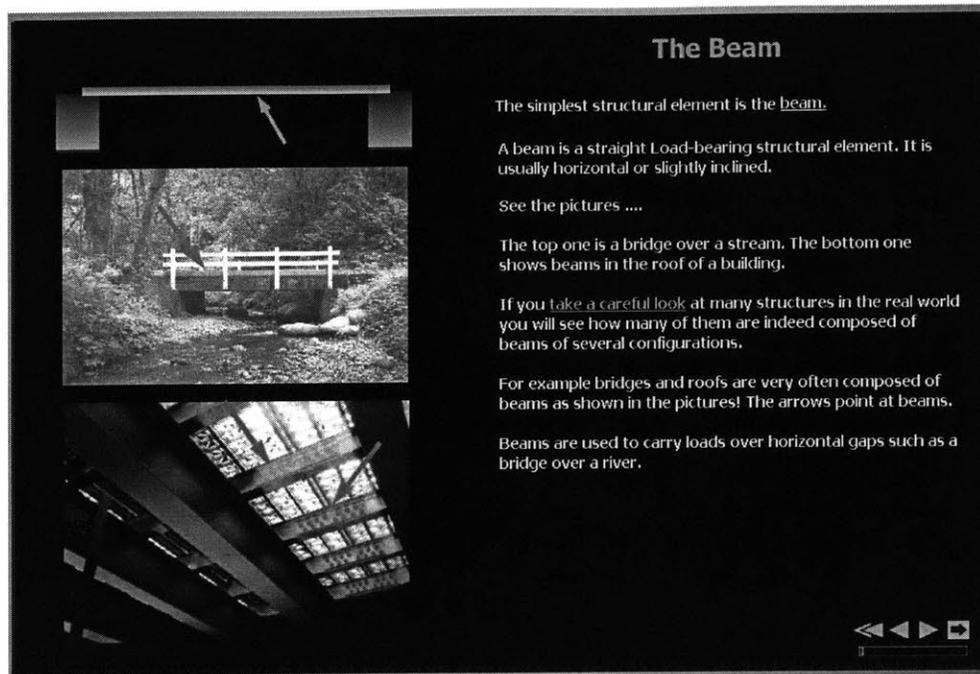


Figure 4.11 Introduction of the beam

4.1.14.2 Introduction of loads

The introduction of loads is done also in a simple screen shown in Figure 4.12. The student is shown the representation of two cases of loading of a beam; one shows a case of point load, while the other shows a case of a distributed load applied on the beam. Familiar images, in this case, animals are used to represent these two cases. The use of images facilitates the connection between the cases represented by the animals and the vector notation commonly used in structural analysis to represent the two types of load presented to the student.

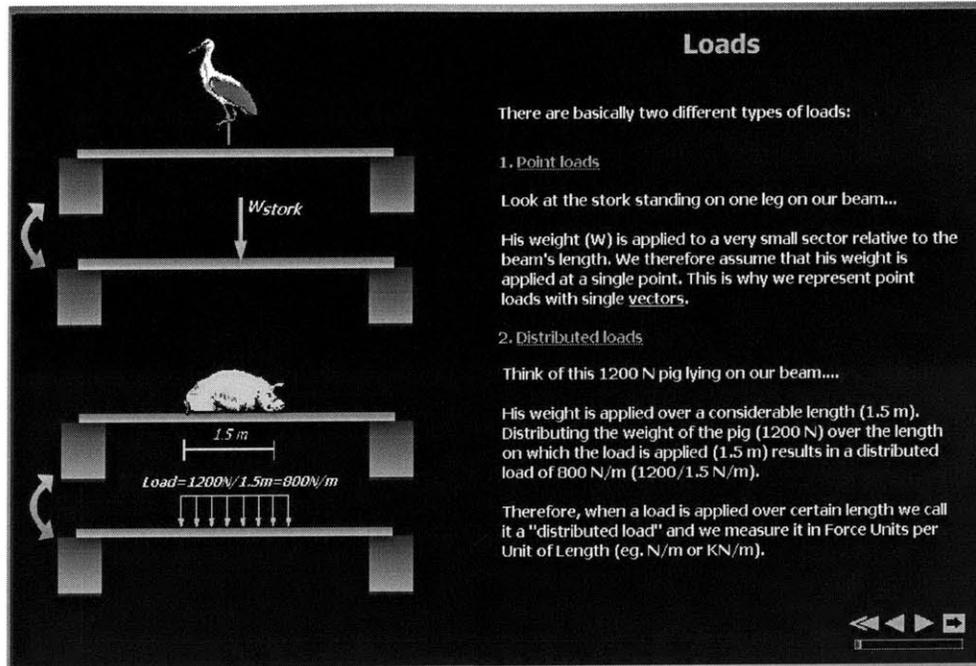


Figure 4.12 Introduction of types of load

4.1.14.3 Load transfer

Once the beam and the loads have been introduced, the student is then shown how the loads are transferred to the support points of the beam. For vertical loads, the case of a point load is used keeping its analogy with the stork standing on the beam.

Figure 4.13 shows two screen shots; one at the beginning and another at the end of the animation sequence used to explain this case. In the first shot, the beam, where the stork is standing, is supported by a hand. Below this representation, the same beam is shown now using vectors to represent the load and reactions; at the beginning two point loads are shown opposite to each other. In the animation, the beam, stork, and hand are displaced downward until the ends of the beam come in contact with the edges at *A* and *B*. Once this happens, the hand continues moving downward and eventually disappears. At this time, the reaction *R* is divided in two reactions that are then transferred to each side of the beam. This animation is also enhanced with sound, which

adds reality to the moment when the beam comes in contact with its supporting points at the sides. The second shot of the figure shows the end of the sequence when the load imposed by the stork has been transferred to the sides of the beam. The reactions at the sides are now labeled accordingly; this convention is maintained throughout the modules.

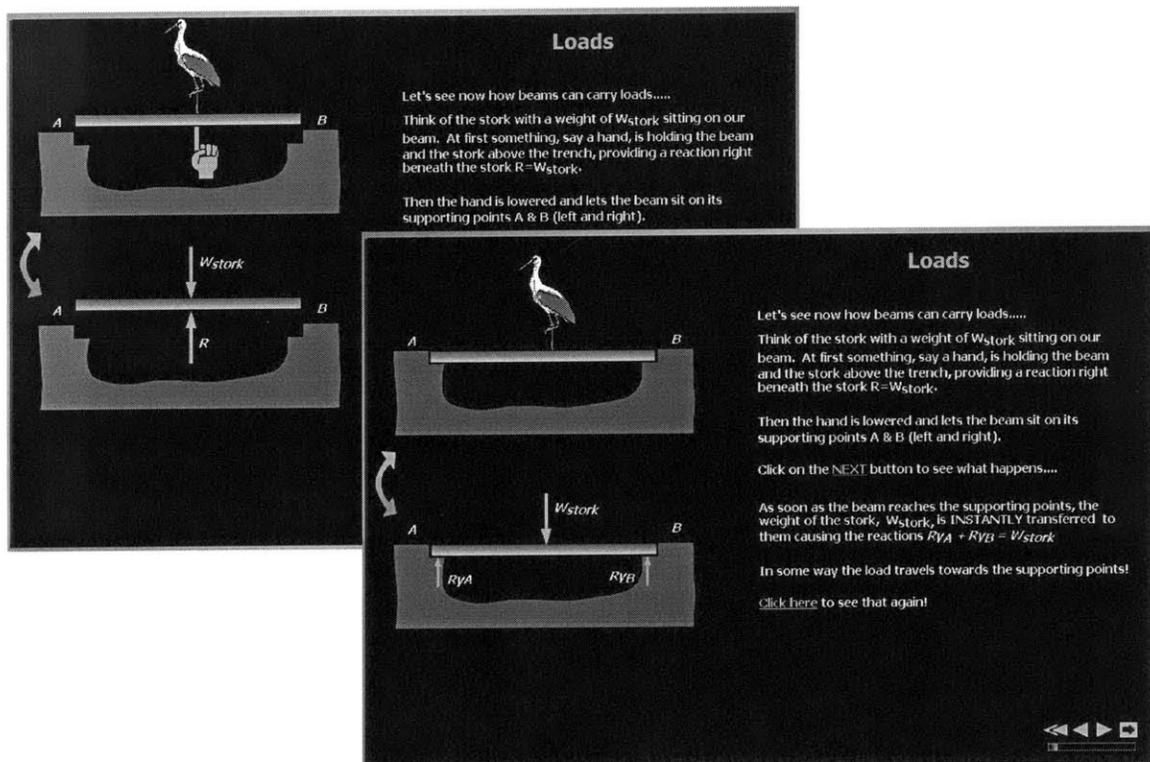


Figure 4.13 Vertical load transfer animation

For the case of horizontal load transfer, a car is now used instead of the stork. The animation sequence is shown in Figure 4.14, which, again, shows the beginning and the end of the sequence. In the first shot, the car is shown standing near the left end of the beam, which is placed on the supports at *A* and *B*. The car is then animated as if it was moving from left to right and then it breaks on the beam. This action generates a horizontal force which is transferred to the support at *B*. The animation shows two representations of the beam; one with the image of the car moving on the beam and the

other with the vectors representing all loads and reactions imposed on the beam. In this case, the vertical reactions at the supports vary depending on the position of the car on the beam and the horizontal force increases as the car braking progresses; this behavior is shown during the animation by increasing the size of the vectors representing the corresponding variable forces. The student is given the possibility to run the animation as many times as desired.

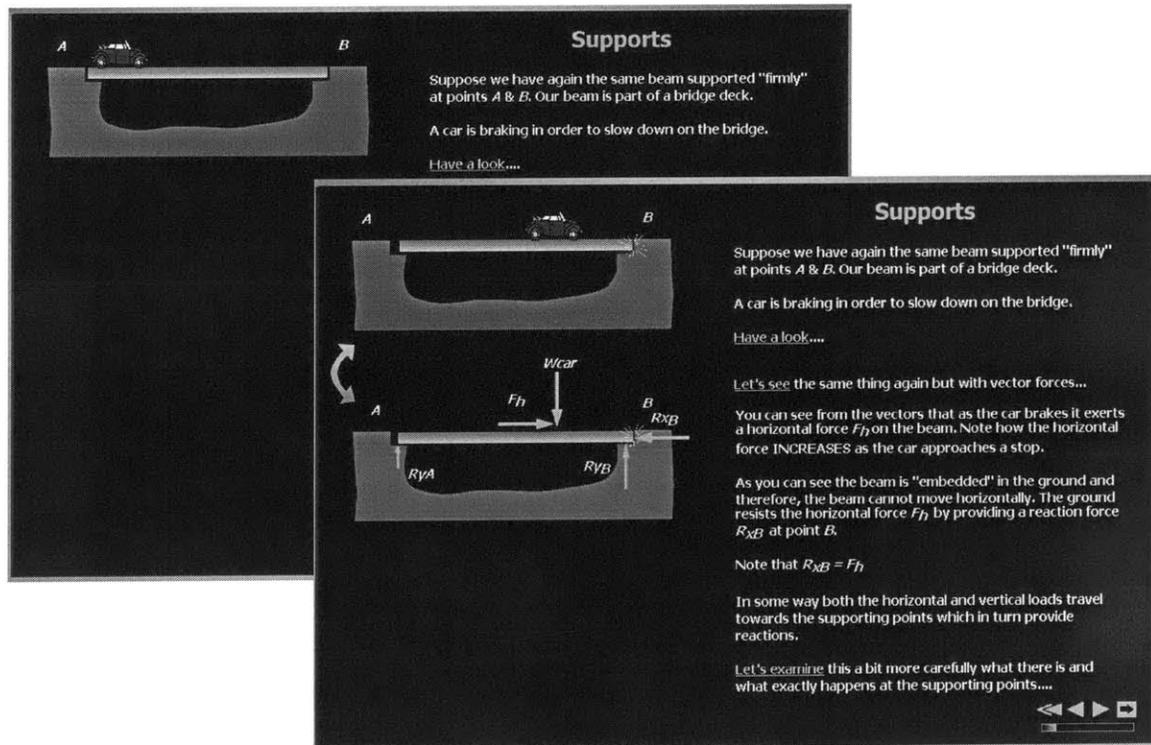


Figure 4.14 Horizontal load transfer animation

4.1.14.4 Support configuration – Rollers

The element used to explain the behavior of the rollers is again the animation of images. Figure 4.15 shows the first and last screen shots of the animation sequence that explain the basic behavior of rollers as supports. In this figure, the car is shown on the beam, depicting the reactions that had been previously introduced. The animation shows how

the beam deforms when supported by two rollers and what type of displacements are induced by this deformation.

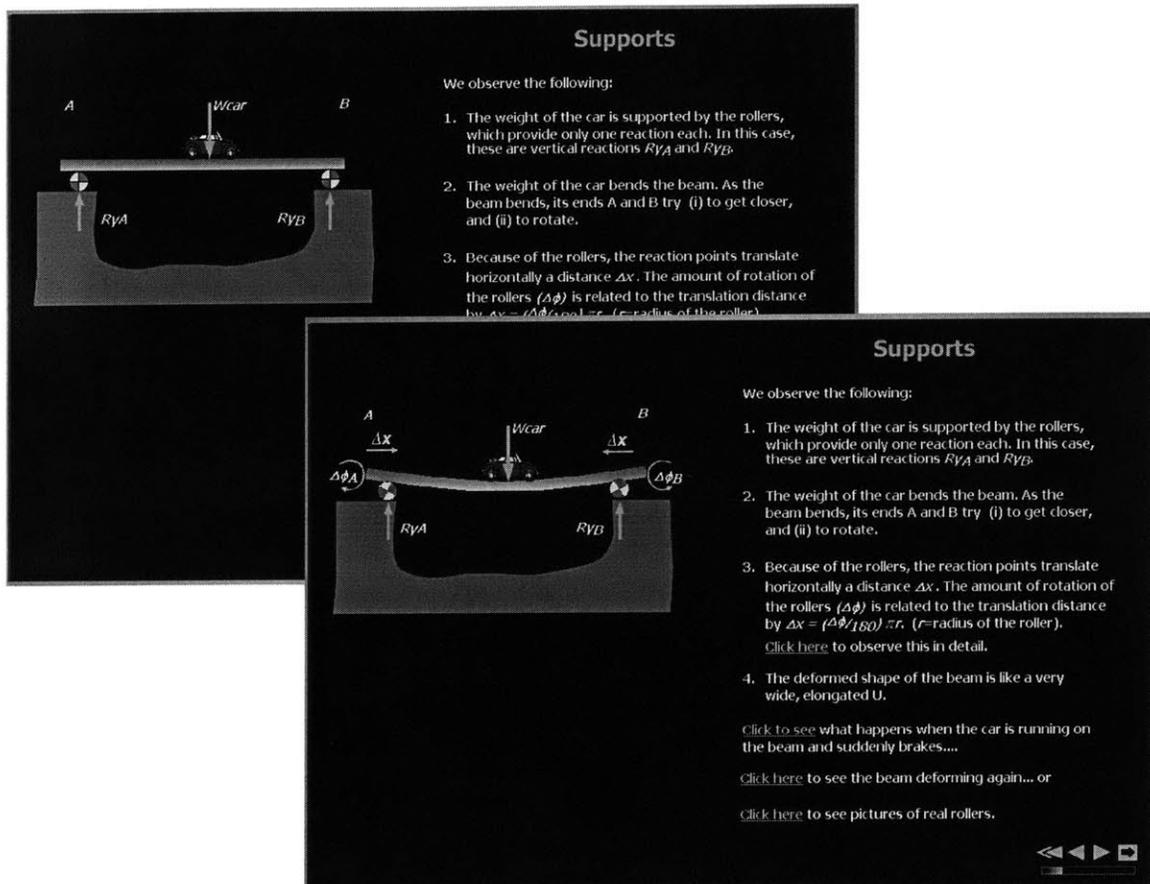


Figure 4.15 Support configuration - roller animation

Figure 4.16 shows the last screen shot of the animation used to illustrate the instability of the system when subjected to horizontal loading. The car is shown breaking on the beam, which then displaces to the right and loses its support on the left, causing the car to fall down. This animation shows the behavior of the rollers and their ability to provide a reaction force in only one direction.

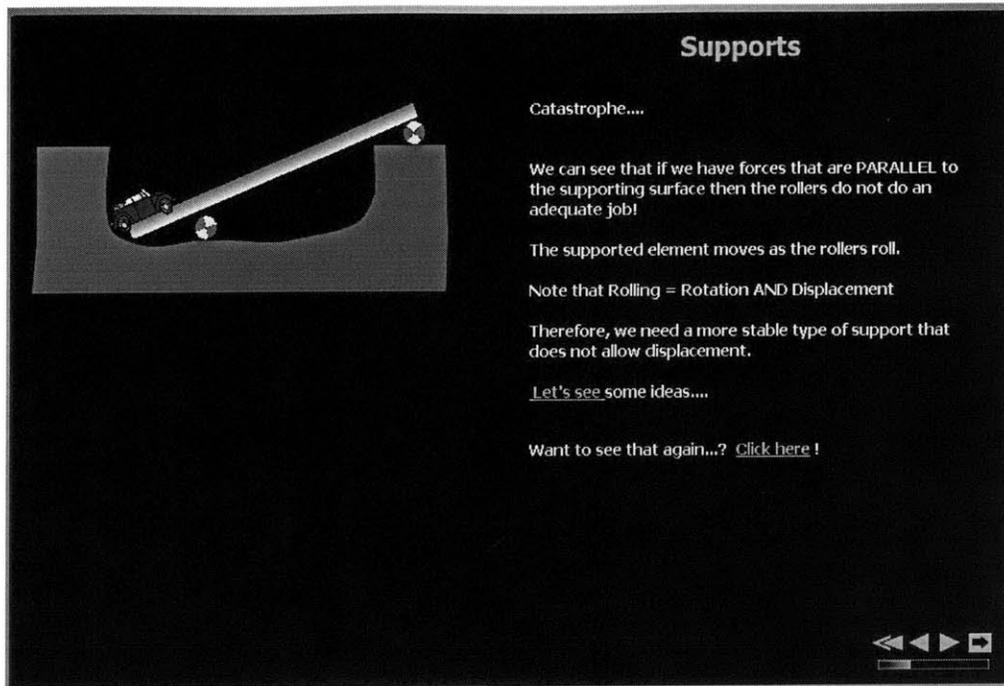


Figure 4.16 Roller support instability animation

Figure 4.17 shows an analogy used in the module when trying to explain the behavior of a roller that has been placed in grooves located on the beam and on the supporting surface. With this analogy the student is introduced to the behavior of another type of support; the hinge. The screen shot presented in the figure shows a detail of the support located at the right end of the beam and a shoulder joint. The objective here is to illustrate, through animation, the similarities between the behavior of the support and the human shoulder. This illustration is followed by animations that portray the deformation of the beam when the car is simply standing on it and the behavior of the system when the car imposes a horizontal force on the beam.

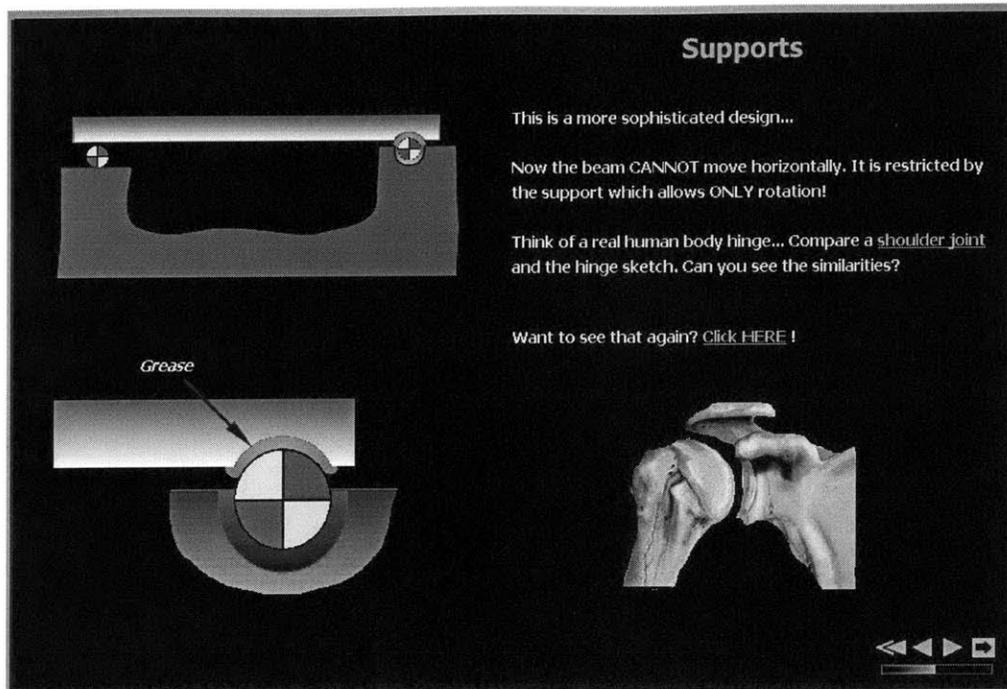


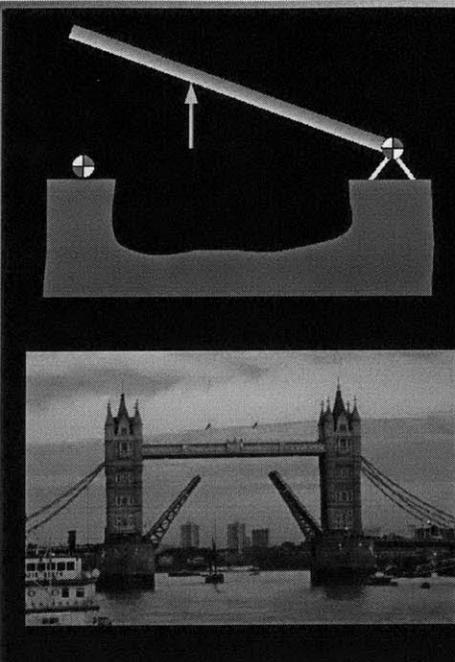
Figure 4.17 Support configuration - double-grooved support

4.1.14.5 Support configuration – Hinges

The next section of the module introduces the properties of hinges. In this section, the student finds, for the first time, a multiple choice question. Figure 4.18 shows the screen shot with the formulation of the question, its two choices, yes or no, and the correct answer follow-on. This element marks the implementation of one of the possibilities of the discovery path for learning, depicted in section 4.1.7, in its simplest manner. Notice that the student is slowly introduced to the methodology of the modules; later implementations of multiple choice questions will be more complex in their design.

Figure 4.18 also shows a picture of a real structure utilizing an arrangement similar to that represented in the figure above it. Again, the illustration of the real-world behavior is meant to connect reality and abstractions.

Supports



The diagram shows a beam supported by two hinges. An upward arrow indicates a point load on the beam. Below the diagram is a photograph of the Tower Bridge, illustrating a real-world application of hinged supports.

Do you think that we have now solved the problem? Is the beam stable against any force?

YES
 NO

We restricted the upward movement only on one of the sides. Therefore the beam can rotate around the hinge on the other side.

Such potential rotation may be desirable as in the case of the Tower Bridge.

However, we may not want to allow this potential single-sided uplift. A solution is to have hinges on both supported sides. Let's see how the beam works in that case...



Figure 4.18 Multiple choice question on hinge behavior

The behavior of the hinges is also illustrated by showing an animation of how a beam, supported on two hinges, deforms when loaded by a point load induced by a car standing on the beam. Figure 4.19 shows one of the first and the last screen shots of this animation which starts with an unloaded beam that slowly deflects when the weight of the car is progressively applied to it. The figure shows how the magnitudes of the horizontal reactions, provided by the supports, vary corresponding to the deformation of the beam. During the animation, the hinge symbols rotate, so do the curved arrows representing angular deformations. This sequence is similar to the animation presented to explain the behavior of the rollers in the previous section.

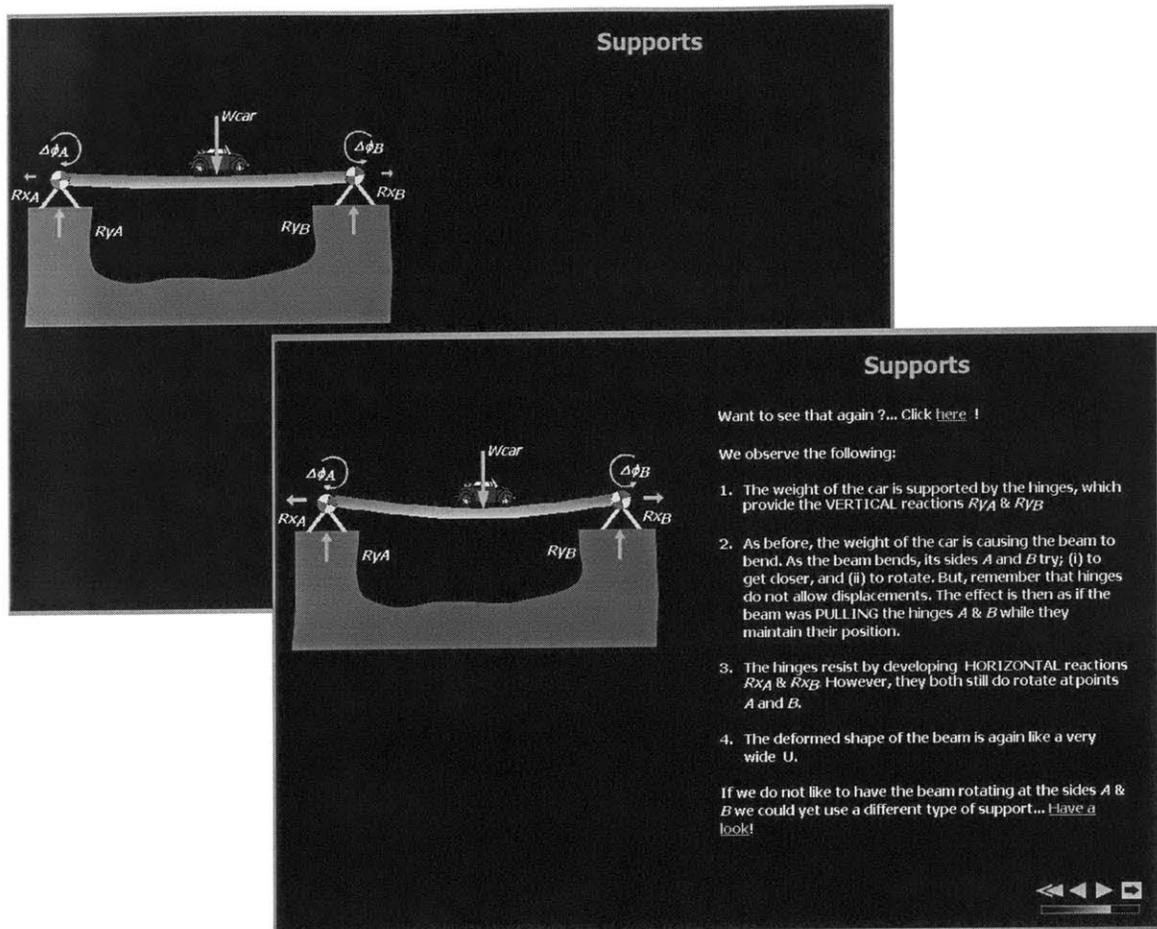


Figure 4.19 Support configuration - hinges deformation animation

4.1.14.6 Support configuration – Fixed supports

The introduction to the fixed supports is done by evolving a hinge support. This is more clearly portrayed in Figure 4.20, which shows a fixed support introduced as a support that has the same behavior as a hinge, except that the fixed support does not allow rotations. This constraint is represented by using a clamp instead of a roller-like drawing used in the hinge. This simple use of real-world objects should facilitate the understanding of this type of support. The student is then introduced to the symbol commonly used in solid mechanics literature to represent the fixed support.

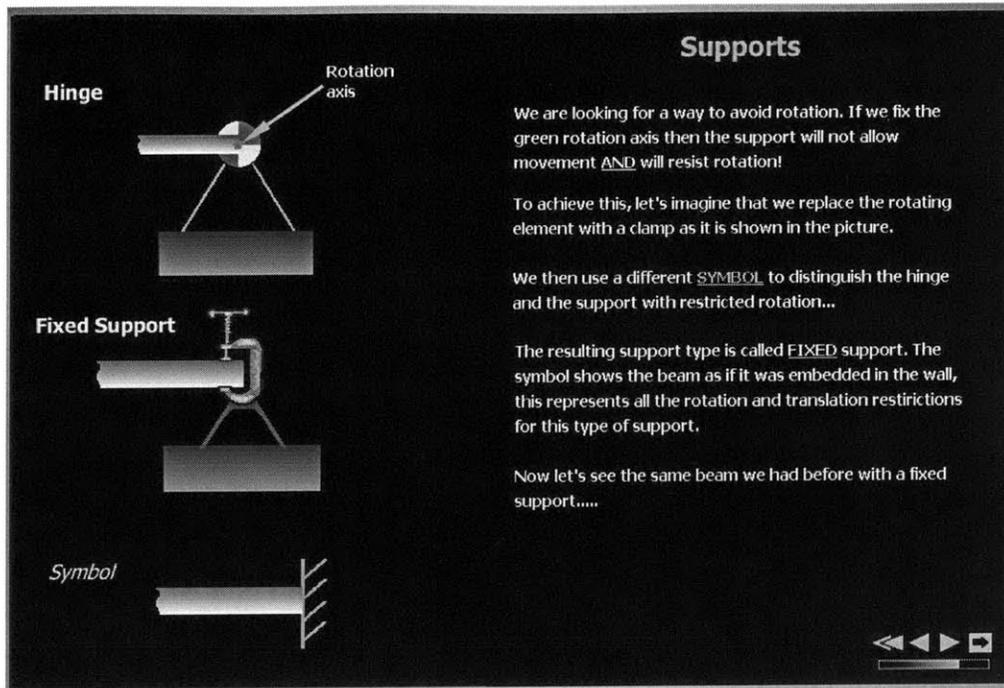
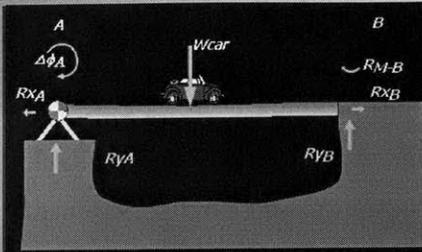


Figure 4.20 Fixed support symbols

The behavior of the fixed support is then presented to the student using the same type of animation used in the previous support types. Figure 4.21 shows one of the first and the last screen shots of the animation implemented for this purpose. Again, the car is shown standing on an initially unloaded beam supported by a hinge at the left side and a fixed support at the right side. The weight of the car is then applied on the beam, which deforms according to its support configuration. Two important new aspects are introduced here; the moment reaction, represented by the curved arrow on the right support, and the lack of rotation of the deformed beam at the fixed support. This representation also allows one to compare the behavior of a hinge versus that of a fixed support. Additionally, it serves as a transition to the introduction of the moment concept, which students do not know at this point in the module.

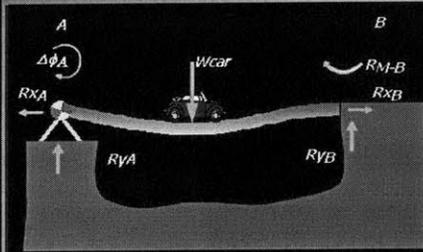


Supports

In a first stage we substitute only the right support at *B* with a fixed support. Note the symbolic representation in the lower circle.

Again the same car is simply standing on the beam....

[Click](#) to see what happens when one of the supports is a hinge and the other one is a fixed support.



Supports

Want to see that again? ... [Click here](#) !

We observe the following:

1. The beam at the point of the fixed support does not rotate in contrast to the other side.
2. The deflected shape of the beam differs at the two sides A and B. Obviously this is due to the fact that the fixed support does not allow rotation.
3. The fixed support does exactly the same thing as the hinge (no horizontal or vertical displacement) but it also prevents rotation at the support point.

[Click here](#) to see pictures of real fixed supports.



Figure 4.21 Fixed support deformation animation

4.1.14.7 Moments

The moment concept was found to be one of the more challenging concepts to illustrate, despite the advantages that IT offers. The abstract nature of the concept itself made it very difficult to present in simple terms. This section of the module underwent a long process of iteration where different strategies to present the concept were explored. Finally, the concept is presented in the module by using three different elements. The first element is a still image, shown in Figure 4.22. The purpose of this figure is to show with real-world instruments such as a wrench and a nut, the components necessary to generate a moment. The description of a moment in this figure is very similar to the

approach that a textbook would provide, however, it was deemed necessary to introduce the language used in the following explanation.

The second element is shown in Figure 4.23. After the student is shown how a moment is generated in the wrench example, the module tries to set the concept in the students mind by relating the student's experience to the concept. This is done by telling the student that simple every-day activities involve the use of moments. The figure on the left section of the screen then shows a hand opening a jar. This is implemented by animating through a set of four pictures which create the sensation of a movie being played. After the animation is done, then the components that generate the moment necessary to open the cover of the jar are revealed. These components match the ones presented in the wrench example, which were referred to in the introduction of the moment concept. The student should, at this point, have made the abstraction of this concept in his/her mind. This should be achieved by providing the connection between real-life situations, and the theoretical definition of the concept.

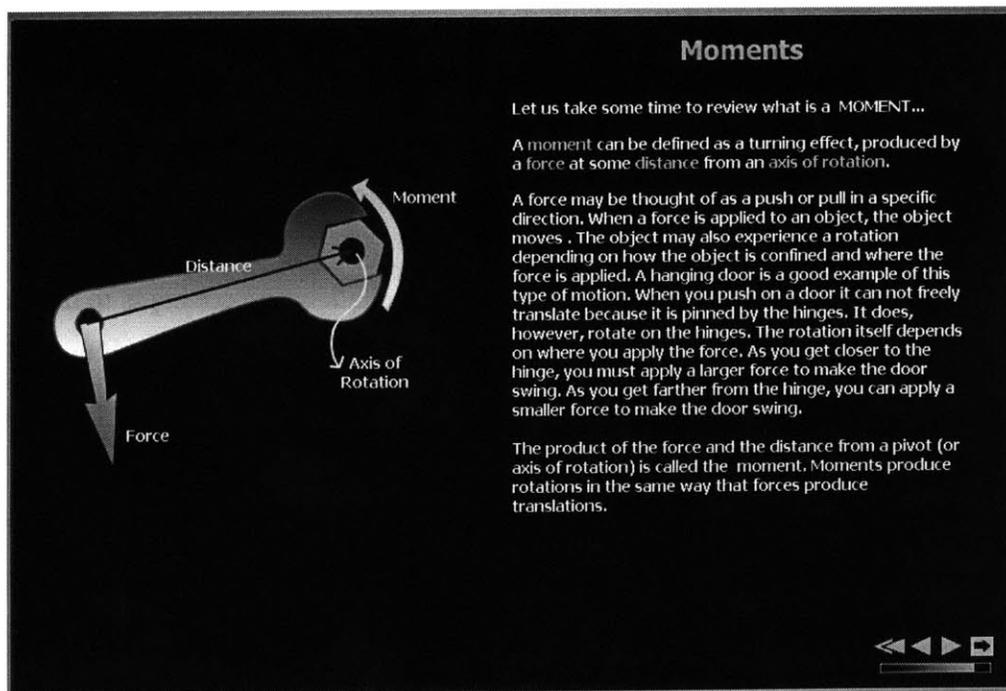
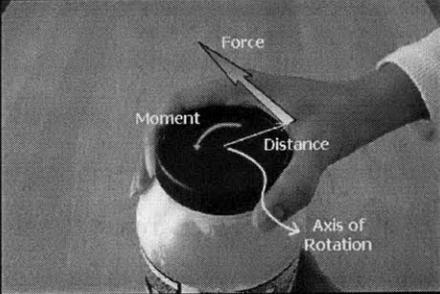


Figure 4.22 Moment concept introduction

Moments



In fact, we use moments all the time in our every-day activities. Let us look at one example...

Something as simple as opening a container requires the application of a moment.

How can that be?... Let us reveal where the moment is applied in the case shown to the left.

As you can see, moments are more common than we sometimes think. Like this, there are many more examples of moments, think about activities such as opening a door or biking, just to name a couple more. Moments are applied there too.

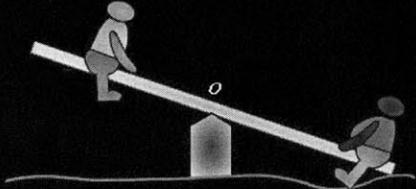
Let us play with this concept a little more, remember the seesaw?, well, it makes a very nice example for the understanding of moments...



Figure 4.23 Moment concept animation

Moments

Moments Game



Use the sliders to change the weight and the location of each person riding the seesaw. The moments are calculated as the weight (force) times the distance to the axis of rotation O .

Observe that as soon as one side is applying a greater moment the seesaw rotates towards that side. If the moments are equal, then there is no rotation, we then say that the seesaw is balanced.

This is another clear example of how moments work!

Weight	←———— 90	————→ 164
Distance	———— 4.0	———— 5.4
Moment	360.0	885.6



Figure 4.24 Moment concept simulation

The third element presenting the moment concept is portrayed in Figure 4.24. This element represents the first fully interactive simulation implemented in the modules. Here, the student is presented with a see-saw game, where he/she is given the opportunity to modify the location and weight of each of the two persons sitting on the see-saw. This game-like simulation then calculates the moment applied by each person on the pivot point, the center of the see-saw, and then reacts to the changes; the side generating a larger moment will go down to the floor, while the other side goes up. The moment is calculated simply by multiplying the weight of the person by the distance to the pivot point. The simulation reacts in real time, i.e. when the distance is modified the person changes position along the see-saw and when the weight is modified the belly of the person increases. The resulting moment for each side, shown below the controls, is also updated in real time. This allows the student to play a what-if scenario where the basic concept of moments is put into practice in a very common real-life situation and the concept of equilibrium is implicitly introduced to the user.

4.1.14.8 Summary of beam supports

This summary marks the end of Module 1. In this summary the student is shown a side-by-side comparison of two beams supported by different configurations. The comparison is made by animating a car standing on each beam and showing the deformations induced as the load is applied. At the end of the animation, a scale measuring the deflection of each beam is drawn to highlight the difference of the behavior of both configurations.

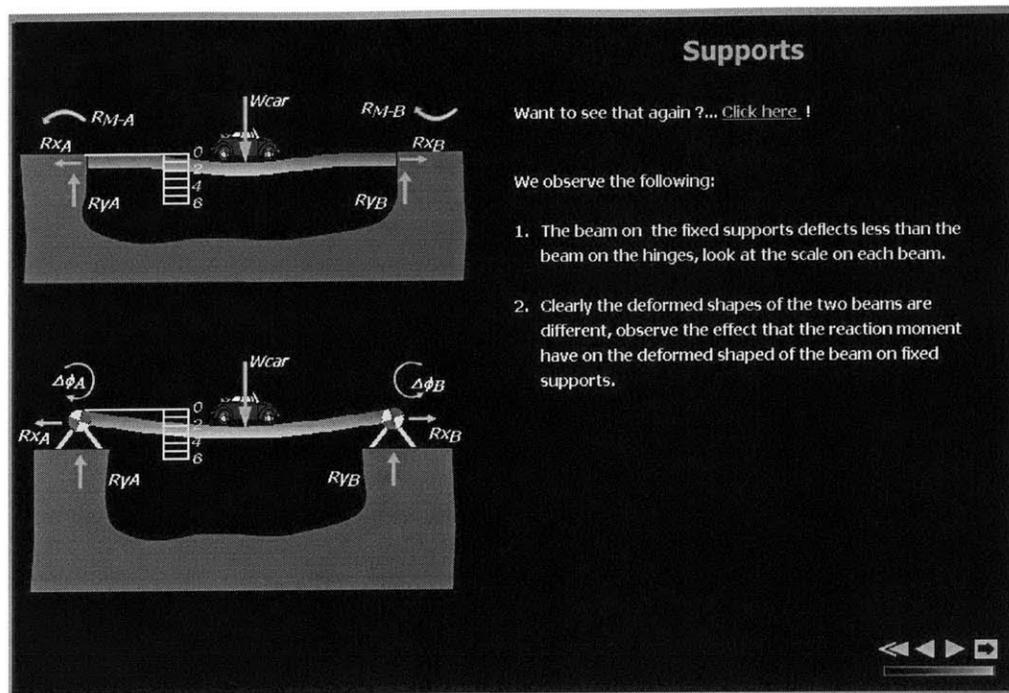


Figure 4.25 Summary of support behavior

4.1.14.9 Equilibrium

The equilibrium concept marks the beginning of Module 2 where, ultimately, the student is introduced to the concept of equilibrium equations. Equilibrium is introduced through a very basic approach. Figure 4.26 shows a screen shot of the module where two very simple simulations, to the left of the screen, introduce the student to the concept of action-reaction. In these simulations, the student is allowed to modify the length of the force being applied on each block while the counterforce also changes in magnitude to equilibrate the force. To the right of the screen, an animation instructs the student on how to experience what is shown by the simulations. This can be done by pushing the two index fingers together and applying a force with one hand while the other hand is required to provide an equal force in order to keep the hands from moving.

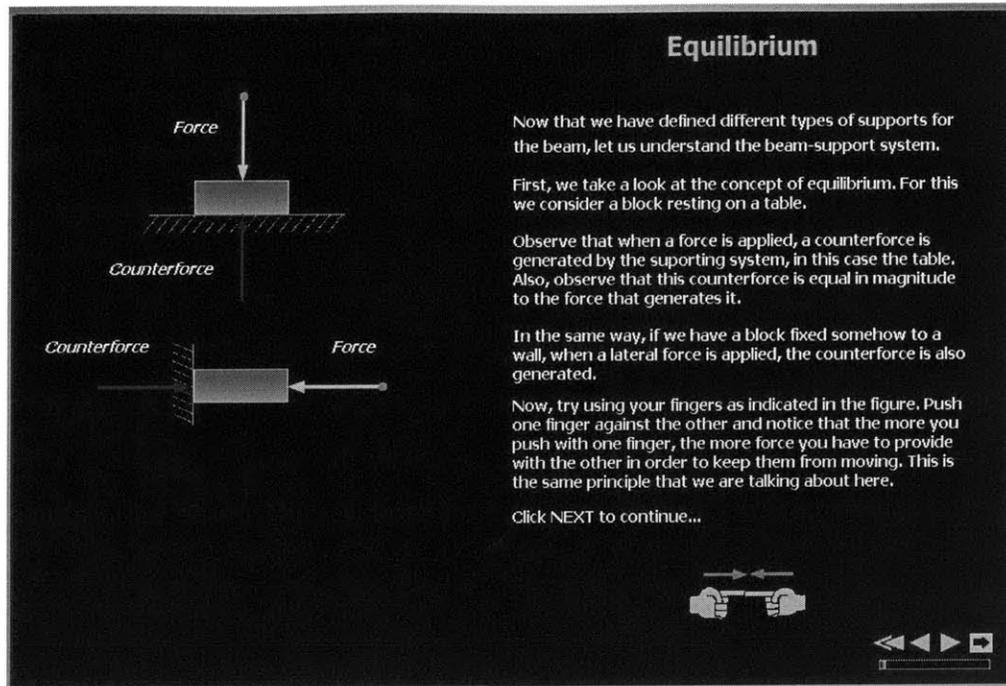
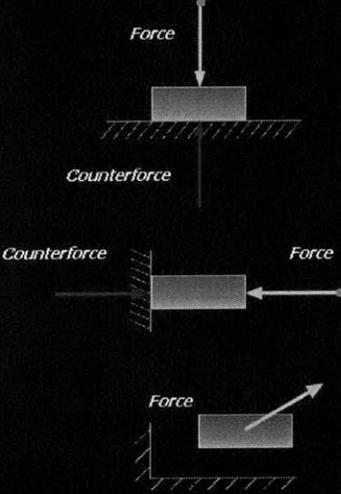


Figure 4.26 Equilibrium concept introduction – force-counterforce simulations

The next step shows a block that combines the two support situations shown in the two previous simulations. This block is shown in Figure 4.27. In this step, the student is given the opportunity to modify the magnitude as well as the orientation of the force being applied on the block. The simulation then calculates the counterforce generated in the vertical and the horizontal walls on which the block is supported. The next screen, portrayed in Figure 4.27 asks the student to respond whether the block will move away from the walls when the force is applied upwards. This is a multiple choice question with its respective feedback and reinforcement elements.

Lastly, the student is presented with another simulation which connects what has just been learned with the support properties explained in Module 1. This simulation is shown on the left portion of Figure 4.28. In the simulation, the student is given the possibility to change the magnitude and orientation of a point load being applied on a simply-supported beam. The reactions provided by the supports change accordingly.

Equilibrium



Now, let us see if you have understood this concept.

Do you think that the block at the bottom will still not move when we apply a force that points upward?

Yes No

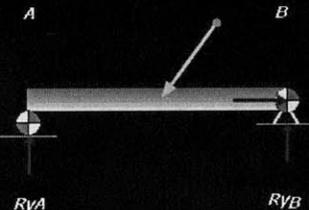
The block will not move only when the vertical and horizontal components of the applied force point downward and leftward respectively.

If one or both components point in any other direction, then the block will move since there is not a support that generates a counterforce.

[Click here to see what happens again...](#)

Figure 4.27 Equilibrium concept introduction – multiple choice question

Equilibrium



We have previously studied what type of reactions (counterforces) the different supports used for beams can provide.

If we take a look at this example we can now see the reactions generated by the applied force and their behavior when the force is changed in magnitude and direction by dragging the orange dot.

Just like with the blocks, the beam will not move in one direction as long as there is a support providing a reaction in that direction.

The magnitude of the reactions is a function of the magnitude, location and orientation of the applied force or forces. We will point out how to calculate these reaction forces at a later stage in this module but first let us look at the concept of equilibrium...

Figure 4.28 Equilibrium concept introduction - simply supported beam simulation

4.1.14.10 Rigid body stability

The rigid body stability section of Module 2 serves as the transition between what has been learned about the beam and its supports and the equilibrium equations. This subtopic uses a random-shaped, unsupported body to explain concepts that will help the student move from the graphical representations of loaded bodies to the graphical representation of the loads in a system to the equilibrium equations.

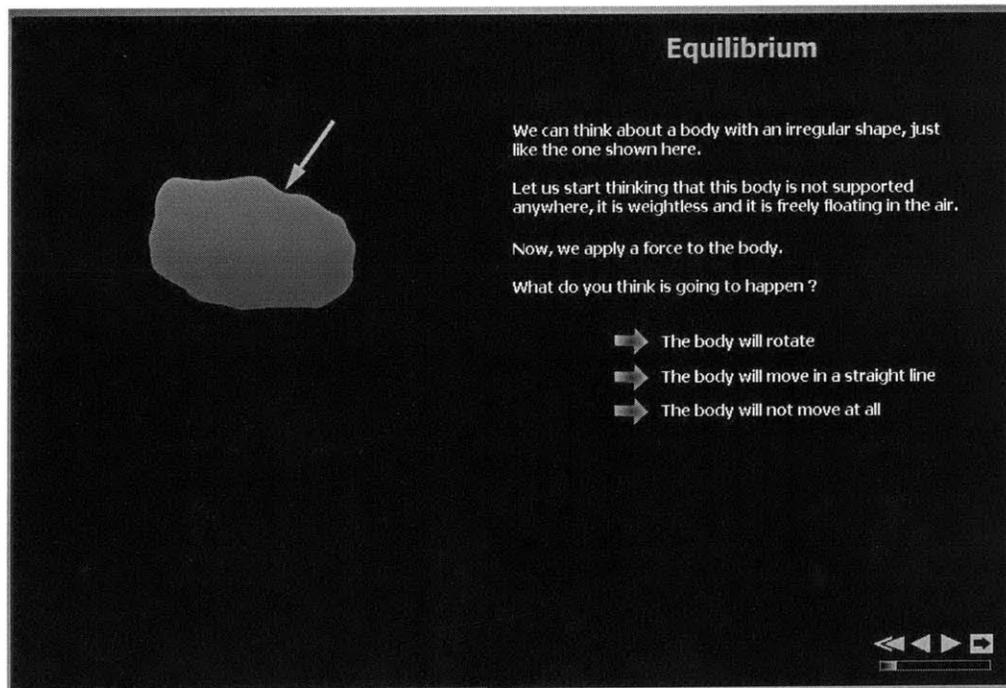


Figure 4.29 Rigid body stability - multiple choice questions

This section starts by covering the stability of the body from the point of view of rigid body motion, defining the requirements for stability in a body loaded by a point load and suspended in the air. Figure 4.29 shows an early screen shot of this presentation where the student is asked a multiple choice question about what is going to be explained. This tries to awaken the curiosity of the student towards the upcoming material. The student is then shown, through animations, three conditions that the equilibrating force has to fulfill to achieve rigid body stability; force location, magnitude,

and orientation. The animations show the consequences, i.e. the body displacements generated, when one or a combination of these requirements is not met. In doing so, the student is introduced, through animations, to the use of the graphical method of addition of vectors as shown in Figure 4.30, and the couple concept, as shown in Figure 4.31. This figure also shows the first implementation in the modules of the specialized feedback of student response. The introduction of the couple concept involves the derivation of the moments induced on the body by the two forces applied on its surface. These moments are labeled M_1 and M_2 . The top screen shot shows that the moment induced by one of the forces, labeled M_1 , has been derived previously and is now shown in the graphic representation in the lower left section of the screen. The derivation of the moment labeled M_2 is then left to the student. The module asks the student to fill in the blanks with the expression corresponding to this moment. The student's response is evaluated and feedback is provided in the text below. This feedback tells the student what part of the equation is not correct. At this time, if the student has made a mistake in the expression for M_2 , the module displays a hypertext message that allows the student to obtain the correct answer by clicking on it. This control is located next to the submit button. If the answer is correct, the student is told so and the module continues. The case of a correct answer submitted and the feedback associated to it is illustrated in the bottom screen shot shown in Figure 4.31.

Once the requirements for rigid body stability have been set out, the module continues with an equilibrium game, designed to reinforce what has been presented up to this point. This game is a simulation that starts with an unsupported body loaded by one point load. The purpose of the game is to set a second load that will equilibrate the body. Figure 4.32 shows the interface of this game. The user can utilize two levels of hints, chosen by pressing on the light bulb. The first hint will draw the line of action of the force to equilibrate (the lower force in Figure 4.32), while the second hint will show the magnitude of the forces. When the user submits a solution to the problem, the simulation provides feedback indicating what requirements for the equilibrating force

are being fulfilled. In the case of the figure, the proposed solution only fulfills the location requirement; the equilibrating force has the wrong direction and magnitude. A correct answer in this game awards 20 points for an answer without using any hints, 10 points for a correct answer with one hint and 5 points if the user chose to use two hints. The user can play again once he/she has submitted a correct answer. This is done by pressing the “play again” icon. At this time, the user is given a new location, orientation and magnitude for the force to equilibrate.

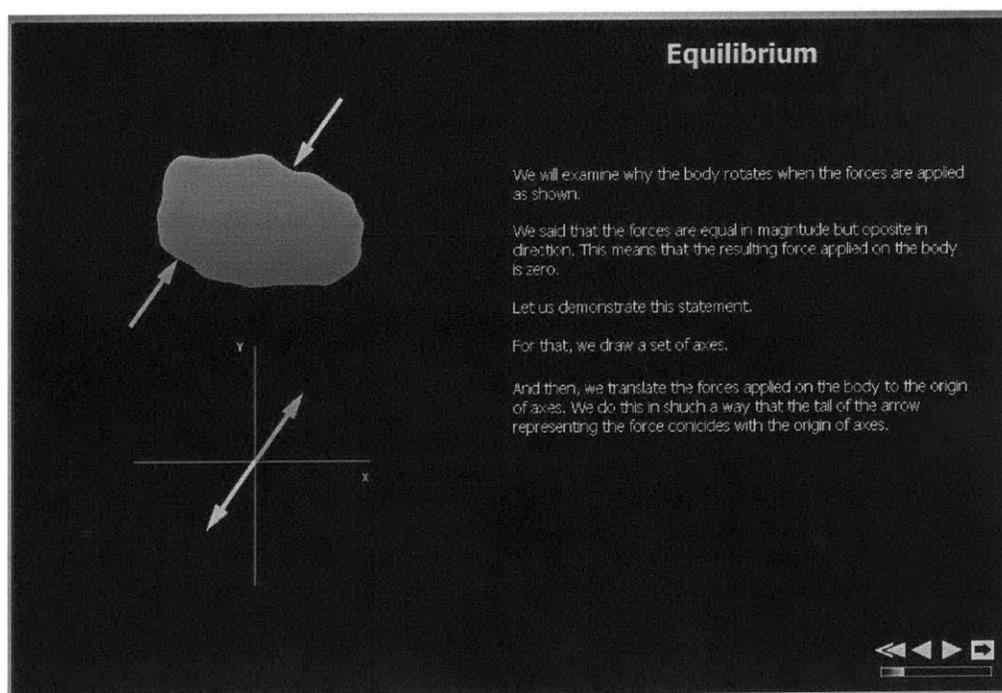


Figure 4.30 Rigid body stability - graphical addition of vectors

Once the concept of rigid body stability has been explained to the student and reinforced through the equilibrium game just presented, the module moves to explain the concept of rigid body stability using more than two forces in the system. Figure 4.33 shows a screen shot of this explanation, where the body has now been loaded by the two upper loads and the module is instructing on the various ways to achieve equilibrium with one or more forces. This procedure is presented using a Cartesian plane where the loading vectors are added graphically, yielding a resultant force, which is then inverted and

decomposed into two forces that are then transferred to the body as the equilibrating forces. The lines of action of all forces are also shown to illustrate that the proposed solution does not generate a couple on the body.

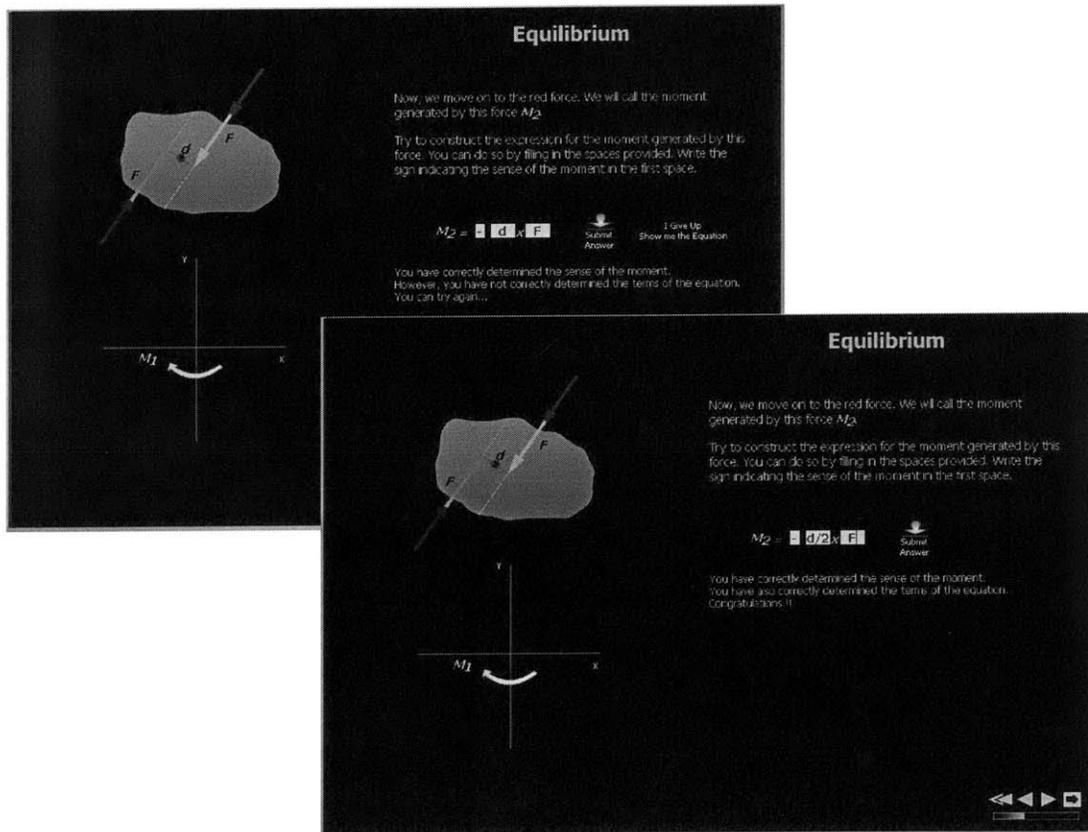


Figure 4.31 Rigid body stability - couple concept

The concept of stability with more than two forces in the system is also reinforced through the use of a second equilibrium game. The interface of the game is shown in Figure 4.34. In this game, the student is challenged with a body loaded by three or four loads. The student is then given the task to equilibrate the body by correctly locating up to four forces on the body so that the vertical and horizontal resultants, as well as the resulting moment acting on the center of the body are equal to zero. The student is shown these three resultants in real time in the Cartesian plane shown in the lower left of the screen. Once the student has achieved equilibrium on all three fronts, he/she can

proceed to the next screen or click on the “play again” button which should present the student with another set of three to four forces to equilibrate.

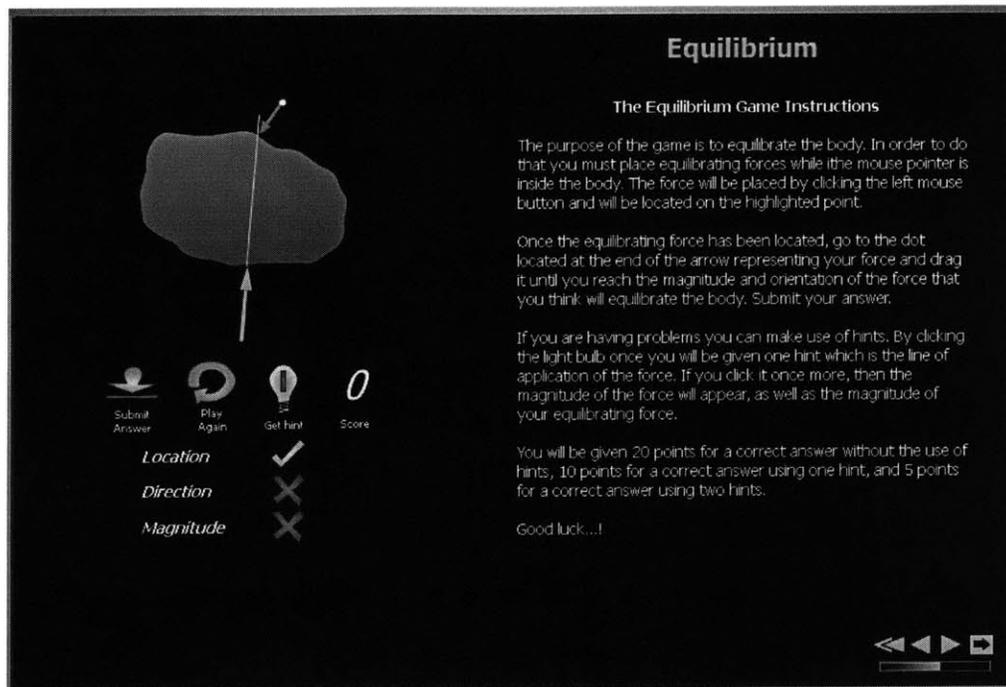


Figure 4.32 Equilibrium Game 1 interface

The second equilibrium game should provide a good transition towards the concept of equilibrium equations. The student is expected to make a connection between the loading condition of an object and its equilibrium condition, divided into three components; vertical, horizontal, and moment equilibrium. The graphic representation of the object loading should facilitate the student’s abstraction of this concept.

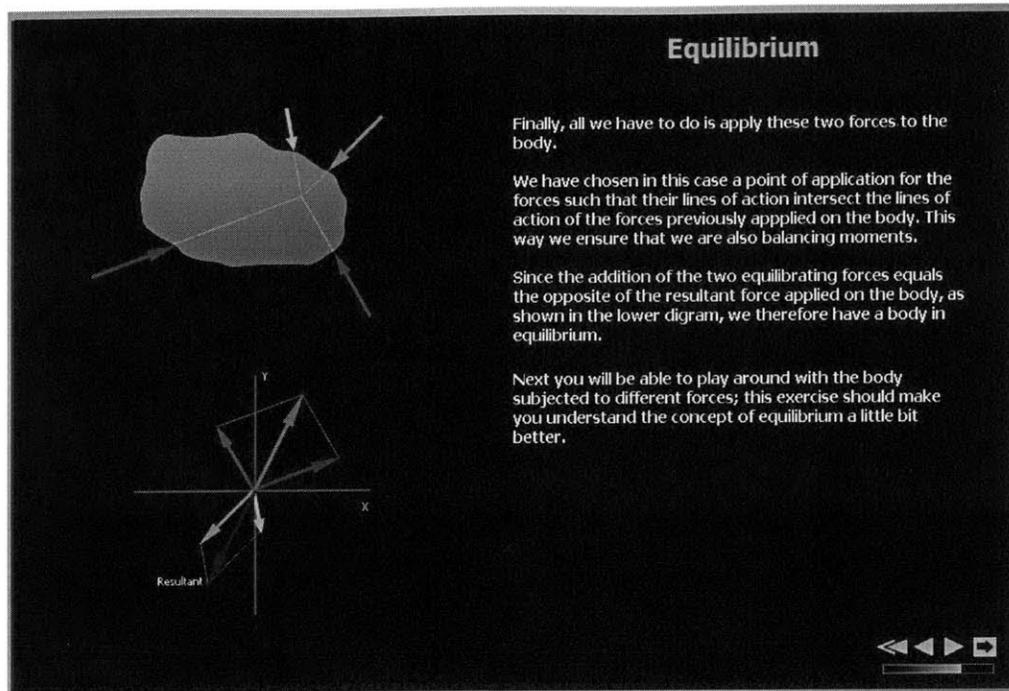


Figure 4.33 Rigid body stability with more than two forces in the system

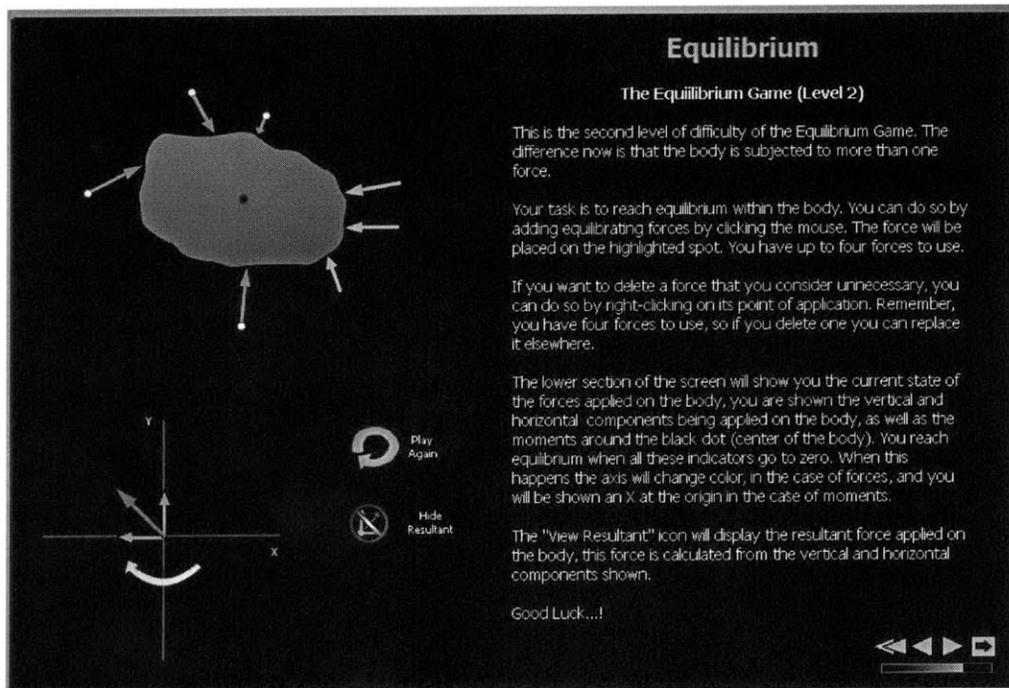


Figure 4.34 Equilibrium Game 2 interface

4.1.14.11 Equilibrium equations

The equilibrium equations are given to the student to elaborate what was presented in the last equilibrium game. The introduction of the equations is almost immediate using the Cartesian plane with a representation of the resultant forces and moments. Figure 4.35 shows the screen shot where this introduction takes place.

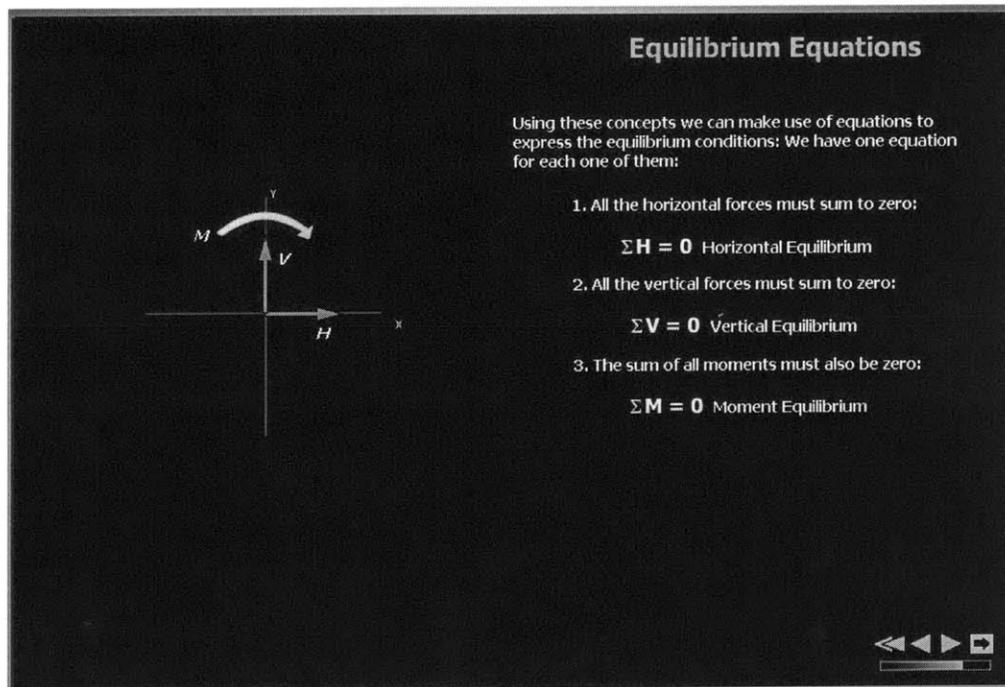


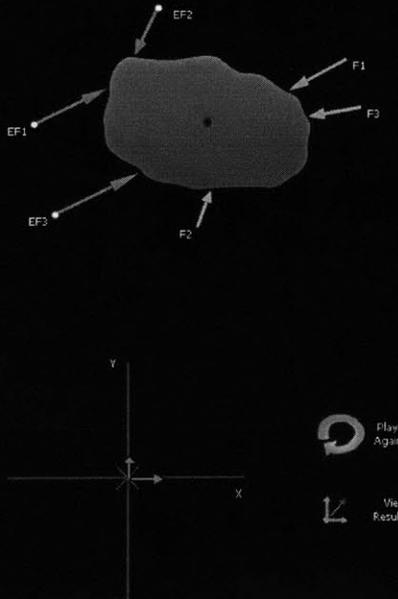
Figure 4.35 Equilibrium equations – introduction

The equilibrium equations is one of the concepts considered somewhat difficult for students to learn. Similar to the moment concept it is abstract. The analytical representation of a physical concept is something that requires reflection from the student; this is not something easily achievable. The advantages of IT to use imagery, enhanced through animations and simulations facilitated the transition from physical reality to analytical representation. This is done by allowing the student to relate the image of a loaded object to a graphic representation of forces acting on it, which is later easily translated into equations.

Once the equations have been introduced, the student is again given access to a modified version of the equilibrium game. The interface of this game is shown in Figure 4.36. There are now two new elements in the game; the presentation of the written equilibrium equations included in the lower right of the screen, and the labels that identify each of the forces applied on the object. The equations are also updated in real time allowing the student to visualize how changes in direction of the modifiable forces affect how the force is considered in the equation. The equations are shown as the addition of forces or moments resulting in a quantity different from or equal to zero; this corresponds to a non equilibrated or equilibrated component. For the loading case shown in Figure 4.36, the moments are in equilibrium and the equation shows an “equal to” sign connecting the moment equation factors to a value of zero. The other two components are not equilibrated, as shown in the graphical representation, and their equation is shown to be connected to zero by a “not equal to” sign.

The last interactive element implemented to reinforce the understanding of equilibrium equations is a simulated game where the student is presented with an object loaded with five to seven point loads. The interface of this game is shown in Figure 4.37. The objective is for the student to construct the equations that represent the summation of vertical force, horizontal force, and moment components based on the orientation of the forces. The student fills in the equation in the spaces provided and submits his/her answer. At this time, the simulation evaluates the student’s response and provides specialized feedback to the student. This feedback provides information to the student for each of the equations. It tells the student if the equation is correct, if there is an error in any of the signs within one equation, and/or if there is one or more forces that have not been included in the equation. For a correct answer in the first try, the student receives 20 points. If the student submits a correct answer after having submitted a wrong answer in the first try, 15 points are awarded (i.e. a maximum of 20 points minus 5 discounted for the mistake incurred in the first try). The number of points received continues to be reduced by five for each wrong answer submitted. The minimum

number of points awarded is 5. After two failed submissions, the student is given the option to obtain the correct answer from the simulation.



Equilibrium Equations

The Equilibrium Game (Level 2)

Remember, your task is to reach equilibrium within the body. You can do so by adding equilibrating forces by clicking the mouse. The force will be placed on the highlighted spot. You have up to four forces to use.

If you want to delete a force that you consider unnecessary, you can do so by right-clicking (Windows) or control-clicking (Macintosh) on its point of application. Remember, you have four forces to use, so if you delete one you can replace it elsewhere.

The lower section of the screen will show you the current state of the forces applied on the body, you are shown the vertical and horizontal components being applied on the body, as well as the moments around the black dot (center of the body).

You are also given the following Equilibrium Equations:

$$\sum H = -F_1x + F_2x - F_3x + EF_1x - EF_2x + EF_3x \ll 0$$

$$\sum V = -F_1y + F_2y - F_3y + EF_1y - EF_2y + EF_3y \ll 0$$

$$\sum M = -MF_1 + MF_2 - MF_3 - MEF_1 + MEF_2 + MEF_3 = 0$$



Play Again



View Resultant



Figure 4.36 Equilibrium Game 2 - equilibrium equations

Equilibrium Equations
The Equilibrium Game (Level 3)

Here you are given the body randomly loaded. The body is **not necessarily in equilibrium**. Your task is to write the equilibrium equations based on the orientation of the forces applied on the body.

The notation and order in which you write the equations is up to you, as long as you provide the number that identifies each force.

You can fill out the fields by typing in the equations. You can select each field by clicking on it. The Tab key will move the selection from one field to another.

The score you are shown at the beginning is the same score that you had in the previous scored Equilibrium Game. If you answer correctly in the first try you are given 20 points. 5 points are taken off thereafter for every incorrect answer you submit. A minimum of 5 points will be awarded for a correct answer.

Once you submit your answer you will be shown the equations to the left as they have been input and an evaluation of your equations in a box below. After two unsuccessful tries you will be given the opportunity to obtain the correct answer to the problem.

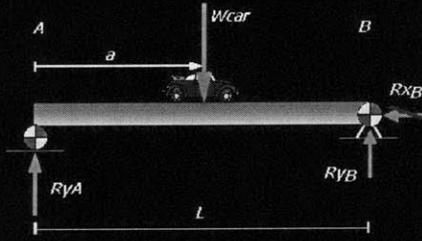
Answer Evaluation:
One or more signs of the horizontal equilibrium equation need to be checked.
Vertical equilibrium equation: OK
One or more signs of the moment equilibrium equation need to be checked.
There is one or more forces that have not been included in the moment equilibrium equation.

Submit Answer Play Again Score

Figure 4.37 Equilibrium game 3 - equilibrium equation feedback

4.1.14.12 Simply-supported beam

At this stage in the module, the student is now ready to put together what has been learned previously. The solution of a simply-supported beam is the first problem presented to the student where the knowledge on supports and the equilibrium equations come together to solve for the reactions of the system. The solution of this problem is purely instructional, i.e. the student is simply shown how it is done through the use of animations combined with the text where all analytical expressions are derived. Figure 4.38 shows a screen shot of the module where the equations are being derived in order to find expressions for the unknown reactions.



Equilibrium Equations

This is what we have up to now in our analysis:

$$R_{xB} = 0 \quad (1)$$

$$W_{car} - R_{yA} - R_{yB} = 0 \quad (2)$$

$$W_{car} \times a - R_{yB} \times L = 0 \quad (3)$$

Note that Equation 3 (obtained from moment equilibrium) relates one of the unknowns with known quantities (highlighted in orange). Therefore we can solve for R_{yB} . Equation 3 then becomes:

$$R_{yB} = (W_{car} \times a) / L \quad (3)$$

Being able to solve for R_{yB} allows us to solve for R_{yA} by using Equation 2:

$$R_{yA} = W_{car} - R_{yB} \quad (2)$$

Since we know the value of R_{yB} from Equation 3, we can rewrite Equation 2 as:

$$R_{yA} = W_{car} - (W_{car} \times a) / L \quad (4)$$

$$R_{xB} = 0 \quad (1)$$

$$W_{car} - R_{yA} - R_{yB} = 0 \quad (2)$$

$$R_{yB} \times L - W_{car} \times a = 0 \quad (3)$$

Figure 4.38 Simply-supported beam problem

Figure 4.39 shows the follow up to the animated presentation of the derivation of the reaction expressions. After the animations are completed, the beam turns into a simulation that allows the student to move the point load around the beam, while the magnitudes of the reactions change according to the just derived equations, presented on the right. Below this illustration, an exercise is suggested to the student which he/she can set-up on his/her desk to experiment how the vertical reaction varies with changes of the location of a load placed on a ruler, which is supported by a table or desk on one side, and by the student's fingers on the other.

Equilibrium Equations

Let us now play with our results. We know that the reactions depend on the location of the load W_{car} .

We can then examine what happens when we give a value of 80 to W_{car} and we assume that the length of the beam is 3.

You can drag the load around and observe how the reaction magnitudes change according to the equation we obtained:

$$R_{xB} = 0$$

$$R_{yB} = (W_{car} \times a) / L$$

$$R_{yA} = W_{car} - (W_{car} \times a) / L$$

You can experience this exercise very easily. Try the following:

- Place a long ruler on your desk the way it is shown to the left.
- Hold with your finger the end on the opposite side to the one that is being supported on the desk.
- And now "load" the beam (in this case the ruler) by placing an object on it. Try different locations for the object and feel how the force on your finger changes as you move the object. Discover the similarities between the two arrangements.

Figure 4.39 Simply-supported beam simulation

4.1.14.13 Cantilever beam

A cantilever beam loaded by a single point load is presented to the student. In this case, the student is guided through a number of multiple choice and fill-in questions that lead to the solution of the problem. In other words, the student is actively involved in solving the problem through interactivity, implemented with the help of feedback and reinforcement.

Equilibrium Equations

$W_{car} = 80$

Let us start by calculating the moment that R_{xA} generates at A.

R_{xA} produces a moment in A equal to:

- ⇒ R_{xA} (counterclockwise)
- ⇒ $R_{xA} \times 1.50$ (clockwise)
- ⇒ $R_{xA} \times 0 = 0$

Unfortunately you are not correct. The correct answer is zero. Note that the force R_{xA} is applied right at point A, which leaves the force with no arm to develop a moment.

Figure 4.40 Cantilever beam problem - multiple choice question

Figure 4.40 shows a stage of the solution process where a follow-on comment is presented after the student has given an incorrect answer to the question.

After the solution has been reached, the representation of the loaded cantilever beam turns into a simulation, similar to the case of the simply-loaded beam. The simulation allows the point load to be moved around the cantilever beam while the reactions change in magnitude according to the equations just derived. This simulation is shown in Figure 4.41, which also shows another exercise, suggested to the student, for the set-up and experimentation of a similar system. In this case the student is suggested to hold a ruler by its end with his/her hand so that the ruler remains horizontal. The student is then asked to place an object on the ruler and feel how the reactions of the system, applied by the student's hand, change with changing position of the object on the ruler. The student should be able to feel how the moment necessary to keep the ruler in place increases as the object is placed farther away from his/her hand.

Equilibrium Equations

With this analysis we have completed the solution for the unknowns in this beam. We have determined that:

$$R_{xA} = 0$$

$$R_{yA} = W_{car}$$

$$R_{M-A} = W_{car} \times a$$

Note that the reactions depend only on the magnitude of W_{car} and its point of application, reflected by a .

Now, drag around the force W_{car} with the mouse, change its location and see how the moment changes.

You can try this very easily; grab a ruler by one of its ends and hold it horizontally, as shown in the picture. Now place an object on top of the ruler. Move the object around, in other words, change its distance to your hand. Do you feel the force you have to apply with your hand change as you move the object?. How does this behavior compare to the equations we have just derived - the moment should increase as the object is farther from your hand (a is longer)?

Figure 4.41 Cantilever beam problem – simulation

4.1.14.14 Internal forces

The introduction of the internal force concept marks the beginning of Module 3. This concept was also considered to be difficult for students and its presentation was also approached in different ways. The result of this iterative process yielded what is currently contained in the modules.

Specifically, a simply-supported beam is split into two sections. Each section is evaluated separately from an equilibrium point of view, in other words, the equilibrium equations, presented in the preceding model, are applied to each section. The internal forces are then introduced into the system as the forces providing internal equilibrium to each of the split sections and are derived one by one. This derivation is portrayed in Figure 4.42 which shows the derivation of the equilibrium equations of the sections on the right and the beam illustrated with the two separate sections below it on the left. Given the large number of terms used in these derivations, the module implements the

animation with terms that appear to “fly” from the illustration towards the analytical expressions being constructed. This contributes to the understanding of the construction of the equations.

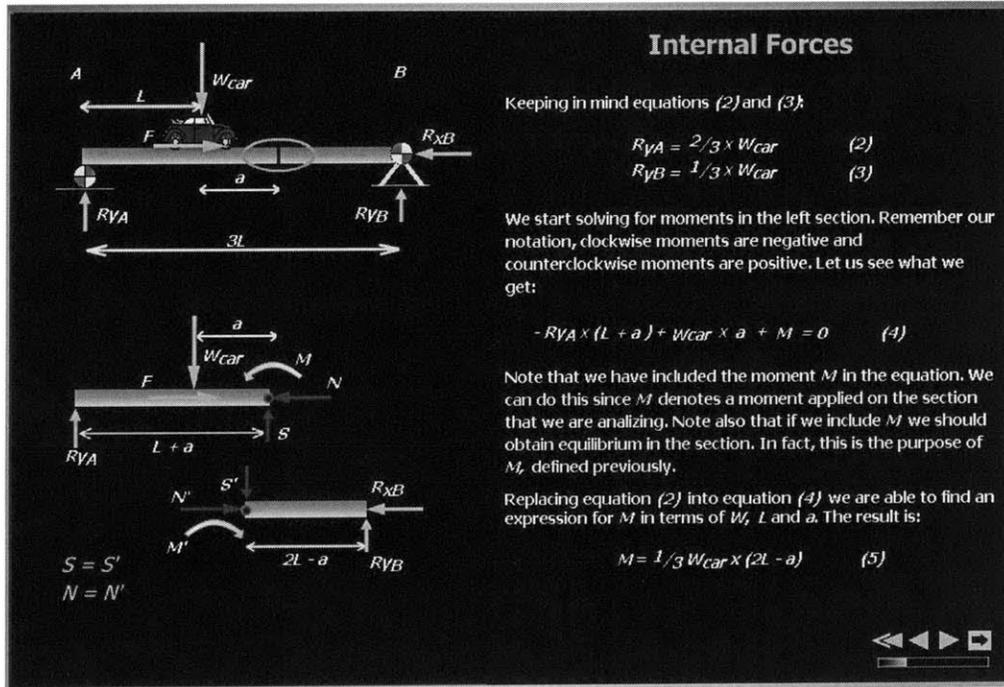


Figure 4.42 Internal force concept introduction

4.1.14.15 Internal force diagram

Once the internal forces have been introduced, the notion of the internal force diagram is presented to the student. For this, the module takes advantage of the methodology used to present the internal forces. For the construction of the diagrams, a simply-supported beam is given dimensions and is now loaded by a point load of a known magnitude. The beam is then split at various points where its internal forces are evaluated. These values are then tabulated. Figure 4.43 shows a screen shot where this tabulation is taking place. Again, this section of the module is heavily driven by animations that add to the clarity of the methodology being implemented.

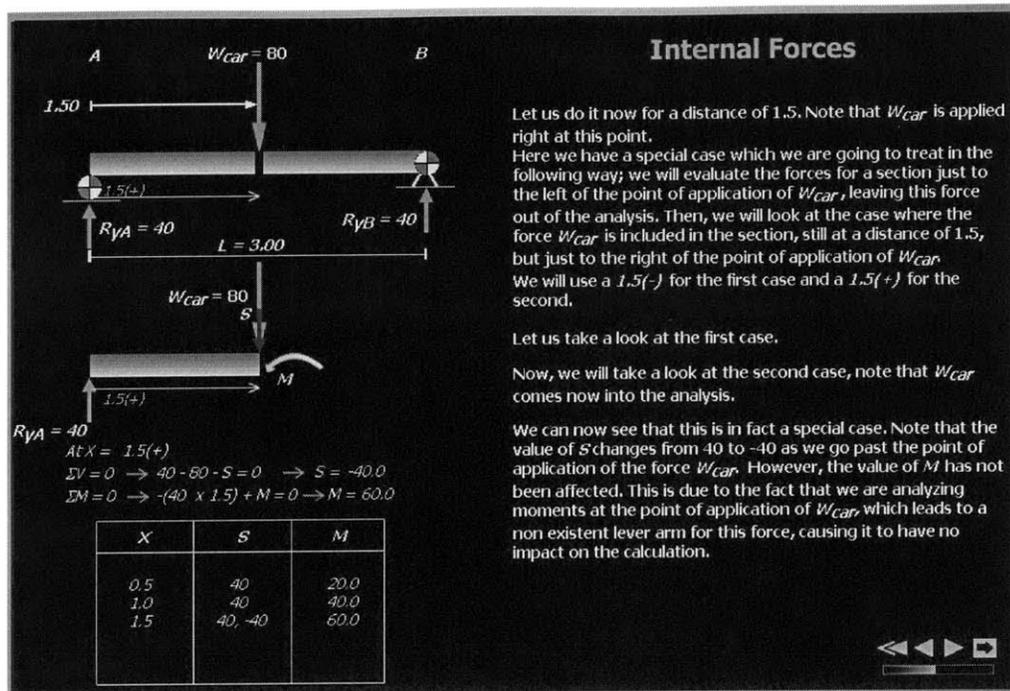


Figure 4.43 Internal force diagram construction – tabulation

The tabulation of the internal forces is then transferred to a graphic representation, following the reverse process implemented for the equilibrium equations, where students were taken from a graphic representation to an analytical expression. Here, an animation is used that clearly plots each value on the table onto what will eventually constitute the internal force diagrams. This process is shown in progress during the construction of the bending moment diagram in Figure 4.44.

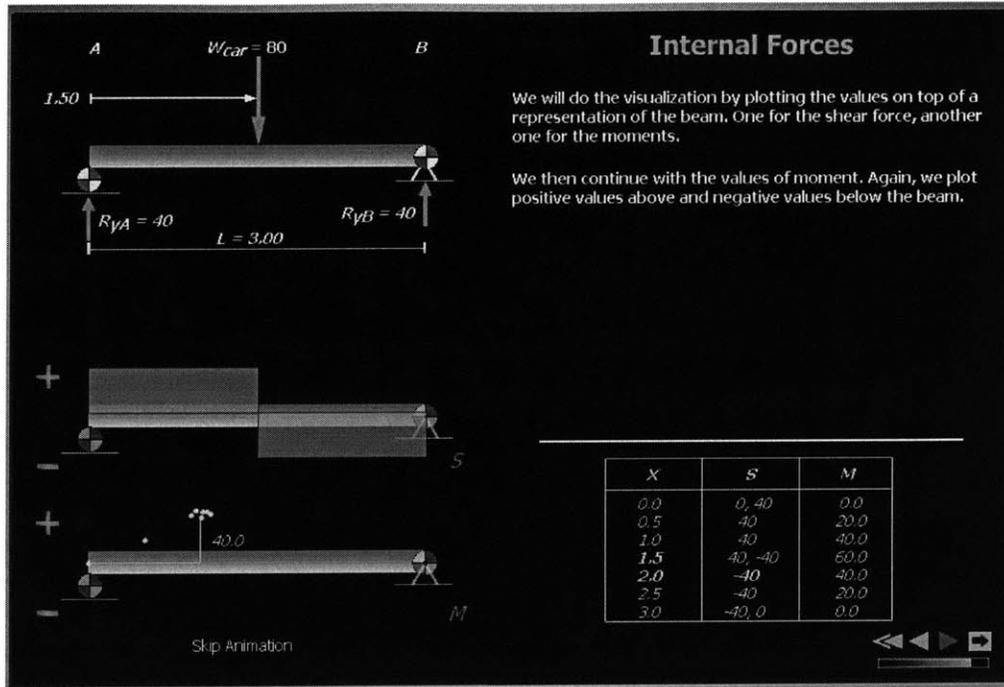


Figure 4.44 Internal force diagram - diagram construction

As reinforcement to the construction of the internal force diagrams, Module 3 finishes with a simulation that allows the user to modify the location of the point load on the simply-supported beam used to illustrate the construction of the diagrams. As the user changes the location of the force, the reactions of the beam and the shape of the diagrams change correspondingly. A screen shot of this simulation is shown in Figure 4.45. As an added feature, the user is also capable of moving a slider located on the beam. The values of the internal forces at the location of the vertical line that extends from the slider on the beam to the bending moment diagram in the figure are displayed below each corresponding diagram.

As mentioned before, the simulation represents the last exercise of Module 3. As shown in Figure 4.2 the student's instruction on the subject would be complemented through the use of the iBeam module (Viteri, 2002), as a follow-up of Module 3. The iBeam module implements intelligent agents that provide feedback to the student on problems dealing with the representation of internal forces.

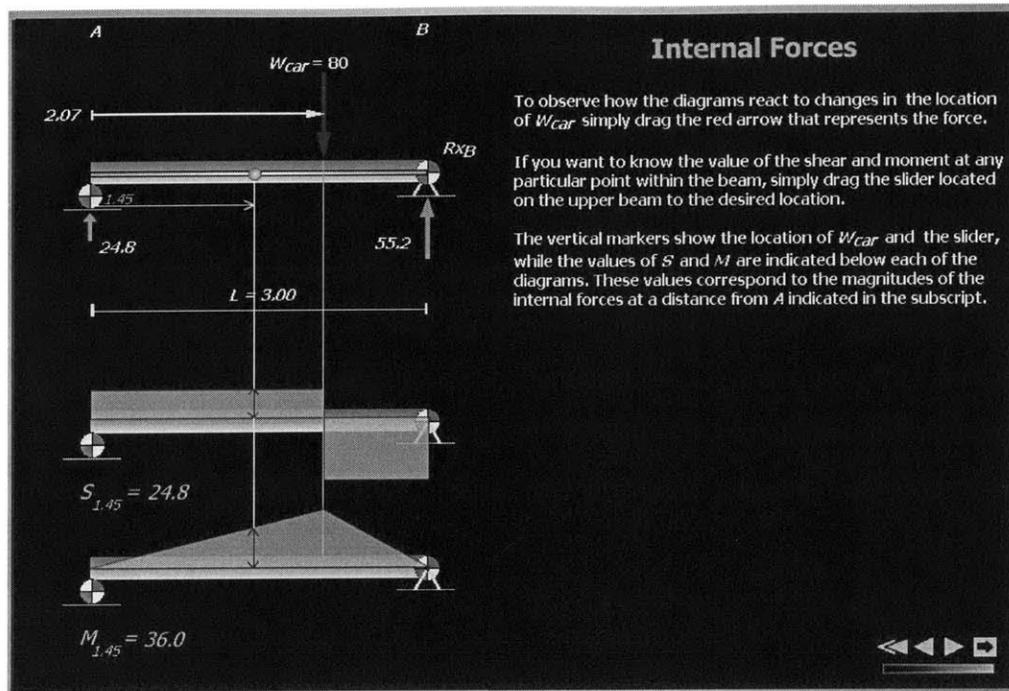


Figure 4.45 Internal force diagrams - simulation

4.1.15 Framework connecting exercises

Simulations are connected to each other through the narrative content of the modules. This arrangement comes from the linear nature of the modules in which the next concept builds on the preceding. This framework was implicitly discussed in the previous section, where each main concept of the modules was explained in detail.

4.1.16 Formative Testing

As mentioned before, the modules were subject to a formative evaluation process throughout their development. This process influenced the quality as well as the quantity of the material covered by the modules. It also tested potential ambiguities and the interaction and navigational methods implemented in the modules. This evaluation process was very important to reveal inappropriate or appropriate methods to present different concepts. It was an iterative process that produced a fine-tuned version of the module.

One of the more important contributions of formative testing was the implementation of simulated games and models into the modules. To explain how these elements were introduced one has to look back into the first stages of development of the modules, when they were conceived as teaching tools that would implement animations to explain basic concepts of solid mechanics. Although the advantages of using interactivity were recognized, the feasibility of its implementation was somewhat unclear at the beginning. As the first versions of the modules were tested, it was obvious that the presentation of concepts, although more clear than a textbook, was lacking some essential elements to fulfill the objective of moving away from the transmission model. As a result of this, the development of the modules took a different approach and began introducing simulations that would allow the student to vary parameters and observe in real-time the changes that these modifications would generate. For example, changing the magnitude of a force being applied on a beam while observing how this change impacts the reaction forces and moments. This approach was considered to be very beneficial especially for the introduction of abstract concepts such as moments and equilibrium equations, where an animation or a very well written narrative content would not do much more than a textbook can do.

Another contribution of the formative testing process was the exploration of new methods to present analytical derivations. These derivations were presented in earlier versions of the modules as one equation after the other always referring to a figure, very similarly to the way a textbook would present them. Formative testing evidenced the lack of added clarity in presenting these concepts and allowed for the exploration of methods such as the animation of equation components which attempt to show where each factor of the equations come from during the derivation process. The cases of the derivation of the expressions for the simple beam and the cantilever beam are another example of this attempt. These cases are discussed in sections 4.1.14.12 and 4.1.14.13.

The concept of internal forces was one that received a large amount of attention during the development stage and is among the sections that were most modified during this stage. This section started out as a purely analytical derivation where reference was made to an illustration presented on the screen next to the narrative content. The concept of internal forces was then introduced through text. The next version implemented the introduction of the internal force concept through an illustration of a beam sectioned into various parts. These parts used some animated components. The final version, discussed in sections 4.1.14.14 uses a sequence of analytical derivations, tabulation, and diagram construction, which ultimately leads the user to the simulated model discussed in section 4.1.14.15.

4.1.17 Review and testing

The modules were subjected to an assessment exercise from which their effectiveness is examined. The results of this summative evaluation are presented in Chapter 5.

4.2 Stereonet Module

The stereonet module is a teaching tool that covers a much more complex problem than that presented in the basic mechanics modules. This module was developed towards the end of the summative evaluation process undertaken for the basic mechanics modules, summarized in Chapter 5 of this thesis. This has allowed the developer to incorporate what has been learned in the evaluation process in the preparation of the stereonet module. It could be said then, that this module represents a refined result of this research project.

The module uses imagery as the principal learning concept. The geometric concepts presented in the module are difficult to understand for a student in a typical classroom environment because it involves analyses in three dimensions, making its instruction a near impossible task to do on the blackboard or paper. The implementation of three

dimensional models on the computer screen is the most important element of this module.

The module also used the methodology proposed by Shepherdson (2001). The following sections describe the topic, contents, and elements of the module in detail.

4.2.1 Definition of topic

The topic of the module is the use of stereographic projections for the evaluation of stability of wedges in jointed rock masses. The orientation of planes or lines in space can be represented by the intersection of the plane or line with the surface of a reference sphere through the center of which the plane or line passes. To communicate this information, a two-dimensional representation of the spherical projection is necessary. The module instructs how to construct these projections and how they can be used to analyze the stability of a rock wedge formed by two independent joint sets and a rock cut.

The module also introduces the necessary concepts to understand the stability analysis process explained in the module and then takes the student in a step-by-step demonstration of the methodology through a pre established example. This demonstration is aided by using three-dimensional models.

4.2.2 Audience

The target audience for the stereonet module is students enrolled in geotechnical engineering graduate courses and students taking advanced undergraduate courses in this area. Students enrolled in related fields of study, such as geology and engineering geology should also benefit from the use of the module.

4.2.3 Assumed prior knowledge of the audience

The user of the module should have basic knowledge of engineering geology notions. The student should understand elements such as joint sets in rock masses and some

basic notions of geometrical representation of joint sets. These aspects, combined with the geometrical representation of forces should be clear to students but they will be reinforced through the module. Mechanics concepts such as frictional resistance and loads should also be part of the student's previous knowledge. These concepts are utilized during the presentation of the methodology for stability analysis.

Although the topic of the module is the use of the stereographic projections for stability analysis of jointed rock masses, basic concepts such as the conventional methods of representation of joint sets orientation and the construction of the stereographic projections are included in the module. These concepts provide the fundamentals to understand the main topic.

4.2.4 Teaching context

The module can be used within two main teaching contexts; as an electronic blackboard during lecture instruction or as a supplemental tool to reinforce the in-class taught material. In both cases, the advantages that IT offers for the presentation of the topic are immense.

The implementation of three-dimensional graphics represents a large step forward in the instruction of the stereonet concept, proven to be difficult to present to students during lectures even with the use of a physical model. IT brings the possibility to generate three-dimensional representations of these models in a clear way so that students can be instructed on that material during class, and then, if necessary, reinforce that instruction with their own manipulation of the models in further reviews of the concepts. This is made possible by the availability of the tools through the World Wide Web (WWW) which goes hand in hand with the OpenCourseWare (OCW) initiative at MIT, providing a free and open educational resource for faculty, students, and self-learners around the world.

4.2.5 Engineering skills to reinforce and specific learning goals

The ultimate goal of the module is to teach students graphical methods for the evaluation of stability of rock wedges; this represents the main engineering skill to reinforce. To achieve this, the module sets some intermediate goals that help the student advance his/her knowledge from basic prior knowledge on the subject to the final goal. These intermediate steps represent the following specific learning goals.

- Representation and interpretation, using different conventions, of the orientation of a plane in space
- Understanding of the construction of equal angle and equal area stereographic projections
- Illustrate the connection between three-dimensional reality and a stereoplot
- Connect the idealization of wedge stability problems with real-life situations and highlight the importance of the methodology being introduced and its application by showing real stability problems
- Predict the different kinematically possible conditions of movement of a rock wedge for any possible orientation of the resulting force acting on it
- Predict the kinetic stability of a rock wedge

4.2.6 Discovery path for learning

The module has been developed following a narrative format. The content of the module is divided into five sections, each section covering a main topic. Each topic (submodule or section) builds on what has been presented in the preceding one. The student is presented in the first section with an introduction to the problem which sets the stage for the methodology explained in the following four sections. The main resources used in this module are three-dimensional models. Each of these models can be manipulated by

the students; rotated, zoomed in and out; some of them are capable of interactive functions.

The stereonet module represents an evolution with respect to its predecessors, the basic solid mechanics modules. The different submodules or sections allow students to come back and start where they left off in previous sessions or, for more advanced students, to skip some already known concepts and jump directly into the desired topics.

4.2.7 Knowledge map

The knowledge map contains the main concepts to be presented to the student. This map is shown in Figure 4.46 where the main topics shown on the left coincide with the five sections of the module. Each concept on the right is then presented to the student in its corresponding section.

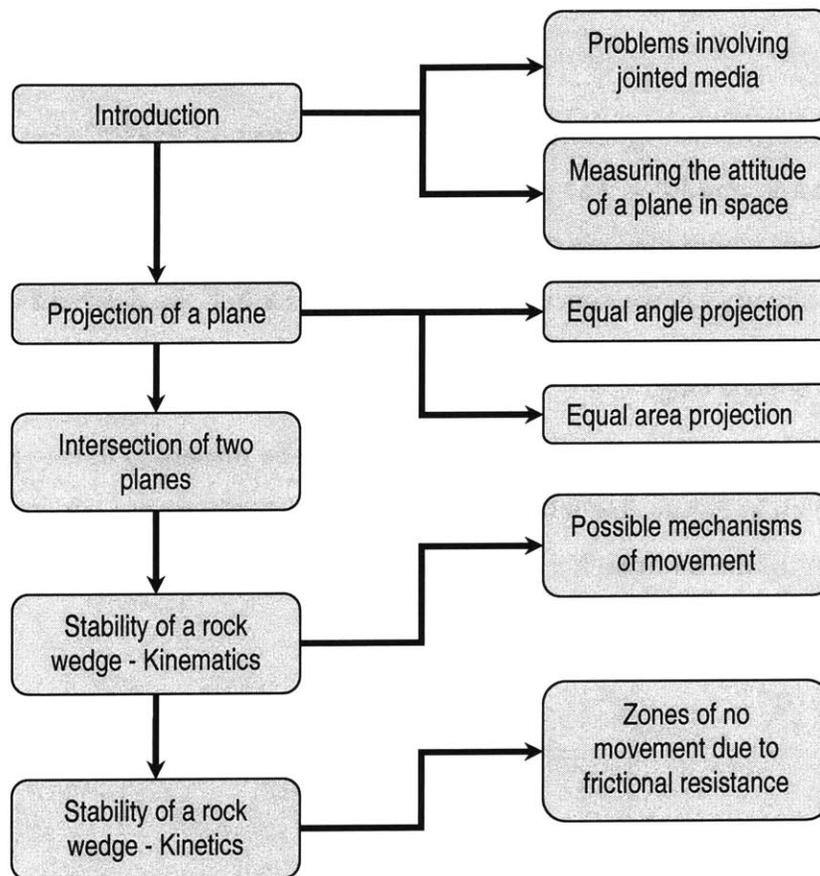


Figure 4.46 Knowledge map specific to the stereonet module

4.2.8 Technology used

Similar to the basic solid mechanics modules, the stereonet module was developed using the Macromedia Director (Macromedia, 2001) platform and is deployed in the WWW as a Shockwave (Macromedia, 2004) movie, available to the public in general. This format was chosen for the same reasons explained in section 4.1.9 and, particularly in this module, for its capability to incorporate three-dimensional graphics through the 3D Shockwave Technology built into Macromedia Director.

The size of the module is 4.8 MB. This file should download in nearly 11 minutes using a 56 Kb modem and in around 4 minutes when a DSL connection is used². Again, the speed of the connections found in educational institutions should yield a download time of less than 20 seconds. Once the initial download has been completed, the movie plays without interruption for the rest of the session.

Through Shockwave 3D and Lingo, the built-in object oriented programming language, Macromedia's Director is able to control the display of three-dimensional graphics generated with a third-party computer program. The program used in this project for the generation of these graphics was AutoDesk's 3dsMax. Director is also capable to generate basic shapes in a three-dimensional domain, allowing one to implement interactive features in such graphics through Lingo. However, this feature is somewhat constrained due to the limited amount of shapes handled by Macromedia. The stereonet module makes use of this capability as will be described in the following sections.

4.2.9 Interactive exercises

All interactive elements implemented in the stereonet module are explained in detail in section 4.2.13. Through the use of three-dimensional graphics, the module is capable to facilitate the visualization of complex three-dimensional arrangements and interactions. The user is given the possibility to rotate in space and zoom in and out all models. Some of the models allow some interactivity in the sense that the graphics react to student input such as changes in the parameters for the orientation of a plane in space. This implementation is constrained by the limited control that Director has over the three-dimensional shapes composing the graphics.

4.2.10 Control path through module

As mentioned before, the content of the module has been divided into five sections, represented by five tabs in the graphical user interface. The control path chosen for each

² Source: www.onlineconversion.com

section is a single path through it, where the last screen of one section connects to the first screen of the next. The module does not contain any multiple choice questions or additional information to be displayed at the user request, i.e. the entire content of the module is accessed by simply advancing through the sections. However, the user is given the possibility to access each section at any time during the navigation through the module by clicking on its corresponding tab. When the user clicks on a tab, the first screen of the corresponding section is displayed. Backward navigation is allowed within each section. When a user attempts to move backward from the beginning of a section, the user is then taken to the beginning of the preceding section, as opposed as being moved to its end. This scheme is shown in Figure 4.47.

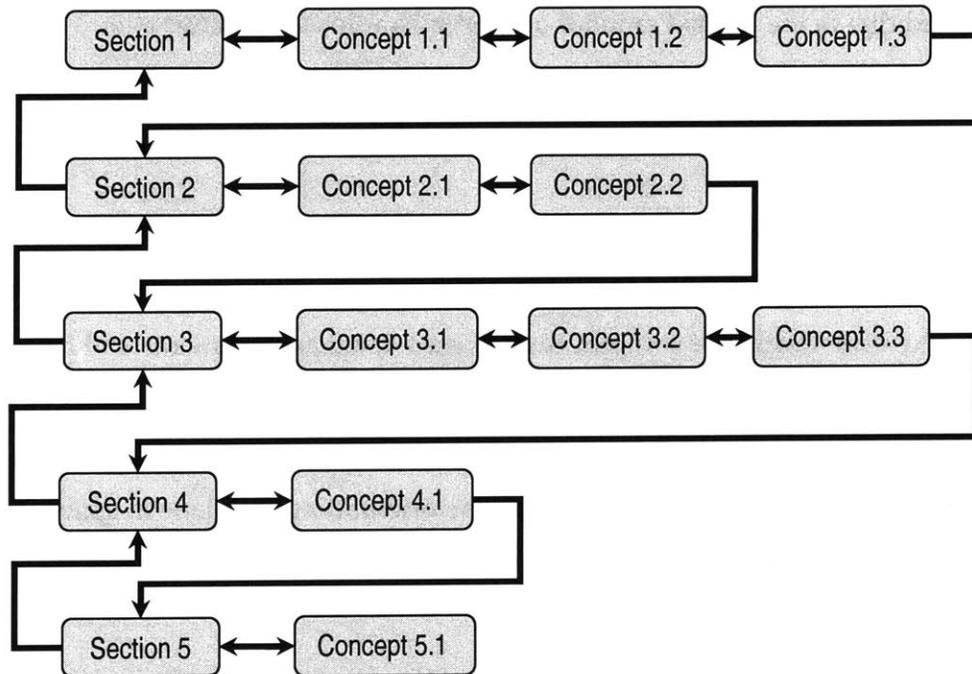


Figure 4.47 Control path for stereonet module

4.2.11 Graphical user interface and navigation controls

The graphical user interface (GUI) of the stereonet module is shown in Figure 4.48. The lower section of the interface contains the tabs that provide access to the different sections of the module. By clicking on the tabs, the user gains access to the corresponding section. The first three sections of the module present a split-screen design, where the right side of the interface is used to display the text, two-dimensional graphics, and the navigation controls, while the left side is used for the display of the three-dimensional models and their control elements. This configuration is shown in Figure 4.48.

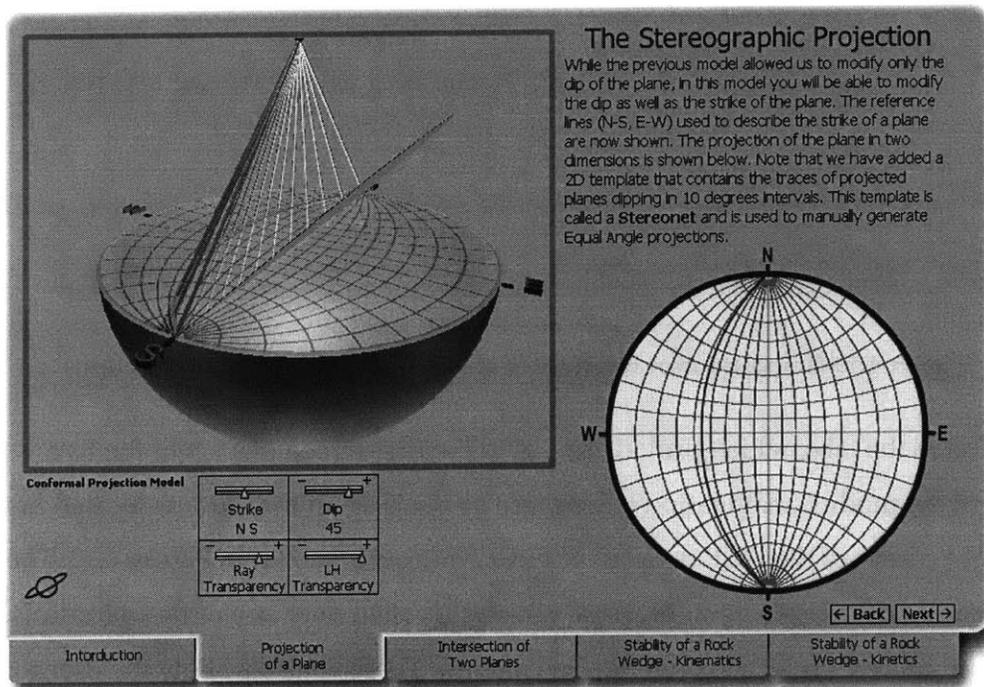


Figure 4.48 Graphical user interface of stereonet module – initial sections

Figure 4.49 shows the GUI for the last two sections of the module, where the screen is now divided into four main sections; the upper left section contains a three-dimensional model of the slope-wedge arrangement, the lower left section contains text. The upper right section contains the three-dimensional representation of the reference sphere and

its controls and the lower right section contains the resulting stereoplots and the navigation controls.

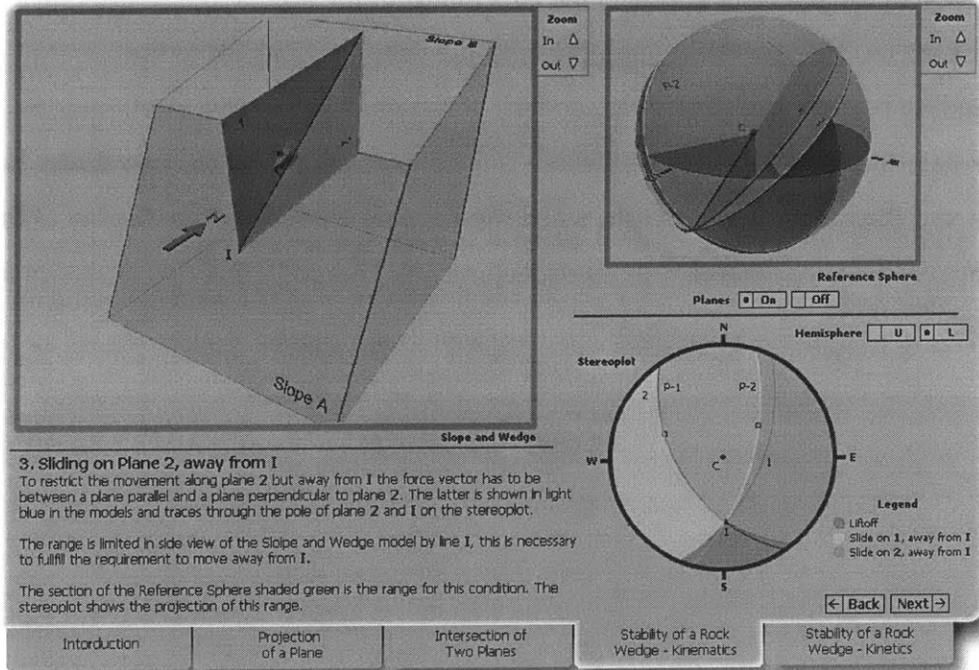


Figure 4.49 Graphical user interface of stereonet module - last two sections

In addition to the tabs, which provide access to the first screen of each of the five sections of the module, navigation takes place by clicking on the buttons located in the lower right corner of the GUI. A detail of these controls is shown in Figure 4.50. The mouse pointer changes to a finger shape when it is rolled over any of these controls. The color of the control under the pointer also changes. These controls allow the user to advance to the next screen or to move backwards to the previous screen within a section. When the “Back” button is pressed on the first screen of a section, the user is taken to the first screen of the previous section.



Figure 4.50 Stereonet module navigation controls

4.2.12 Storyboard

The storyboard of the stereonet module is shown in Figure 4.51. Analogously to what was discussed in the case of the basic solid mechanics modules, it should match the knowledge map of the module, presented in Figure 4.46. The storyboard shows each section of the module as a box in the figure. Each box outlines the components of each section.

Section 4.2.13 will explain in detail each of the three-dimensional models and interactive elements included in the modules.

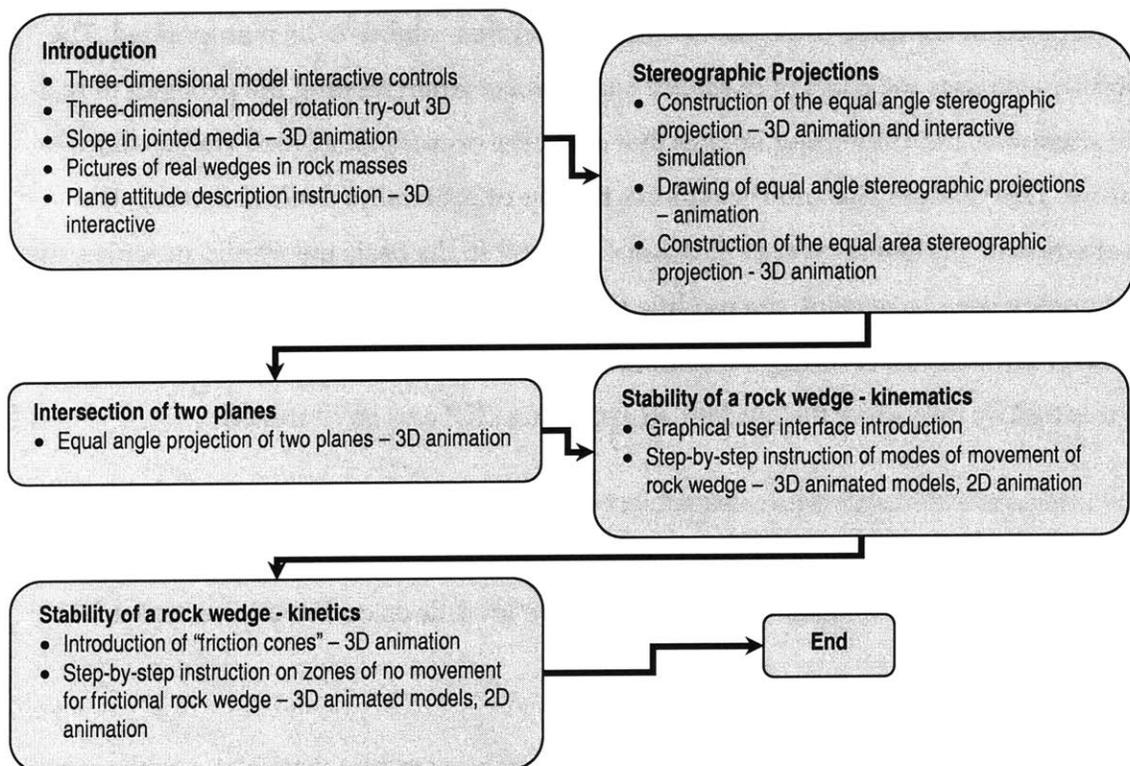


Figure 4.51 Stereonet module storyboard

4.2.13 Interactive elements

As was mentioned before, the principal learning concept utilized in the stereonet module is imagery. This is well represented by the implementation of three-dimensional models that allow the visualization of concepts. All interactive elements in the module involve the use of a three-dimensional model that the student can manipulate by rotating the view point around it or by zooming in and out. Some of these models implement some additional interactivity. In these cases, the user can modify different parameters through controls provided in the GUI and observe the resulting changes in the three-dimensional model.

The most important learning concept associated to the stereonet module is *imagery* represented in the three-dimensional models and their ability to be manipulated. The module also uses the concept of *context and situation* when relating the problem to real-life situations and presenting images that show the occurrence of rock wedge slides in nature. This module also briefly explores the use of *informative feedback* through the evaluation of student answer evaluation. Similarly to the basic mechanics modules, the technology used to develop the module implies the use of the learning concept of *mastery*. The *motivation* concept is also one that was considered during the development of this tool by providing the student an appealing GUI and environment.

The interactive elements were also subject to formative evaluation in an iterative process of testing and improvement during their development. The following subsections will present each of the elements implemented in the module as outlined in section 4.2.12.

4.2.13.1 Slope in jointed media

The slope in jointed media is the first three-dimensional model that relates to the subject of the module. When the user reaches this point in the module, he/she has been instructed on how to rotate and zoom in and out three-dimensional models. This is done

through the manipulation of a model that contains an easily recognizable object, along with instructions on how to perform these functions.

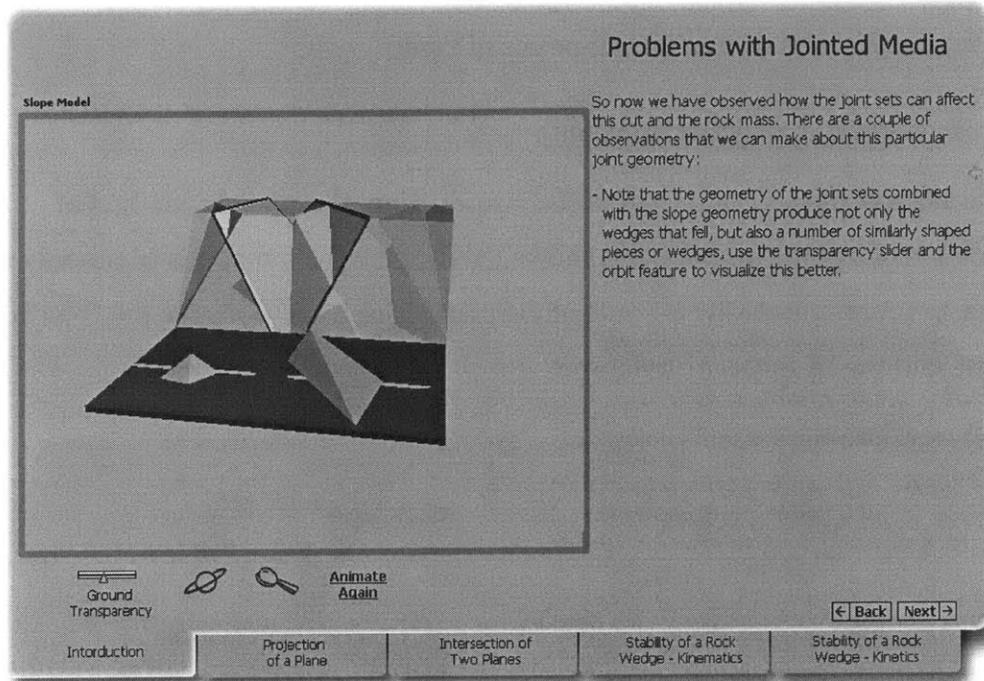


Figure 4.52 Stereonet module - Slope in jointed media model

The slope in jointed media model serves as an introduction to the subject. It illustrates the effect that joint sets can have on a road cut. It does this by presenting an animated three-dimensional model that gradually introduces each of the components of the problem, while permitting the user to modify the transparency of the material that represents the rock surface to visualize the joint system arrangement within the rock mass. A screen shot of this animation is shown in Figure 4.52 where a road cut in a rock mass dissected by two joint sets is shown. The effect of the two sets is illustrated by the animation of the sliding of two blocks towards the road. These blocks are depicted in the figure. The model presents three controls, indicated at its bottom; a slider bar that allows the user to set the transparency of the material representing the rock surface, the orbit icon which indicates that the user can orbit around the model by using the mouse, and

the zooming icon, which tells the user that zooming is possible by using the up- and down- arrow keys on the computer keyboard. The model also offers the option to the user to run the animation of the block sliding again, allowing him/her to repeatedly observe this mechanism from different points of view.

4.2.13.2 Plane attitude description instruction

The plane attitude model is also part of the introduction. It explains a method of representation of a plane in space and shows the user the two notations commonly used in practice to communicate the attitude of the plane. These notations are the “North American” and the “European” notations.

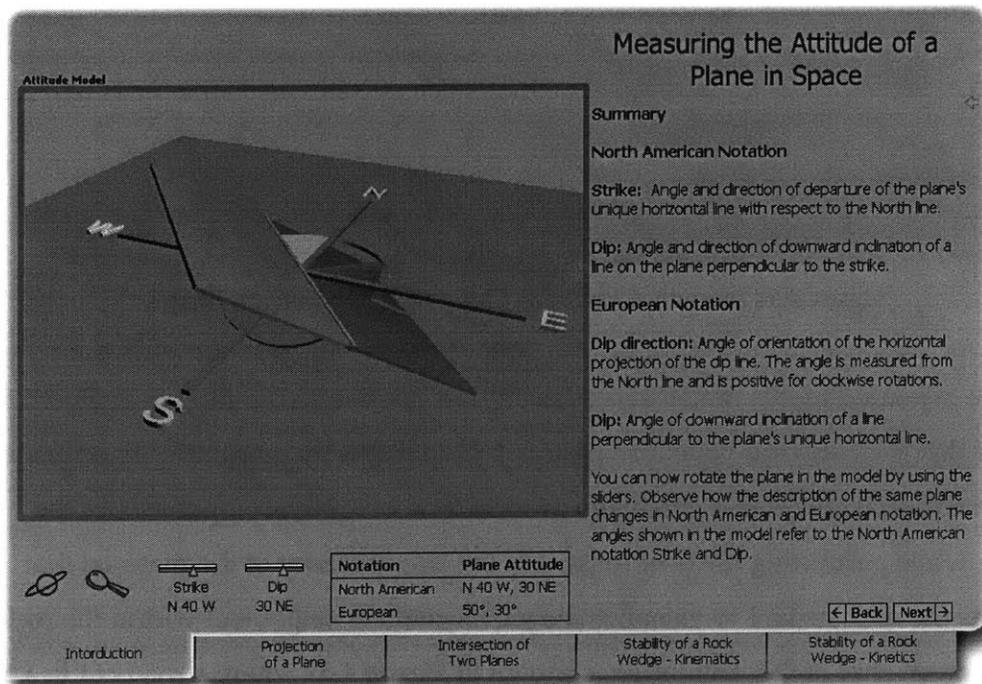


Figure 4.53 Stereonet module - Plane attitude

The model is shown in Figure 4.53 and consists of a plane oriented in space to which the strike and dip lines are gradually added while the concept of the notations is explained through the text on the right side of the screen.

The plane attitude model is presented with four controls, as seen in the figure. The two icons indicate the orbit and zooming options which have been explained before. The two slider bars control the strike and the dip of the plane shown in the model. When these controls are operated the orientation of the plane changes accordingly. The module then updates in real time the respective descriptions of the attitude of the plane in the two notations. These are shown in the small table located in the lower right corner of the model.

This section also provides an interactive application in which the plane is presented in a new random orientation. The student is then expected to denote the attitude of the plane in the two notations just presented. Special input fields are used in the application for the student's input. The student's answer is submitted by clicking on a hyperlink. It is then evaluated by the application which provides specific feedback to the student, detailing what components of the attitude notations, if any, have been incorrectly stated. Once the answer is submitted, the student is given the opportunity to try a different plane attitude. If this option is chosen, the plane randomly changes orientation and the correct notation is covered again in the case the student had uncovered it.

4.2.13.3 Construction of the equal angle stereographic projection

The instruction of the construction of stereographic projections marks the beginning of the second section of the module. In this section two types of projections are introduced; the equal angle stereographic projection and the equal area stereographic projection. These two types of projection are commonly used in engineering geology for the description of joint set attitude.

The module focuses on the instruction of the equal angle stereographic projection, since it is the projection used for the graphical method of stability analysis. The equal area stereographic projection is treated to a lesser extent.

Figure 4.54 shows the model used to illustrate the construction of the equal angle projection. This model shows a plane in space, represented by a disc fit into the lower hemisphere of a reference sphere. The projection is then constructed by projecting points along the plane-sphere intersection up towards the upper pole of the sphere. The model features the orbit option and two slider bars that control the dip of the plane and the transparency of the lower hemisphere for better visualization. The user can then observe in real time how the projection, indicated by an arc on the horizontal plane, changes according to changes in the dip of the plane. This feature is powered by a simulation that uses the dip angle as the only input parameter and then calculates the properties of the circular arc representing the projection. The derivation of the equations along with the Lingo code associated with this simulation is presented in Appendix A as reference to the reader.

Once the concept of the projection has been introduced, the module uses a second model where the user is now introduced to the stereonet. This model is similar to the one described before, with the addition of a picture of the stereonet in the horizontal plane and two new controls; a slider bar that controls the strike of the plane, and a slider bar to control the transparency of the rays used to show the projection of the plane-hemisphere intersection towards the upper pole of the reference sphere. Figure 4.55 shows a screen shot of the module containing this model. The figure also shows a two-dimensional representation of the stereonet and the projection of the plane contained in the model. It is here where the use of the stereonet is introduced to the user and the connection between the three-dimensional model and the two-dimensional representation is made.

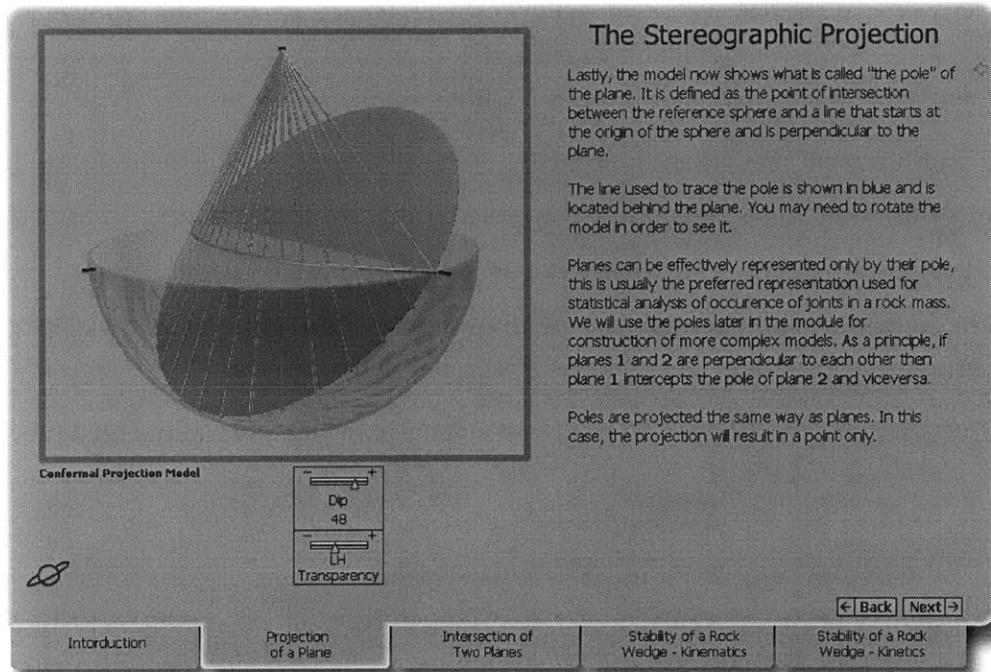


Figure 4.54 Stereonet module - Equal angle stereographic projection construction

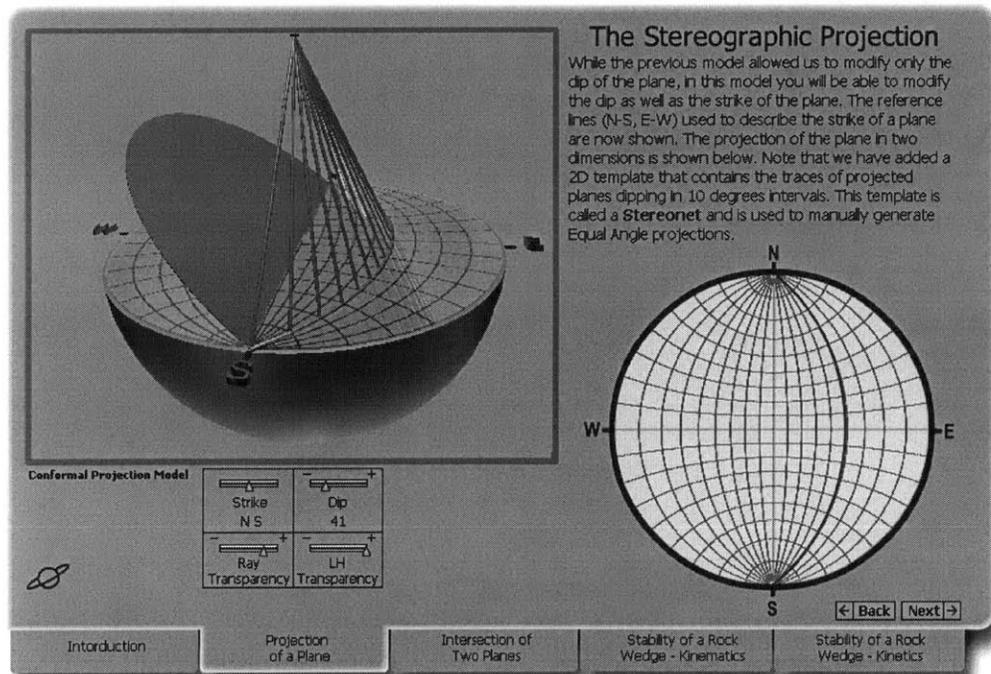


Figure 4.55 Stereonet module - Equal angle projection with stereonet

4.2.13.4 Drawing of equal angle stereographic projections

Once the user has been presented the concept of the stereonet and the meaning of the several arcs presented in it, the module continues with a short instruction on how to draw the projection of planes the orientation of which is known. This presentation is depicted in Figure 4.56. The animations are used to rotate the stereonet over a stereoplot. The corresponding arc is then drawn on the stereoplot. The animation sequence resembles the actual procedure to be followed when preparing stereoplots on a piece of paper.

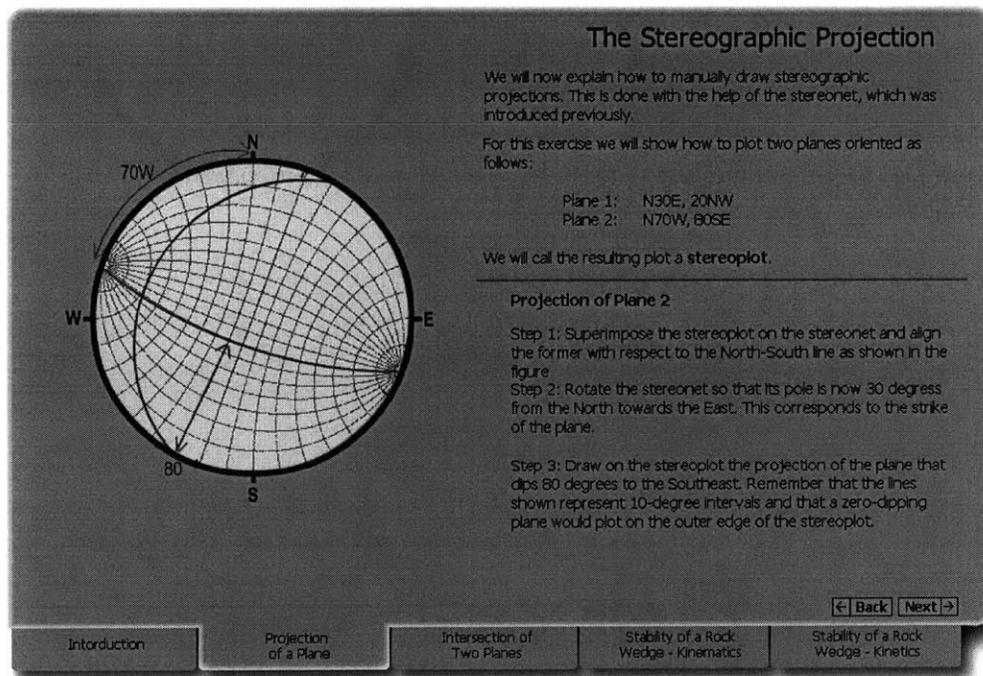


Figure 4.56 Stereonet module - stereonet use

4.2.13.5 Construction of the equal area stereographic projection

Although the equal area stereographic projection is used for applications in rock mechanics not covered by this module (such as joint attitude statistics), its principle is

explained in the module through a three-dimensional model. This model is shown in Figure 4.57. It provides only two controls; orbiting and zooming. The procedure of construction of the equal area stereographic projection is explained in a step-by-step presentation where the model is first shown containing the plane fit into a reference sphere, similarly to the equal angle stereographic projection construction. Then the necessary elements are added to explain how this projection is constructed through the narrative presented on the right side of the screen.

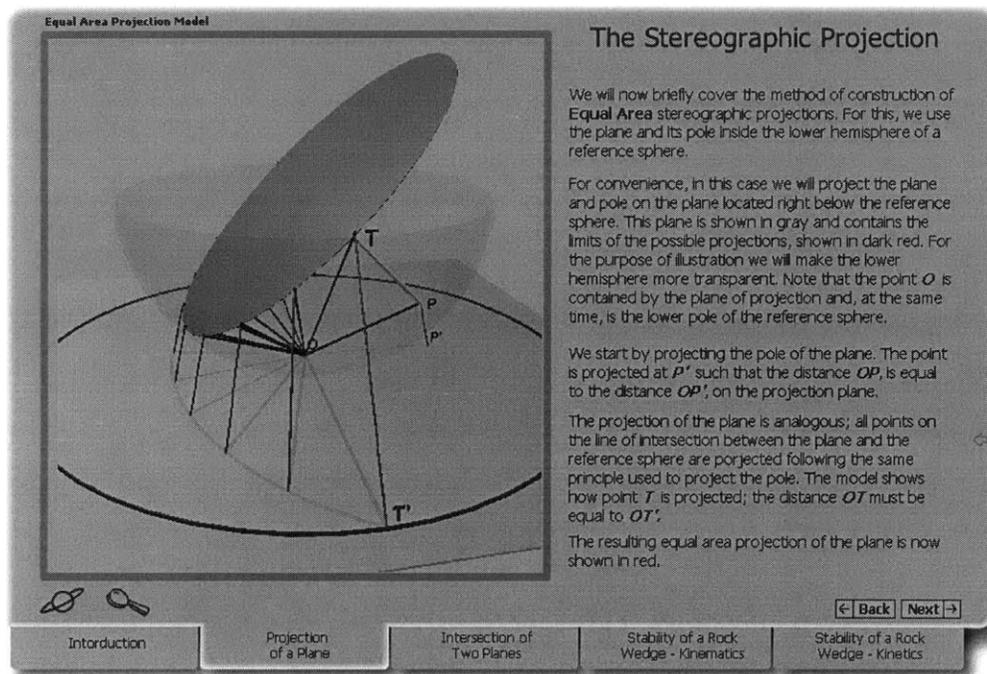


Figure 4.57 Stereonet module - Equal area stereographic projection

4.2.13.6 Equal angle projection of two planes

The third main section of the module illustrates the projection of two planes and the meaning of the resulting stereoplot. For this, the model shown in Figure 4.58 is used. This model presents in detail the construction of the stereoplot of two planes with different orientations through an animation. The final result yields the two planes fit in the reference sphere with the two projections. The point of intersection of the projections

is then highlighted and its meaning is explained. This concept is needed for the instruction of the stability analysis of a wedge formed by two joints which is presented in the last two sections of the module.

The model provides three controls; orbiting, zooming, and a slider bar that controls the transparency of the lower hemisphere of the reference sphere for better visualization.

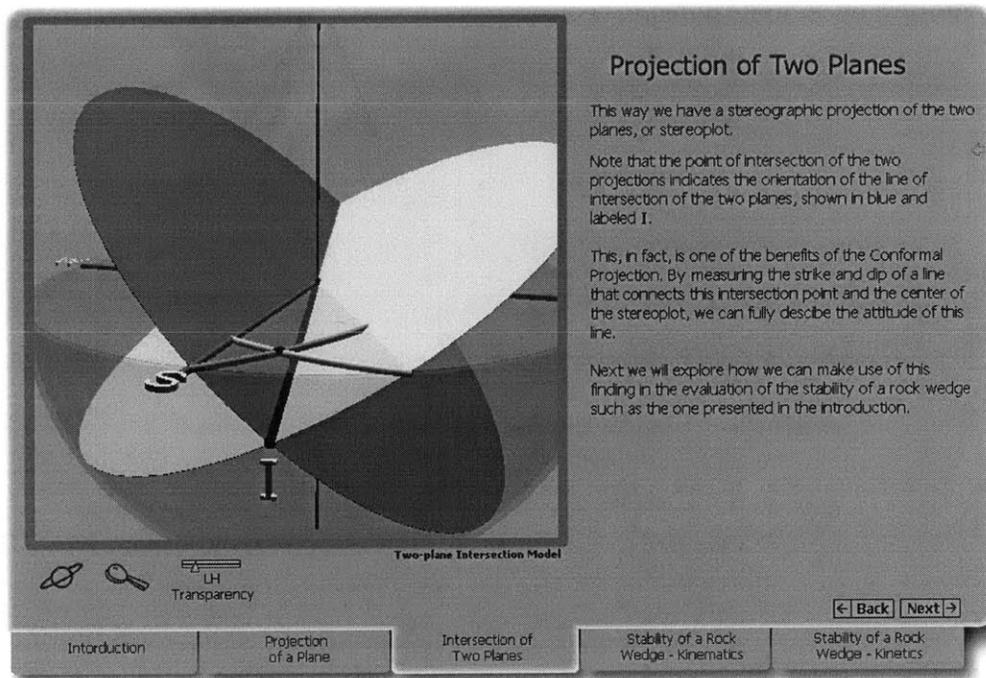


Figure 4.58 Stereonet module - Projection of two planes

4.2.13.7 Step-by-step instruction of modes of movement of rock wedge

The fourth section of the module integrates what has been presented in the previous three sections. Specifically, the user is taken through a step-by-step explanation on how to construct a stereoplot where the zones corresponding to different modes of movements in a rock wedge are delineated. This explanation is rather complex and uses two three-dimensional models with their corresponding stereoplot. The arrangement of the models on the screen is shown in Figure 4.59. The model located on the upper left

portion of the screen represents the three-dimensional model of a wedge in its real-world form. This model is continuously updated with the addition of vector forces used during the illustration of the problem. This model allows orbiting around it and zooming in and out. The zoom control is now located in the upper right corner of the model.

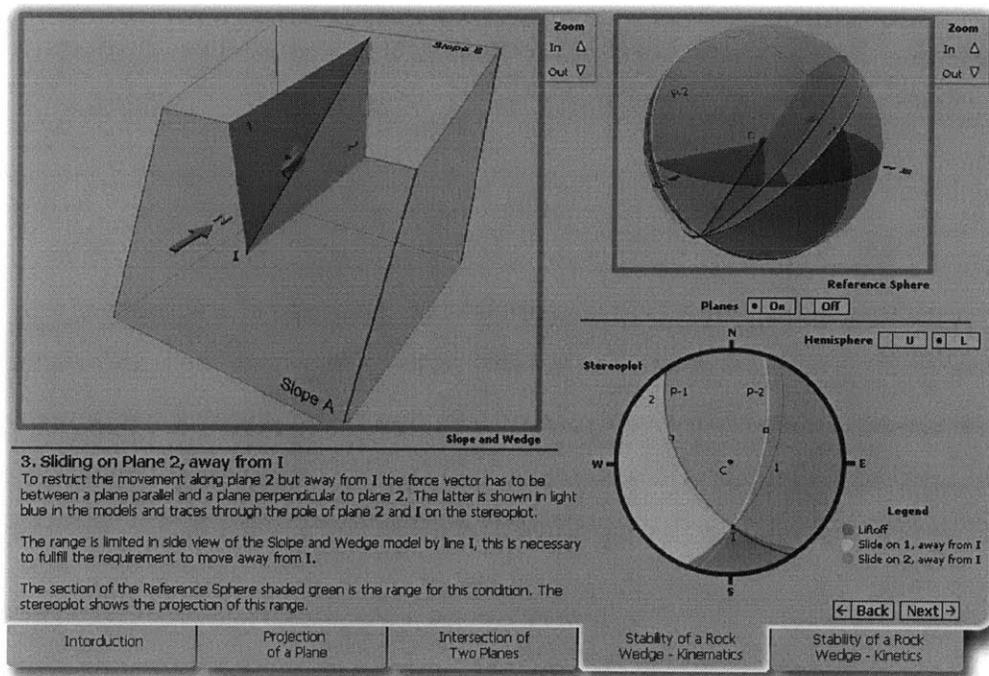


Figure 4.59 Stereonet module - Kinematic analysis

The second model, located on the upper right of the screen is the representation of the reference sphere used in the analysis. The nature of the illustration will cause this model to become somewhat overcrowded by planes. The control buttons located underneath the model allow one to remove such planes for better visualization. In this case, only the traces of the planes on the shell of the reference sphere will be shown. The model also allows one to orbit and zoom through a control located on the upper right corner of the model.

Lastly, the stereoplot is shown on the lower right portion of the screen. This stereoplot shows the traces of all planes used in defining zones, which are then colored for identification. Each zone corresponds to a particular mode of movement of the wedge. A legend is included to the right of the stereoplot for identification of these modes. The module is capable of plotting the upper hemisphere stereoplot or the lower hemisphere stereoplot. The control buttons provided above the stereoplot are used to switch between one and the other. The lower left section of the screen presents the narrative, where the method of construction of the stereoplot is explained.

4.2.13.8 Introduction of "friction cones"

The fifth and last section of the module covers the kinetic stability analysis where frictional resistance in the joint surfaces is considered. This type of resistance is represented, in the graphical method of stability analysis, as a cone the apex of which coincides with the centroid of the wedge. Any resulting vector oriented within the volume of the cone will not cause movement on the wedge due to the frictional resistance generated by the two surfaces in contact. The angle of the cone apex is equal to twice the angle of friction along the joint surfaces.

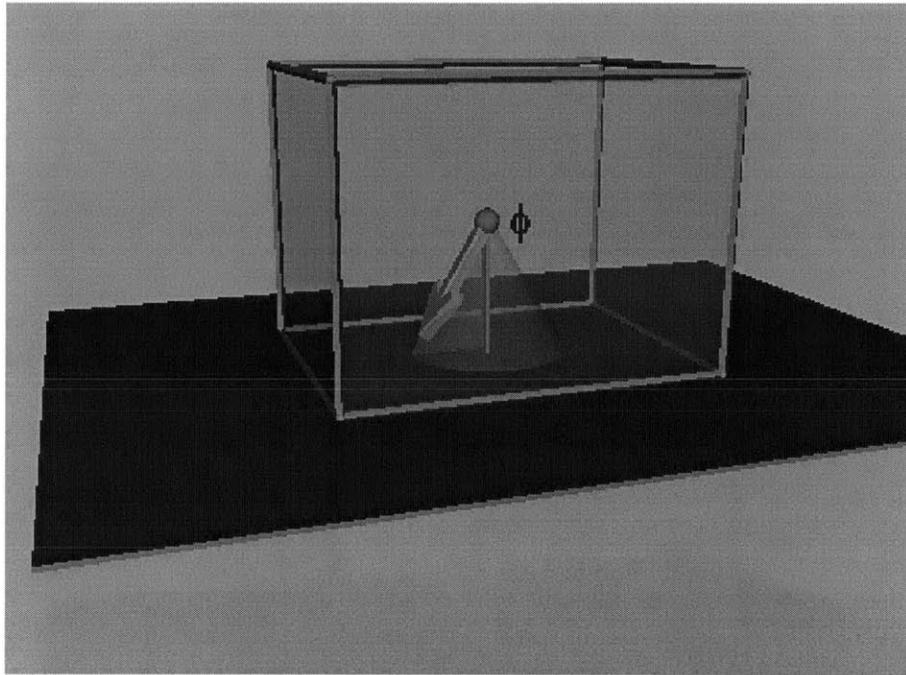


Figure 4.60 Stereonet module - Friction cone

The model used to explain the concept of the friction cone is shown in Figure 4.60. It does so by animation. This model can not be orbited or zoomed in or out. It explains the concept by representing the friction cone of a box lying on a horizontal surface with a friction angle ϕ .

4.2.13.9 Step-by-step instruction on zones of no movement for frictional rock wedge

After the introduction of the frictional resistance representation, the module displays the same models utilized in the fourth section and continues with the instruction by introducing the frictional resistance of the joint sets into the analysis. The result for the stability analysis of the rock wedge and the stereoplots for the possible modes of movement of the wedge are now complete with the incorporation of this resistance. Figure 4.61 shows the final result where the cones have been drawn in the reference sphere and the stereoplot shows zones for all types of movements (and no movement).

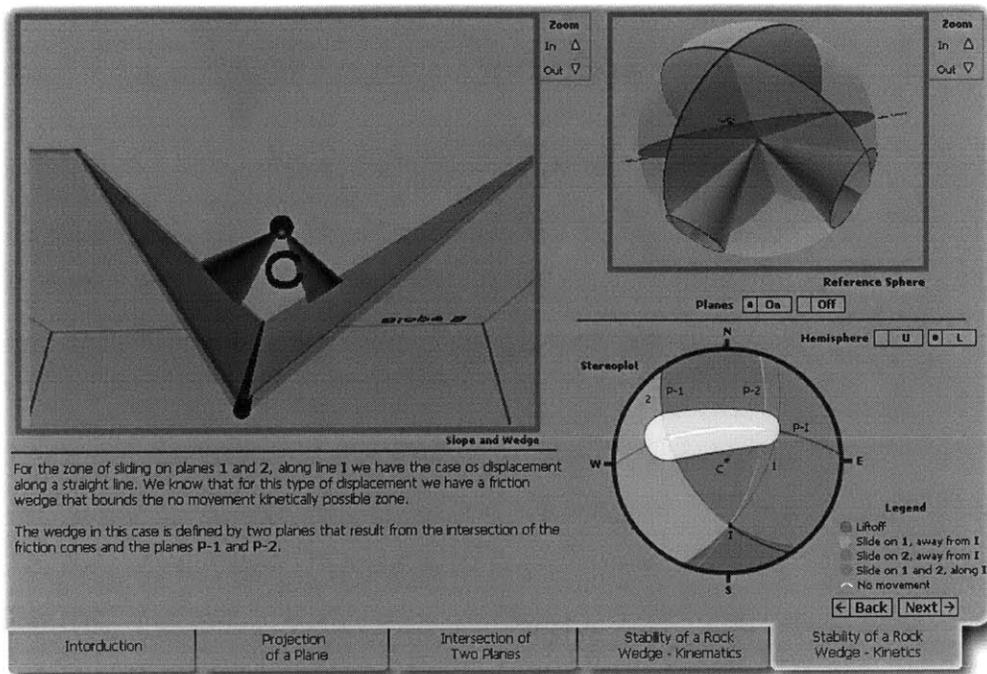


Figure 4.61 Stereonet module – Kinetics

4.2.14 Framework connecting exercises

The framework that connects all interactive exercises is built into the organization of the module itself. Each section accessed by the click of a tab at the bottom of the screen will lead to an independent section of the module; each section uses the knowledge presented in the preceding one and provides a brief introduction at the beginning. This introduction serves as a summary of the concepts covered by the preceding sections. At the same time, it should indicate to the user what is the necessary knowledge required to advance through a section. This is applicable to cases where the user has skipped the review of one or more sections.

The implementation of tabs should also allow the user to move between the sections in case it is necessary to review a concept; this arrangement gives the user freedom to navigate at his/her convenience for a better understanding of the material.

4.2.15 Formative Testing

The stereonet module was submitted to a basic formative evaluation process during its development. This process, however, was not as extensive as the testing performed to the basic mechanics modules. It focused on the assessment of the content covered by the modules and the improvement of model visualization controls and navigation controls. The narrative of the module was also reviewed.

One of the observations made during the final stages of development of the mechanics modules was the lack of navigational controls such as menus or tabs that allowed the user to move among the main sections within a module. This feature was included in the stereonet module and is considered a contribution of the formative testing process conducted in this research project.

The assessment of the content of the module conducted during formative testing resulted in the addition of the plane attitude description, discussed in section 4.2.13.2. This section had not been implemented in the first versions of the module. Its addition represents an important element that assures the completeness of the module. The interactive exercise included in this section was also one of the latest additions to the module resulting from the testing process.

4.2.16 Review and testing

A summative evaluation of the stereonet module was not performed under the scope of this project. Although the general perception is that the module will be a very successful tool available to students and instructors everywhere it remains to be proven in a class application evaluation such as the one undertaken for the solid mechanics modules (see Chapter 5, section 5.2). Its application in courses after the publication of this research project is almost guaranteed and should yield interesting results.

Chapter 5 Assessment of Teaching Tools

The assessment of the developed teaching tools is an essential component of this research. This assessment or evaluation requires the measurement and documentation of student performance and reactions when they used the tools. Moreover, when these data are compared to performance of students instructed in a conventional manner, conclusions can be drawn about the improvement in student education achieved by the proposed tools.

The evaluation of the tools is performed in two different stages; formative testing and summative evaluation. Formative testing typically involves gathering information during the early stages of development of the tools, with a focus on finding out whether the efforts are unfolding as planned, uncovering any obstacles, barriers or weaknesses in the content and presentation of the concepts. Formative testing was undertaken during the development of the teaching tools presented in this research project (see sections 4.1.16 and 4.2.15). This process also allowed one to compare different paths for the presentation, better explanation of concepts covered by the modules, and the improvement of their navigational controls. IT also allowed one to compare different types of solutions to different types of problems, yielding what is thought to be an overall solution close to the optimum, which is represented in the content of the modules.

The summative evaluation process involves the preparation of an evaluation program, its application, and a corresponding report that outlines the impact of the tools being evaluated. The following paragraphs will focus on the preparation and application of these evaluation programs as part of a summative evaluation process.

The research community has developed a variety of definitions, standards, and criteria to ensure that collection and analysis of data that result from a summative evaluation program in educational research are of good quality. These developments have resulted in principles that ensure that research instruments, methods, and procedures yield findings that can be validly interpreted. The application of these principles yield what is known in education as a “research design” which is defined as a procedure that produces data to support inferences. The strength of a research design revolves around the extent to which the study rules out alternative explanations of the study’s outcomes.

Section 5.1 of this chapter presents, for the benefit of the reader, the important aspects of different research designs used in educational research. The sources used for this Section were Campbell & Stanley (1963), Wiersma (2000), Redfield & Sivin-Kachala (2003), and Cook and Campbell (1990). Section 5.2 describes the evaluation procedure followed for the assessment of the proposed mechanics modules, while Section 5.3 presents the results of this assessment.

5.1 Summary on Research Designs

The nature of the research design depends on a number of factors, including the goals of the research, the extent to which the study is part of a larger body of research, and the conclusions that the researchers or developers want to make on the basis of the research data. Experimental and quasi-experimental designs are the most widely used designs when the demonstration of cause and effect relationships is needed. However, there are other non-experimental approaches such as surveys, ethnographic research, and case studies that are appropriate or even better suited to addressing certain research questions. Terms such as pretest and posttest may be used to fully describe designs,

especially experimental designs. Pretest refers to a measure or test given to the subjects prior to the experimental treatment. A posttest is a measure taken after the experimental treatment has been applied.

Following is a brief overview of these several designs.

5.1.1 Experimental and quasi-experimental designs

The characteristic of both experimental and quasi-experimental designs is that they employ experimental and comparison groups. An experimental group is a group in a research study that receives the “treatment” or intervention under investigation. In order to determine whether or not there is an experimental effect, experiments and quasi-experiments require a basis for comparison. This comparison is made through the use of comparison groups, which are groups that receive a different kind of treatment than the one being investigated. Sometimes a special type of comparison group is used, called a control group, (i.e., a group that does not receive an experimental treatment). In education, a control group usually consists of a group of students taught by a traditional method rather than by the “experimental” method. While experimental and quasi-experimental designs must include at least one comparison group, they may or may not include a control group.

The main difference between experiments and quasi-experiments is that in experiments, study participants are randomly selected from the population to participate in a study and then, once they are selected, they could also be randomly assigned to experimental or comparison groups within the study. Quasi-experiments do not employ random selection or random assignment. Random selection follows a specified procedure using a Table of Random Numbers or a computer program for this purpose.

Random assignment also refers to the use of a Random Numbers Table or computer program to assign members of the sample, whether randomly selected or not, to experimental or comparison groups. The process of random assignment helps ensure

that any differences between the experimental and comparison groups, before the start of the experiment, are due to chance alone (i.e., due to random sampling fluctuations). In theory, if the number of participants is sufficiently large, the random assignment of participants to groups will “even out” preexisting differences. This allows one to attribute measured differences in outcomes (following the intervention) to the treatment itself.

Random selection adds to the generalizability of the results of a study to other students, locations, or circumstances that were not involved in the study. Random assignment helps to control factors besides the experimental treatment that can influence the results of a study. When both random selection and random assignment are not feasible, researchers must determine which is more important to the claims they want to be able to make on the basis of the results. When neither random selection nor assignment can be achieved, then quasi-experiments are the next best designs for accumulating evidence in support of a claim regarding cause and effect.

5.1.1.1 Experimental designs

The basic experimental design requires the random selection of study participants and/or the random assignment of participants to experimental and comparison groups (Campbell & Stanley, 1963). There are several variations of what Campbell and Stanley call “true experiments,” but only the three most common designs (Wiersma, 2000, Redfield & Sivin-Kachala 2003) are presented here, : (1) the posttest-only control group design, (2) the pretest-posttest control group design, and (3) the Solomon four-group design . These three designs are relatively equal in terms of their ability to demonstrate causation. The ability to demonstrate causation is directly related to the extent to which an experiment rules out alternative explanations of cause by eliminating threats to validity. Threats to validity are discussed later in this chapter.

Posttest-only control group design

Experimental designs commonly involve two or more groups, one for the investigated treatment, others for any other types of treatment, and possibly a control group. The posttest-only control group design in its simplest form involves just two groups, the group that receives the experimental treatment and the control group. The subjects are randomly assigned to the two groups prior to the experiment, and the experimental group receives the experimental treatment. Upon the conclusion of the experimental period, the two groups are measured on the dependent variable under study. Preferably, this measurement is taken immediately after the conclusion of the experiment, especially if the dependent variable is likely to change with time.

Since random assignment of study participants to experimental and control groups theoretically “equalizes” the groups, pretesting is not a requirement of experimental designs. When random assignment is possible, the Posttest-Only Control Group Design can be both an economical and effective design. It is especially desirable when the researchers want to generalize to real-world populations that will not normally be pretested. Posttest-only designs also have an advantage in that the participants are not sensitized to the treatment, which may be important depending on the nature of the intervention.

The steps in conducting a posttest-only control group experimental design are as follows:

1. Based on theory or empirical observation, formulate a hypothesis about the cause for an observable phenomenon.
2. Randomly select a sample, representative of the population to which results will be generalized.

3. Randomly assign members of the selected sample to either an experimental group or a control group.
4. Apply the treatment intervention to the treatment group, being careful to plan and document the nature, specific elements, length, intensity, and context of the treatment. This will facilitate for replication.
5. Measure both the experimental and comparison groups. This measurement constitutes the posttest.
6. Analyze the results of the posttest measurement to determine the chances attributable to the treatment.

Pretest-posttest control group design

The addition of a pretest given prior to administering the experimental treatments essentially extends the posttest-only control group design. The subjects are randomly assigned to the two or more groups and tested just prior to the experiment.

The pretest score can be used as a control in the analysis. In this format it is desirable to analyze gain scores – the difference between the pretest and the posttest.

The steps in conducting a pretest-posttest control group experimental design are as follows:

1. Based on theory or empirical observation, formulate an hypothesis about the cause for an observable phenomenon.
2. Randomly select a sample, representative of the population to which results will be generalized.
3. Randomly assign members of the selected sample to either an experimental group or a control group.

4. Pretest both the experimental and comparison groups using a reliable and valid measure of the outcome variable.
5. Apply the treatment intervention to the treatment group, being careful to plan and document the nature, specific elements, length, intensity, and context of the treatment. This will facilitate for replication.
6. Measure both the experimental and comparison groups. This measurement constitutes the posttest.
7. Analyze the results of the posttest measurement to (1) verify that the groups scored similarly on the pretest measure, (2) determine whether they performed differently at the time of posttesting.

Solomon four-group design

Combining the pretest-posttest control group design and the posttest-only control group design in their simplest forms produces this design which includes two control and two experimental groups, with the experimental groups receiving the same experimental treatment. However, only one of each type of group is pretested, and all of four groups are posttested at the conclusion of the experimental period. The assignment of subjects to all groups is random. A graphical representation of this arrangement is shown in Figure 5.1.

The advantage of this design is that it enables to check on possible effects of pretesting. It is possible that pretesting affects the posttest score or that pretesting interacts with the experimental treatment.

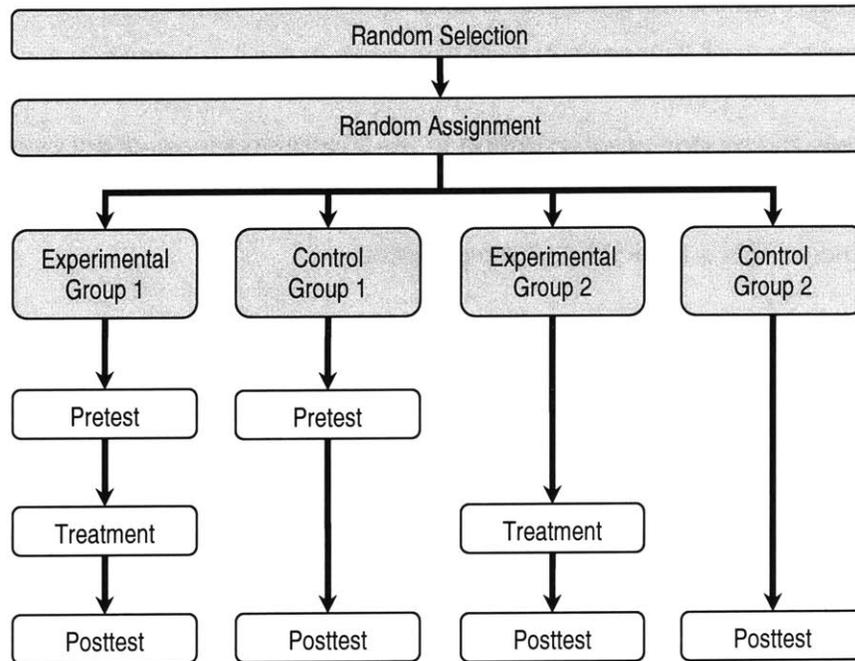


Figure 5.1 Solomon four-group design representation

5.1.1.2 Quasi-experimental designs

Due to the difficulties that can be encountered when conducting true experiments in real-world settings, quasi-experimental designs are often the designs of choice in educational and other social science research. However, because groups are not randomized in quasi-experimental studies, the groups are, by definition, nonequivalent from the beginning. Therefore, pretesting is more important in quasi-experiments than in experiments to help demonstrate that the experimental and comparison groups are initially similar. While researchers typically refer to eight to ten different quasi-experimental designs (Cook and Campbell, 1990, Wiersma, 2000), only two that have particular relevance for product effectiveness research in educational settings (Redfield & Sivin-Kachala 2003) are described.

Untreated control group design with pretest and posttest.

This design is one of the most frequently used designs in all of social science research, including educational research. It appears to be the same as the Pretest-Posttest Control Group Design discussed under experimental designs, except that the groups are not randomly formed. While there is no substitute for randomization, pretesting can help document that the experimental and comparison groups do not initially differ on the variable that is expected to be affected as a result of the treatment intervention. Pretest scores can also be used for statistical control, and in some cases gain scores or improvements can be generated when the value of a variable is expected to increase due to the treatment intervention. This gain is calculated as the value after treatment minus the value before treatment.

Time series designs

Time series designs are used with one or more intact groups that have been previously formed. Since there is no random selection of the evaluation participants, this type of design is a quasi-experiment. The design involves repeated measurement with the treatment inserted between at least one of the measurements for at least one of the groups. This type of design is useful for situations that require the evaluation of a variable that may change over time such as the student's performance in statistically equivalent tests. The implementation of this type of test in this case would lead to conclusions about how much a student "forgets" between testing sessions and would lead to conclusions about the benefits obtained from the treatment received when a comparison is made between results of students from the control and treatment groups.

Other, more complex variations of the design, which under relevant circumstances can further protect against threats to validity, are detailed by Cook and Campbell (1990).

5.1.1.3 *Threats to the validity of experiments and quasiexperiments*

Experiments and quasi-experiments are specifically designed to control as many threats to the validity of a study as possible. Experiments are the gold standard for demonstrating cause-and-effect relationships between independent (causal) and dependent (outcome) variables.

The validity of the procedures employed in experiments and quasiexperiments is controlled from two perspectives: (1) internal validity and (2) external validity.

Internal Validity

Internal validity refers to the extent to which the results of an experiment or quasi-experiment can be interpreted with confidence and how certain they are to exclude alternative explanations for the study's outcome. This is critical to demonstrating cause-and-effect relationships.

When threats to internal validity cannot be, or are not, controlled, the internal validity of a study is compromised. However, since it is not always possible to eliminate all threats to internal validity, researchers must determine which threats are the most critical to the purpose of a particular study. The randomized experiment is the best case scenario for controlling threats to internal validity. The following paragraphs describe common threats to the internal validity of experiments and quasi-experiments and offer tips for overcoming them. These threats, as detailed by Campbell and Stanley (1963) and Cook and Campbell (1990), include the following: history, maturation, testing, instrumentation, statistical regression, selection, mortality, and interaction effects.

History. History refers to all events, other than the treatment itself, which may impact the study participants, their responses to the treatment, or the outcome measures.

History may occur during the course of the treatment intervention or at the time(s) when the treatment effects are being measured. For example, a teacher being replaced or a disruptive student, are all historical events that could have impacted students and their

responses to a particular treatment or measurement that was under way when the event occurred. History is a threat to the internal validity of a study when the posttest observation or measure could be completely or partially attributed to an event other than the experimental treatment. Researchers can control for history effects by randomly assigning students to experimental and control groups. When this is not possible, an alternative is to ensure that all students are exposed to the same historical events.

Maturation. Maturation refers to an age-related growth in an attribute or characteristic of the study participants. Maturation is a threat to the internal validity of a study when changes in a student attribute can be assumed from typical human growth and experience between the time of pretesting and the time of posttesting—even when students have not received the experimental treatment. When randomization is not feasible, researchers control for maturation by using a pretest-posttest control group design to determine if differences demonstrated by the treatment group exceed those demonstrated by the control group, assuming that both groups matured the same over the course of the treatment period.

Testing. Testing refers to the effect that taking a test has on subsequent performance. The term test is used broadly to mean any number of measures such as interviews, questionnaires, and the like. For example, a student may remember questions from a pretest and study the answers to those questions such that his/her posttest scores are invalidly influenced. Researchers control for testing effects by using distinct pretests and posttests. The two forms should be statistically demonstrated to be equivalent. Emotions are another aspect of testing. For example, a student may receive poor results on a pretest, become anxious, and underperform in the posttest. As with the other threats to internal validity, random assignment of study participants to experimental versus control groups is the best strategy. Through randomization, differences in student reactions to effects of testing are randomly and, hence, evenly distributed across groups.

Instrumentation. Instrumentation concerns the reliability of the measuring instruments or procedures included in a research study. If tests or data collectors are not reliable in their measurements, then the results of the study will not be reliable or valid.

Researchers protect against instrumentation threats by using instruments of demonstrated and documented reliability, such as standardized achievement tests, or establishing the reliability of any instruments they develop.

Statistical regression. Statistical regression can occur when pretest scores are unusually high or low. The more pretest scores deviate from the norm, the more likely it is that on second testing they will regress toward the mean. Researchers protect against this threat by avoiding the selection of extreme groups such as very high or low achievers. The best strategy for controlling statistical regression is to randomly assign study participants to experimental versus control groups. Another strategy is to remove from the study any selected participants who scored unusually high or low on the pretest. The downside of this strategy, however, is that results of the study cannot then be generalized to students who usually score in the ends of the spectrum.

Selection. When sample selection results in differences between the experimental and control groups at the start, selection is a potential threat to the internal validity of the study. Selection is therefore a threat to quasi-experimental studies because group members have not been randomly selected. Pretesting can help by demonstrating that control and experimental groups are statistically similar prior to application of the treatment to the experimental group.

Mortality. Mortality refers to individuals dropping out of the experimental or control groups. Mortality is a threat to internal validity because differences between the experimental and control groups at the time of posttesting may be due to differences between the kinds of individuals who dropped out and those who did not. Researchers may try to control for threats to mortality by randomly assigning subjects to groups; however, this is only effective if mortality is due to external factors. Mortality is a form

of selective dropout, usually of the experimental group, and possibly due to the experimental treatment being unpleasant or difficult. It is unlikely that mortality would be much of a threat in the testing of educational software products.

Interaction effects. Interaction is the effect of one independent variable on another. Interaction occurs when the effect of one variable does not remain constant over categories of another. For example, two teaching tools might interact with student ability levels such that one product works well with high-ability students but not very well with low-ability students. The other software product might have the reverse effect. Nearly every threat can interact with selection to threaten the validity of experimental findings. Since the strategy of choice for controlling selection is random selection of study participants, experiments are the best way to counteract interaction effects. A usually justifiable second choice would be pretesting to demonstrate that groups are similar at the time of pretesting.

External Validity

External validity is the extent to which the findings from a research study can be generalized to people, places, or contexts external to those included in the study. While internal validity primarily concerns a study's design factors such as measurement instruments and treatment intensity and duration, external validity primarily concerns the selection of study participants, settings, and contexts. The three primary threats to external validity involve selection, setting, and history.

Interaction of selection and treatment. When samples are not randomly selected, there is always a chance that the treatment effect is a function of the sample. To illustrate, suppose that the sample of students in a study were all individuals who volunteered to participate in the study. It may be that these volunteers were all relatively motivated to succeed and, in fact, their level of motivation would have influenced the treatment effects. Hence, results from the study would have limited generalizability.

Interaction of setting and treatment. Interactions between setting and treatment can threaten the ability of the experimental findings to be generalized from the experimental setting to another setting. An example of this case is the generalization of a result obtained in a study performed in a rural setting to an urban setting. A potential solution to this threat is to include various settings as part of the experimental design and to analyze for effects in each of the settings.

Interaction of history and treatment. Interactions between history and treatment threaten the extent to which findings from a study can be generalized to another past or future time. One way to improve the ability of findings to be generalized is to replicate the study.

5.1.2 Pretests and posttests

Designs incorporating pretests and posttests allow one to compare measures taken both before and after a treatment intervention. In the educational research literature, it is common to find designs that include both pretests and posttests but not a comparison group. While such studies can show gains over time for the group tested, they cannot demonstrate cause and effect, due to the lack of a comparison group. Of course, pre- and posttesting can be incorporated into an experimental or quasiexperimental design, thereby allowing one to measure gains over time as well as providing evidence of cause and effect.

Researchers sometimes use pretest-posttest designs without comparison groups to demonstrate that a variable measured in the treatment group increases its value. For example, such a design might be used in the development or pilot-testing stages of a product to show that when students engage with a particular software product, they demonstrate gains in achievement between the time of pretesting and posttesting. Such an investigation might later be followed up with an experimental or quasi-experimental study. The pretest and posttest measures should either be the measure of the same test given to participants with a sufficient period of time between administrations to control

for the effects of remembering or practicing test items or, the pretest and posttest should be different tests shown to be statistically equivalent, i.e. both proven to yield the same distribution of results in a group. Such information should either be available from the test developer or it may be established by the researchers conducting the study.

5.1.3 Correlational analysis

Correlation is a type of statistical analysis. While such analysis cannot show cause and effect, it can be used to describe other kinds of relationships such as the relationship between the amounts of time students are exposed to a product and their scores on an achievement test. If correlational findings are replicated over time and/or with other samples of students, the strength of the finding is increased. However, the way to demonstrate that the relationship is causal is to conduct experimental or quasi-experimental studies. Studies that use correlational analyses are fairly common in educational research. They can be used as part of a body of evidence supporting a particular approach to product design or for the development of hypotheses that can be tested through experimental or quasi-experimental research.

Correlational approaches are able to show the relationship between measures of variables taken on the same set of individuals. Correlational studies do not have experimental and comparison groups. Essentially, they are One-Group, Posttest-Only designs. The goal of correlational studies is to demonstrate the magnitude (i.e., weak versus strong) and direction (i.e., positive versus negative) relationship between two variables.

5.1.4 Case studies

The primary purpose of case studies is to focus on understanding one or two issues that are fundamental to understanding a larger system. In education, a case study might focus on observing, describing, and understanding the behaviors that teachers exhibit in classrooms where students are excelling in one particular area. The scope of a single case

study can range from the study of an individual student or teacher to the study of a classroom of students, to a group of students sharing certain characteristics.

Case studies typically involve the collection of data, particularly descriptive or qualitative data, from individuals or individual groups. Case studies are not designed to discover universal truths or to demonstrate cause-and-effect relationships. Rather, they usually emphasize exploration and description.

While it is sometimes assumed that case studies are qualitative in nature and do not yield quantitative data, this is not necessarily so. Qualitative is not a synonym for case study, just as quantitative is not a synonym for experimental or quasi-experimental studies. All approaches—experimental, quasi-experimental, correlational, and case study—can draw upon both qualitative and quantitative data. In fact, many times, numerical values are assigned to nominal data and then analyzed. When this is done, researchers should be careful to explain the limitations associated with such practice.

Yin (1994) recommends that individual case studies be part of a carefully designed set of studies and that each case include the following components:

- The study's questions
- Its propositions, if any
- Its unit(s) of analysis
- The logic of linking the data to the propositions
- The Criteria for interpreting the findings

Case studies can be useful follow-ups to experiments and quasi-experiments, or they can be incorporated into quasi-experimental designs. They can also provide data to help troubleshoot a product in ways that provide ideas for the next generation of the product,

or, perhaps most importantly, provide insights into why a product did not work as intended.

5.1.5 Anecdotes

While anecdotes are not research designs, they are mentioned because they are commonly found in the education research literature. They are typically used to illustrate findings from any variety of study designs. While anecdotes can help illustrate a point, they cannot prove the point.

5.1.6 Sample size for research designs

There is no single or simple answer to the question of sample size. In general, if the sample size is too small, it increases the probability of drawing false negative conclusions (e.g., concluding that there is no significant difference between the groups being compared when there really is a difference). However, if the sample size is extremely large, it increases the probability of drawing false positive conclusions (e.g., concluding that there is a significant difference between the groups being compared when, in fact, the difference has no practical importance). The ideal sample size for any given study depends on the number of variables being studied, the unit of analysis, and how willing the researcher is to draw false positive conclusions versus false negative conclusions. Sample representativeness, more than sample size, is a key factor in the extent to which findings from a particular study are generalizable.

For experimental and quasi-experimental studies, researchers often use a rule of thumb sample size ranging from 20 to 50 members per group (i.e., each experimental group and each comparison group). The closer to the upper range, the more likely it is that true differences will be detected.

In the case of correlational studies, it is recommended that at least 100 individuals, and preferably 200 or more, be measured (Kerlinger and Pedhauzer, 1997). This recommendation is based on the fact that all correlational studies include measures of

the same individuals on at least two variables and that sample size should be based on at least 50 individuals per variable. Thus, studies with 20 variables should include at least 1,000 individuals.

5.2 Evaluation of Mechanics Modules

The Mechanics Modules were evaluated with the purpose of measuring their impact on students within the treatment group, currently enrolled in courses that cover the same material as the modules. This summative evaluation process yields important conclusions about the effectiveness of these tools and therefore, should provide an idea of the worth of undertaking this type of development as related to the improvements in education that they generate.

The evaluation process carried out and reported herein represents the first cycle of evaluation of the modules and their effectiveness. However, the modules used for this evaluation had undergone extensive testing during their development, and, it can be affirmed, that all of their implemented features were fully functional at the time of application.

Moreover, it can also be ascertained that a formative evaluation process was followed during the time of development of the modules, where often different paths were explored for the presentation and better explanation of certain concepts covered. This process allowed one to compare different types of solutions to different types of problems, yielding what is thought to be an overall solution close to the optimum, which is represented in the content of the modules.

The evaluation design chosen for this study was a pretest-posttest control group. The impossibility to have random selection of the participants forced this study to be a quasi-experiment. A survey was also used in the evaluation process designed to obtain additional information.

The following subsections describe the tests and survey used in the evaluation as well as the procedure followed for each of the evaluation sessions.

5.2.1 Tests

The pretest for both groups was divided into three main sections plus a short survey at the beginning of the test. This five-question survey asked for the student identification, which was not necessarily the student's real name, the academic department where the student is currently enrollment, the year of enrollment, the student's gender, and the number of courses related to structures previously taken by the student.

As mentioned before, the pretest for both groups was divided into three sections; this was also the case for the treatment group posttest. Each section tested the material covered by each of the modules. Each question evaluated the student's ability with respect to the modules' learning goals and therefore focused on a single goal or a set of goals to test. Table 5.1 shows how the tests were composed by illustrating the goals tested by each question.

The treatment group pretest and posttest were the same in format. Questions asked in these two tests were combined to produce the control group pretest, which has been included in Appendix B , Section B.1. Figure 5.2 shows a schematic of the test configuration, while Table 5.2 shows the control group pretest and also lists which questions were included in each of the tests given to the treatment group (i.e. pretest and posttest).

Table 5.1 Specific goals tested by each question in the pretest and posttest

Question Set	Concept	Problem Type	Purpose of Question
1.1	System stability	Check if assembly is stable	<ul style="list-style-type: none"> • Check understanding of stability • Check understanding of behavior of different types of supports
1.2	Deformed shape	Identify correct deformed shape	<ul style="list-style-type: none"> • Check understanding of behavior of different types of supports • Check understanding of effects of loads on a beam
1.3	Support reactions	Determine the number of reactions of each support element	<ul style="list-style-type: none"> • Check understanding of behavior of different types of supports
1.4	Moments	Determine the moment at the fixed support	<ul style="list-style-type: none"> • Check understanding of moment concept • Check understanding of moment sense
2.1	Rigid body stability	Check equilibrium of free body	<ul style="list-style-type: none"> • Assess understanding of free body equilibrium
2.2	Determinacy	Determine if element is statically determinate or not	<ul style="list-style-type: none"> • Identify if determinacy concept is understood
2.3	Static analysis – equilibrium equations	Solve for unknown reaction	<ul style="list-style-type: none"> • Check understanding and use of equilibrium equations
3.1	Internal forces – shear forces	Pick correct moment diagram	<ul style="list-style-type: none"> • Check understanding of internal forces concept and representation
3.2	Internal forces – bending moments	Pick correct moment diagram	<ul style="list-style-type: none"> • Check understanding of bending moment concept and representation

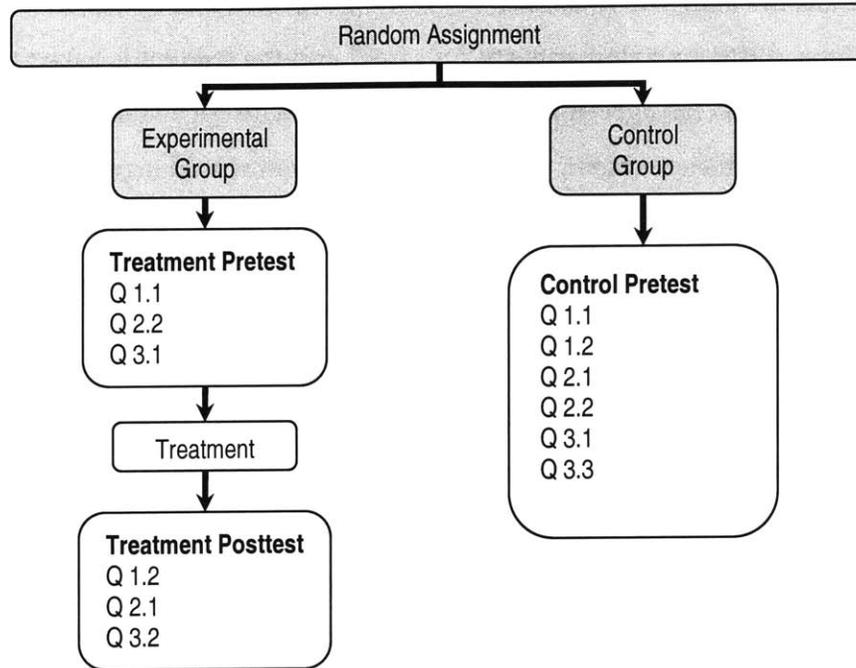


Figure 5.2 Pretest-posttest configuration scheme

Table 5.2 Questions from control group pretest included in treatment group tests

Test Section	Questions of Treatment Group Pretest	Questions of Treatment Group Posttest
1	1.1.a, 1.1.b, 1.1.e 1.2.b, 1.2.c 1.3.a, 1.3.b, 1.3.c 1.4.a, 1.4.c	1.1.c, 1.1.d, 1.1.f 1.2.a, 1.2.d 1.3.a, 1.3.b, 1.3.c 1.4.b, 1.4.d
2	2.1.a, 2.1.c, 2.1.d 2.2.a, 2.2.b, 2.2.f 2.3.b, 2.3.d	2.1.b, 2.1.e, 2.1.f 2.2.c, 2.2.d, 2.2.e 2.3.a, 2.3.c
3	3.1.b, 3.1.d 3.2.b	3.1.a, 3.1.c 3.2.a

5.2.2 Survey

The Survey starts out collecting the student’s identification, necessary for comparison purposes. It also questions the student’s approximate time to complete each module. It then continues with three main sections, the first two try to obtain the student’s opinion

on how the modules compare to lectures, in section one, and text books, in section two. In these sections, different statements are proposed and the student is asked to rate in a scale from one to seven his agreement or disagreement with each statement. A rating of one indicates strong disagreement, while a rating of seven would signify a strong agreement. The statements contrasted aspects such as the intuitive feel for the concepts provided by the module versus lectures or textbooks, the visualization benefits, the engagement level, etc.

The third section of the survey was oriented to disclose the learning style or cognitive behavior of each student. It concentrated on asking students how well the descriptions offered represented how they learned complex mechanical concepts. This section also used a rating system similar to the one used in sections one and two with descriptions that included answers to the question such as memorizing the important features of the concepts, establishing conceptual models, drawing visual representations, writing notes exactly as they appeared in textbooks, or using analogies.

The complete Survey is included in Appendix B , Section B.2.

5.2.3 Procedure

5.2.3.1 4.440 Basic structural theory

The first evaluation of the Mechanics Modules was performed on March 15, 2004. The participants were the students enrolled in the “4.440 Basic Structural Theory” class, offered by the Department of Architecture at the Massachusetts Institute of Technology (MIT) and taught by Prof. John Ochsendorf. This course is an undergraduate level subject, where all students were juniors or seniors, with the exception of one graduate student participating in the exercise. Figure 5.3 shows a distribution of the student population in the class by year of enrollment. The treatment and control groups were divided by alphabetical order and were composed by 10 and 9 students, respectively. The two groups were treated at the same time, during their three-hour laboratory work

session. The groups were separated in two computer rooms located on the second and third floors of building one of the MIT campus.

Students were informed of the activity in the morning of the day it took place, during regular lecture hours. The professor indicated to students that they were going to be involved in the evaluation of a new alternative teaching method in the subject. Students were also told that scores obtained in the tests performed during the activity would not be counted towards the final grade of the course but would be used by the professor as a good indicator of how students are learning the material covered in lecture. In other words, it would serve as a mid-term assessment of the class, which had not been planned as part of the course evaluation. The professor provided a list of numbers which corresponded to an assigned identification of each student. The purpose of this was to keep the confidentiality of the test, still providing the opportunity for the professor to get an idea of how each of the students is learning the material presented in class. It also solved the problem for linking a pretest and posttest from the same person in the treatment group.

It had been originally planned to perform online pretests and posttest to the control and treatment groups. However, the failure of the server hosting these web pages to provide service to more than 10 clients at a time forced the performance of the tests in written form. A twenty-minute delay was then induced in the evaluation process due to this unforeseen restriction.

The treatment group was given the pretest at the beginning of the session. The students were allowed as much time as they needed to complete the test, which averaged about 30 minutes. Once the pretest had been completed, students were given access to the modules, which, for this exercise, were set up to be launched sequentially, that is, once the student finished the first module, the navigation buttons would launch the second. In the same manner, the third module was launched from within the second module. The modules, despite this arrangement, were still clearly defined so that the students

were aware of which module they were working on. After the students were done working through the exercises and contents of all three modules, they were given the posttest, followed by the Survey.

The control group was instructed to complete the pretest at the beginning of the three-hour period. As mentioned before, this test was prepared so that it combined the same questions included in the pretest and the posttest distributed to the control group. Students were given as much time as they needed to solve this test and then were given online access to the Modules. When students were finished working through all three modules, they were asked to fill out the Survey.

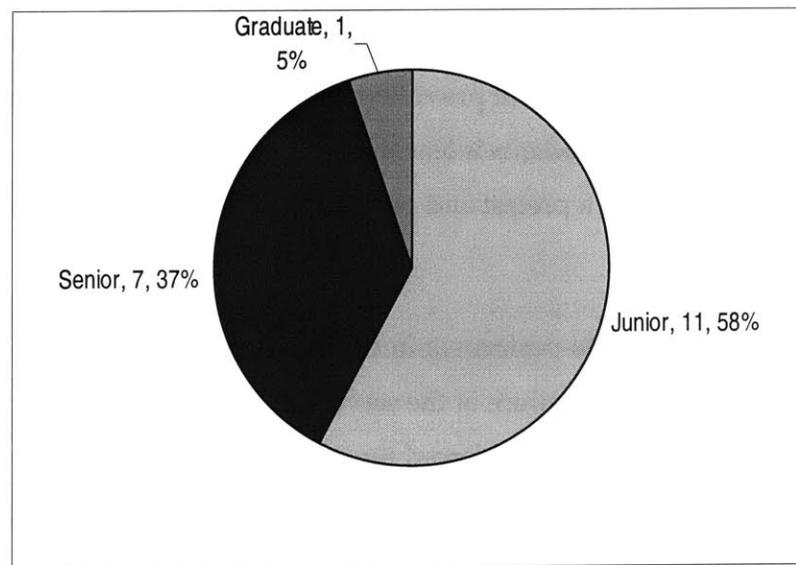


Figure 5.3 4.440 student population distribution by year of enrollment

5.2.3.2 1.012 Introduction to Civil Engineering Design

The second group that evaluated the Mechanics Modules was that of students enrolled in the subject "1.012 Introduction to Civil Engineering Design". This subject is offered by the Department of Civil Engineering at MIT and is taught by Prof. Herbert Einstein. The evaluation took place on April 29, 2004. This course is also an undergraduate level

subject where students came from one of the first three years of their undergraduate program. Figure 5.4 shows the distribution of the class population by year of enrollment.

The test procedure was similar to that followed for the evaluation of the first group; the treatment and control groups were divided by alphabetical order and were treated at the same time, during a two-hour class period. The treatment group, composed of 11 students, was located in a computer room situated on the third floor of building one of the MIT campus. The control group, composed by 8 students, was located on the second floor of the same building.

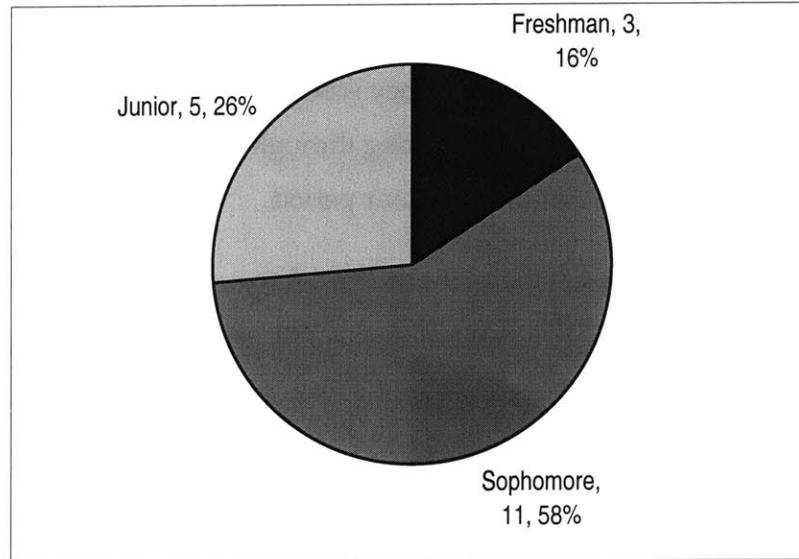


Figure 5.4 1.012 student population distribution by year of enrollment

Students enrolled in 1.012 who took part of the evaluation exercise were previously advised during class about the activity that they were going to be engaged in. They were also told that the evaluations performed during class were not going to be counted towards the final grade of the course. Students of this group, unlike the previous group, were not using in class the material presented in the modules; however, the majority of the students were expected to have covered this material in previous courses at an undergraduate level. Specifically, most of the students had been enrolled in the MIT

course “1.050 Solid Mechanics” the previous semester. This subject covers the fundamental principles and methods of structural mechanics, static equilibrium, force resultants, support conditions, and analysis of determinate planar structures, which clearly fits with the content of the modules.

The pretest and posttest were given to students on paper, abandoning the idea to perform the tests on-line, based on the experience from the first evaluation group. The procedure for the second group was similar to that of the first; the treatment group was given the pretest at the beginning of the session and after its completion, the students were given access to the modules which were set up in exactly the same manner as they were presented to the first group. After the students finished working through the exercises and contents of all three modules, they were given the posttest, followed by the Survey. In general, all students finished working through the tests and the modules at their own pace and, overall, within the two-hour period.

For the control group, the pretest was distributed to students at the beginning of the session. Once the students completed all exercises on the pretest, they were presented with the modules. Around ten minutes before the completion of the two-hour period, students were asked to complete the Survey.

5.3 Results

This section presents the analysis of the data obtained in the evaluation exercise. It is divided in three subsections; section 5.3.1 presents a summary of the profile of the students who participated in the exercise, section 5.3.2 portrays the improvements achieved by the use of the Mechanics Modules, and section 5.3.3 presents the results obtained in the Survey.

5.3.1 Student Profiles

This section summarizes the personal details of the students enrolled in the evaluation of the Mechanics Modules. While sections 5.2.3.1 and 5.2.3.2 presented the student

population distribution by year of enrollment of each group separately, the summaries presented in this section are for the entire population that took part in the evaluation process. The data collected included: year of enrollment, gender, and number of courses taken previously that were related to the subject of the Mechanics Modules. The purpose for collecting these data from students was twofold; first, as a check that the population being evaluated corresponded to the target audience of the modules, and second, as an additional parameter for the performance of correlational analyses for the test data.

The resulting data are presented for completeness. It yielded a gender distribution of the evaluation group of 55% females and 45% males. The sample included students from all undergraduate education years (i.e. freshman, sophomore, junior, and senior) plus one graduate student; this distribution is shown in Figure 5.5.

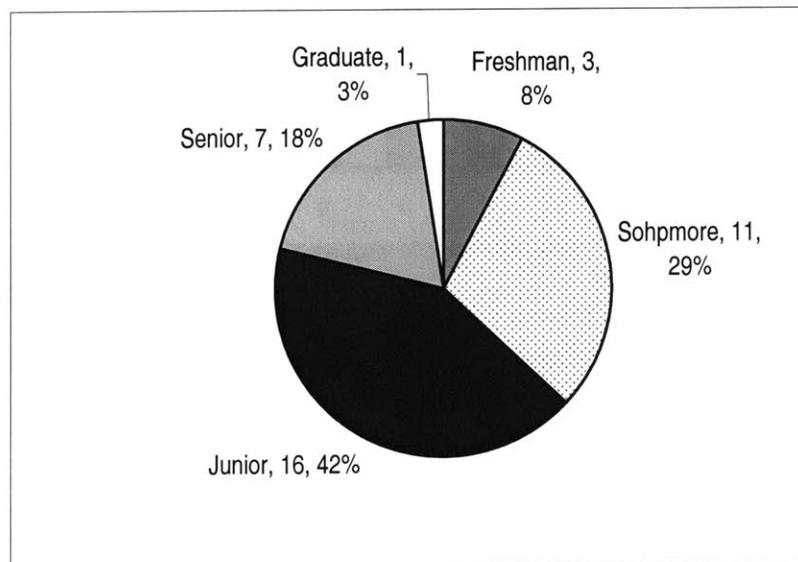


Figure 5.5 Evaluation group distribution by year of enrollment

Figure 5.6 shows the number of courses related to the subject of the Mechanics Modules that the students had taken. The results show a large number of students with two or more previous courses in mechanics. However, this result is considered inaccurate since most students from the "4.440 Basic structural theory" class were clearly involved in

their first structural mechanics course, while the majority of the “1.012 Introduction to Civil Engineering Design” students had just finished their first related course during the previous semester. In other words, it is unlikely that students had more than one previous/simultaneous overlapping mechanics course. This inaccuracy is attributed to the fact that the formulation of the question allowed the student to interpret courses in basic physics, which covered vector analysis and forces, as courses related to the subject of the Mechanics Modules.

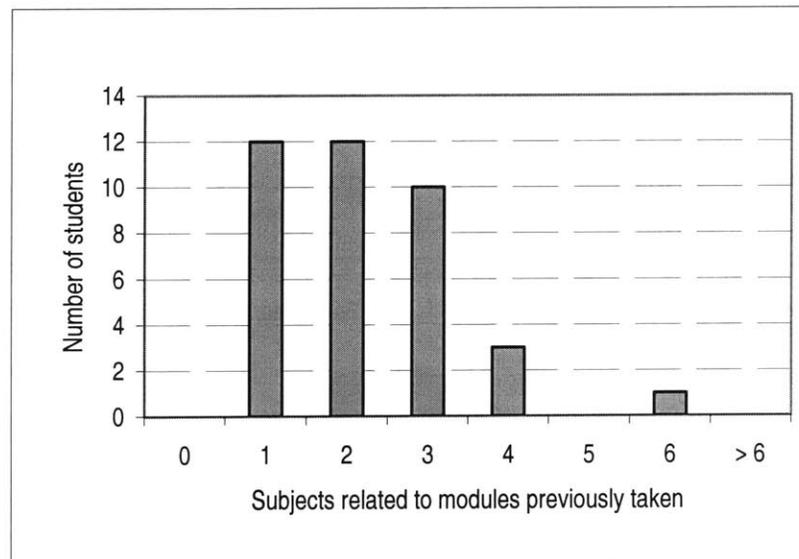


Figure 5.6 Number of courses related to the subject of the Mechanics Modules previously taken by students

5.3.2 Tests

The effectiveness of the modules is measured by the improvement achieved by students using them. In order to demonstrate this, the results of the pretest and posttest of the treatment group are compared. These results are contrasted to the results obtained by performing the same comparison on scores obtained by students in the control group, which, in this case, has not have access to the modules. Ideally, the improvement obtained by the treatment group students should be greater than the improvement, if any, achieved by the control group students.

This section presents the results of this exercise. These results are presented in two different manners; the first presents the improvement achieved by students in the overall test score, and the score of each section of the tests related to Module1, Module2, and Module 3, separately. The second presents the results in a more specialized manner; the improvements being shown for each of the question sets as depicted in Table 5.1. This level of specialization has the purpose to compare the effectiveness of the different methods utilized to present the concepts associated with each question set. In other words, greater improvements in a set would indicate that the learning concepts utilized to present the mechanics concepts associated with the particular set are the more effective ones.

The improvement was calculated for each student based on the change in their performance from the pretest to the posttest:

$$\text{Improvement} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Possible Score}} \quad (\text{Eq. 5.1})$$

For the grading of the tests, one point was awarded for each correct answer; no partial credit was given to any answer. The format of the test, where mostly multiple choice questions were given to students, facilitated the implementation of this grading rule. The only exception was question set 1.4 where students were asked to provide the expression for the moments at a point in a structural member. In this set, students were also asked to indicate the sense of this moment. This question awarded two points when the expression was correctly written and one point for the choice of the correct moment sense, for a total of 3 points per question. Table 5.3 shows the number of questions per question set and the points to be awarded in each set. The maximum score for each test was 25 points.

Table 5.3 Test grading criteria

Question Set	Number of Questions per test	Points per Set
1.1	3	3
1.2	2	2
1.3	3	3
1.4	2	6
2.1	3	3
2.2	3	3
2.3	2	2
3.1	2	2
3.2	1	1

5.3.2.1 Score improvement

Overall

The analysis of the overall test scores provides a broad picture of the effectiveness of the teaching tools. The results are presented in several formats. Figure 5.7 shows a plot of improvement achieved by students in the overall test result versus the score obtained in the pretest, expressed as a percentage of the maximum score. The expression for the improvement is shown in Equation 5.1. The plot differentiates between students from the treatment and the control group. Linear regression lines have been added to accentuate the tendency of the data obtained in the analysis. Two conclusions can be drawn from this plot: The first is that students, in general, performed better in the posttest than in the pretest. This can be explained by two probable reasons, the first being that the posttest questions were easier to solve, and the second being that, as expected, the treatment group members improved their knowledge about the subject, while the control group members matured by taking the pretest and the posttest. In other words, they became more familiar with the subject as they took the tests. This maturation was identified as a threat to the internal validity of the evaluation and was discussed in section 5.1.1.3. The improvement of the control group, however, is a sound result of the evaluation analysis, since it shows that improvements can be attributed to the use of the modules.

The second conclusion that can be drawn from the plot presented in Figure 5.7 is that there is a tendency for students who performed the worst in the pretest to improve the most in the posttest. This is indicated by the negative slope of the regression lines. This result, however, was somewhat predictable, since the students who obtained a poor score in the pretest, had more room for improvement in the posttest. This effect will be addressed later in the presentation of a different type of plot shown in Figure 5.10.

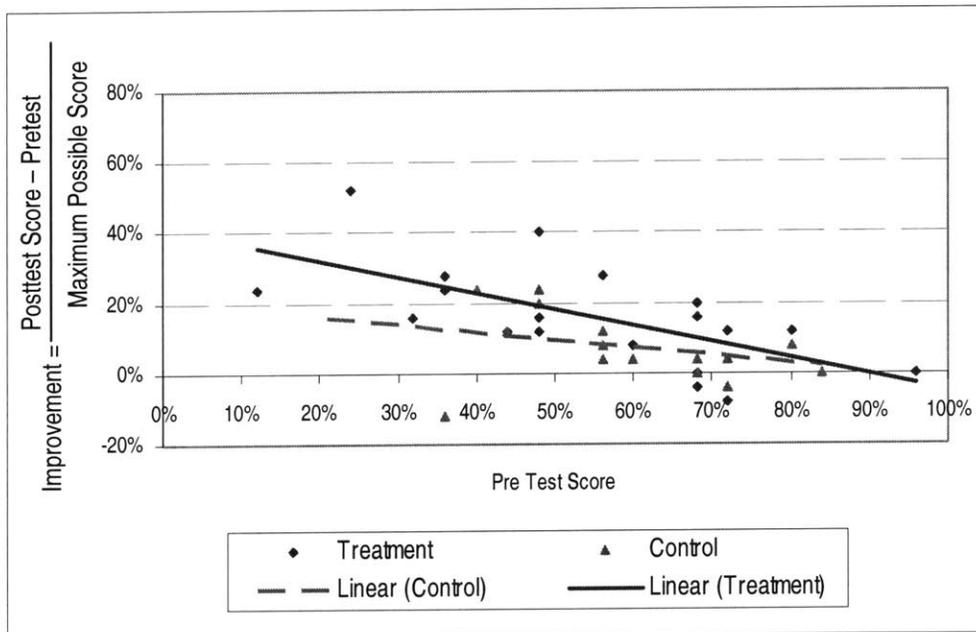


Figure 5.7 Overall test score improvement vs. pretest score

Figure 5.8 presents a chart where the pretest scores have been grouped into four ranges. The improvements for each range represented by the bars are the average improvements of the students who obtained a pretest score falling within each represented range. The plot also differentiates between students from the treatment and the control group. This type of plot confirms the conclusion that students with lower pretest score improve more in the posttest through the use of the modules. An interesting fact observed from this plot is also that the difference between the improvements achieved by students in the treatment group as compared to that of students in the control group decreases for

the ranges with better results in the pretest. While this difference for students who obtained a score between 25% and 50% in the pretest is 8%, the difference is 1% for students in the range between 75% and 100% in the pretest score. The consistency of the results is considered remarkable, especially for an evaluation group composed of students with such a diverse background.

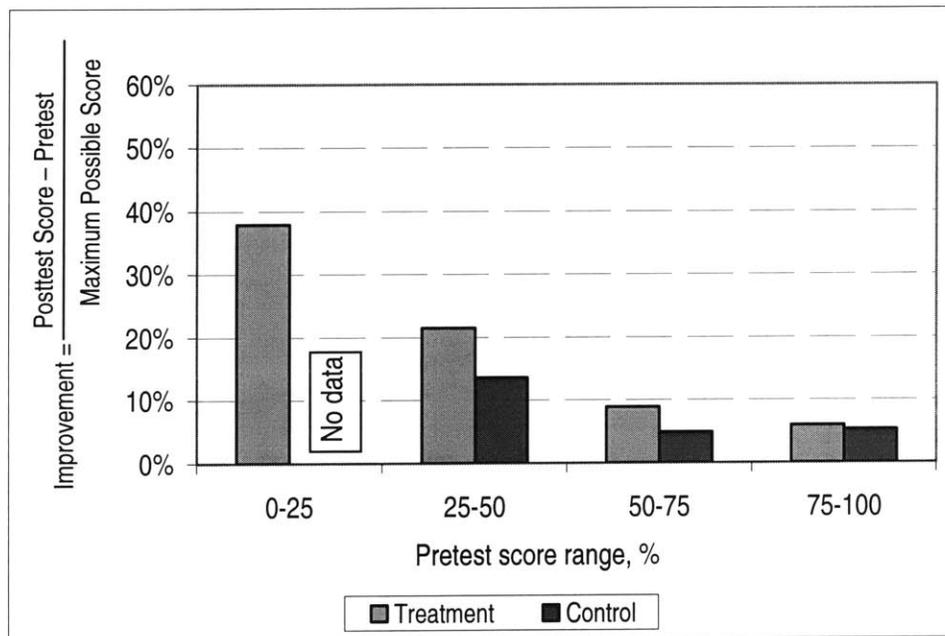


Figure 5.8 Overall test score improvement by pretest score range

The presentation of the data in the format shown in Figures 5.7 and 5.8 does not clearly show how much of the potential improvement is realized by each student. For example, Figure 5.9 shows the case of two students; one with a pretest score of 10% and the other with a score in the same test of 80%. The student who obtained a score of 10% in the pretest has a total potential improvement equal to 90%, defined by a maximum score of 100% in the posttest, minus the score obtained in the pretest. On the other hand, the student who obtained a score of 80% in the pretest has a total potential improvement of only 20% in the posttest. From this analysis, it is clear that a plot such as the one presented in Figure 5.7 is bound by a line of maximum improvement which cannot be

surpassed. This can distort the perception of how much all students are benefiting from the use of the modules, regardless of their score in the pretest. In order to correct for this deficiency of the previous plots, Figure 5.10 shows the data by plotting what has been denominated the “Realized Improvement” by pretest score range. This Realized Improvement represents a measure, in percentage, of how much of the total potential improvement was actually realized by the student in the posttest. Ideally, the realized improvement should be close to 100%, this would indicate that all students obtained a score of 100% in the posttest, independently of their pretest score. The Realized Improvement is calculated by the following expression:

$$\text{Realized Improvement} = \frac{\text{Improvement}}{\left(1 - \frac{\text{Pretest Score}}{25}\right)} \quad (\text{Eq. 5.2})$$

For example, a student who answered correctly five questions in the pretest (20% correct) had a maximum achievable improvement in the posttest of 80%. If this student obtained a score of 60% in the posttest then his/her improvement was 40%. Which means, based on Equation 5.2, that the Realized Improvement of the student was 50%. In other words, the student improved half of the maximum achievable improvement.

What can be concluded from Figure 5.10 is that based on their pretest score, poor performers are able to realize more improvement than students obtaining better results, at least for the overall test results. However, this plot demonstrates that the improvement realized for each group is not as dramatically different as that portrayed in Figure 5.8. Figure 5.10 also shows more clearly the benefits of using the modules when the realized improvements from students in the treatment group are compared to those of students in the control group; there is consistently more realized improvement for students in the former.

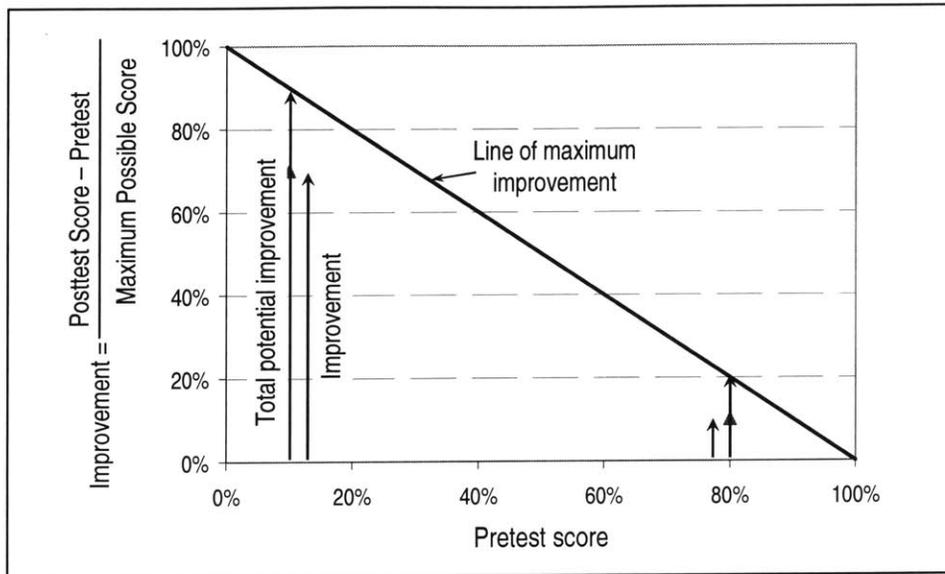


Figure 5.9 Realized improvement calculation

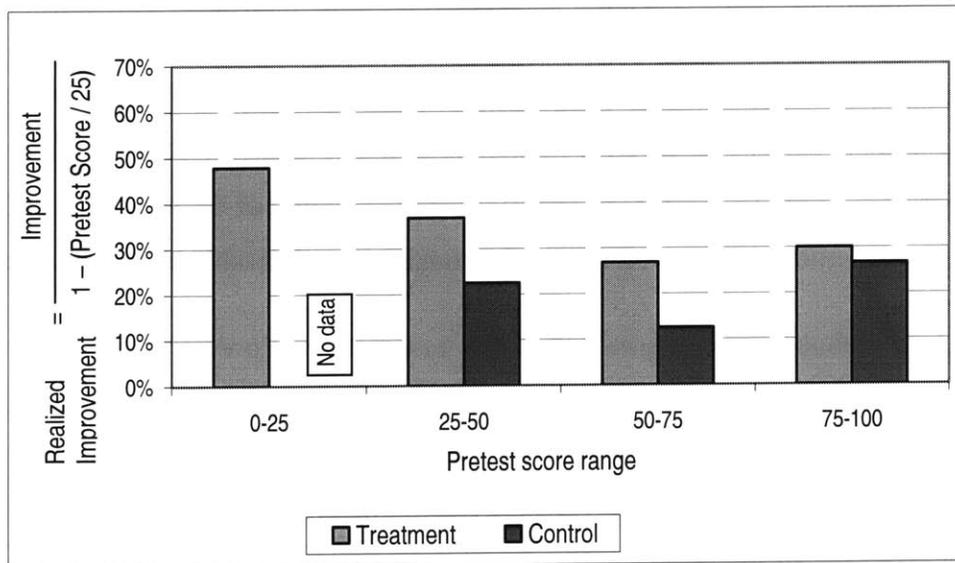


Figure 5.10 Realized improvement in overall test score by pretest score range

It is worth noting, as an anecdotal observation of the evaluation sessions, that students who had problems with the material presented by the modules, showed more interest towards the exercise and approached it as a valuable experience that would help them solve their deficiencies in the subject. More advanced students who seemed to be more

confident about the material did not, in general, show an enthusiastic approach towards the modules. This may be an explanation for the data in the sense that the “more advanced” students in the treatment group show almost the same improvement as students who performed well in the pretest of the control group.

Analyzing the data from another point of view, it is considered that the improvements shown for the poor performers are quite significant as compared to those shown by the better performing groups. Figure 5.8 shows an average improvement of 38% for students in the lowest scoring group. Based on this, a student who obtained a 15% score in the pretest was able to increase his/her posttest score to around 53%, which means that the student more than tripled the pretest score. Along the same lines, a student with a pretest score of 80% would have obtained a score of 85% in the posttest, which represents a 6% gain only. Based on this, while it is considered that the use of the modules did not make much of a difference to a student who knows the subject, the benefit obtained from the use of the modules for a student who is struggling with the subject matter is remarkable and could lead to increase the student’s confidence and interest in the subject.

Module 1

The same type of plots presented for the overall test scores are also presented for the scores obtained in the question sets associated to the content of Module 1. Figure 5.11 shows the improvement achieved by students grouped by pretest score ranges. The pretest scores shown in the figure correspond to the number of correct answers divided by the number of total questions asked in the corresponding question set, that is, question 1.1 through 1.4 of the pretest and posttest. This score is expressed as a percentage. The improvements are calculated based on the gain in score related only to those questions based on the following expression (14 being the number of questions):

$$\text{Improvement Module 1} = \frac{\text{Posttest Score(Questions 1)} - \text{Pretest Score(Questions 1)}}{14} \quad (\text{Eq. 5.3})$$

The tendency of this chart is similar to that of the chart presented in Figure 5.8. However, it should be noted, that the improvements realized by students are higher for the score obtained in the questions associated with Module 1 than for the overall test scores. This demonstrates that the content presented in Module 1 has a greater effect than the combined modules, especially for students who answered correctly less than 75% of the questions. Again, the students who most benefited from this module were the poorer performers, who, on average, achieved an improvement of 52% in the posttest scores.

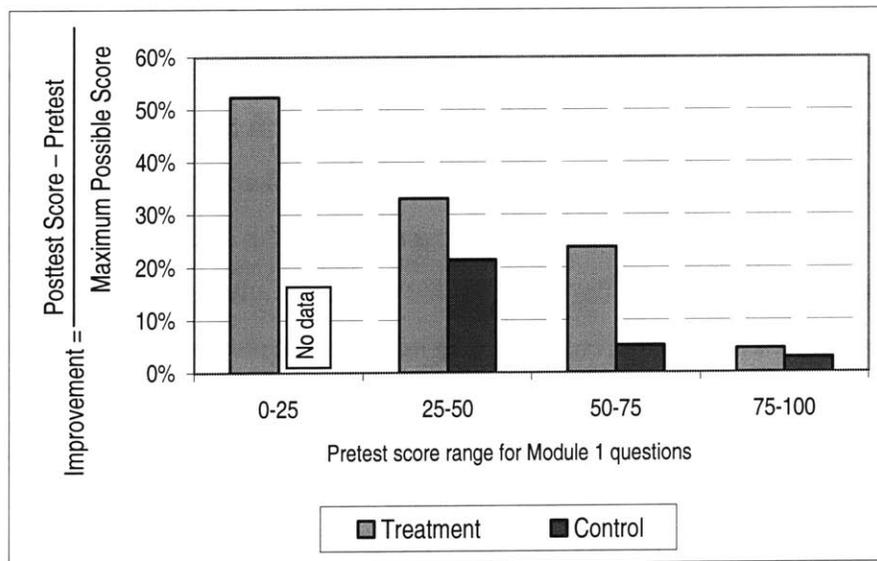


Figure 5.11 Module 1 test score improvement by pretest score range

Figure 5.12 shows the realized improvement by Module 1 pretest score ranges. This figure portrays one of the more encouraging results obtained in the evaluation of the Mechanics Modules. It differs from the tendency shown in Figure 5.10 where the realized improvement is shown to decrease as students obtained better pretest scores. The result for Module 1, however, shows a much higher and somewhat more consistent realized improvement for students with less than 75% of the related questions answered correctly. Again, students falling in the range between 75% and 100% of the questions answered correctly show much less realized improvement than the rest of the group,

reinforcing the theory from the anecdotal observation that more prepared students perhaps tend to approach the use of the modules less enthusiastically than the students who feel the need for more preparation in the subject. This phenomenon is more apparent in Figure 5.13 which shows the individual realized improvement for all students. In this figure, the improvements realized by the treatment group members are consistently higher than the realized improvements by the students in the control group, except for the students who obtained a score in the pretest higher than 85%.

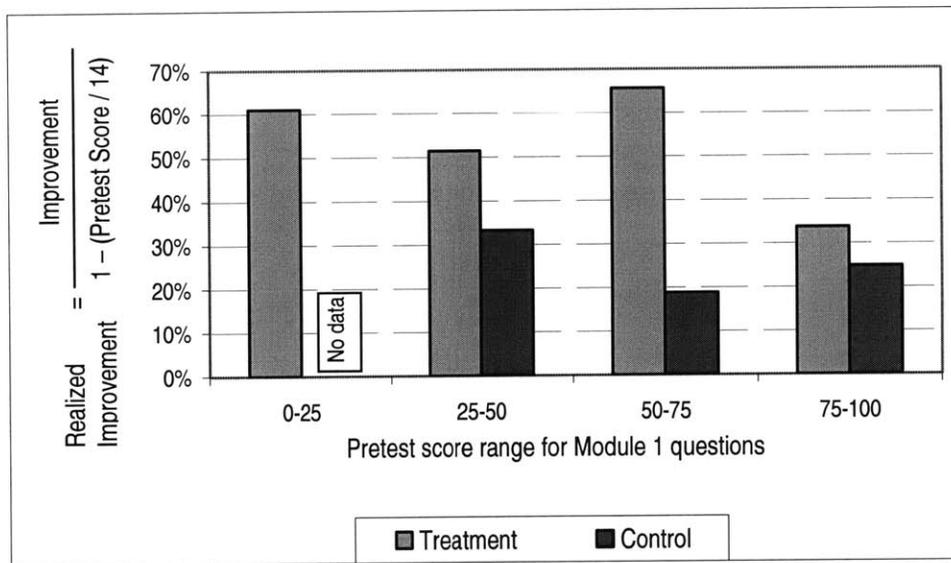


Figure 5.12 Realized improvement in Module 1 test score by pretest score range

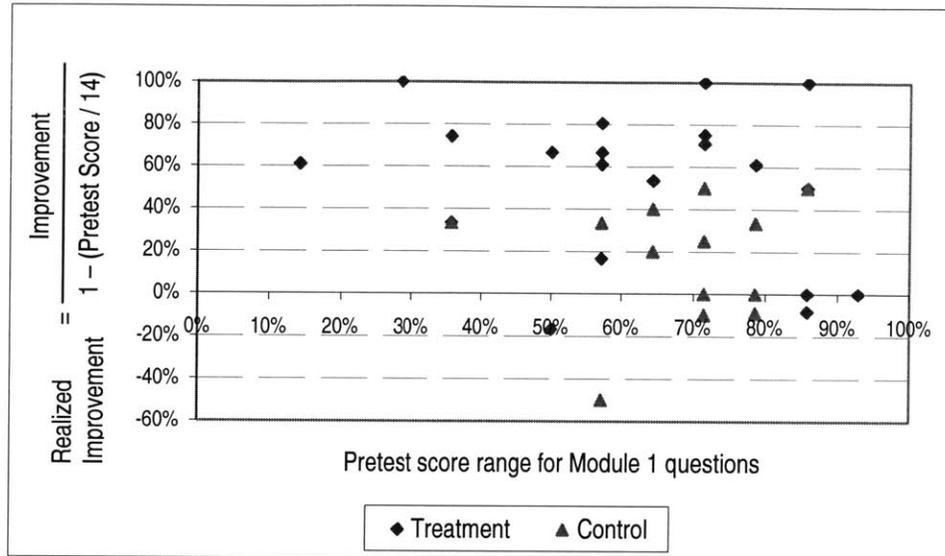


Figure 5.13 Realized improvement in Module 1 test score versus pretest score

Module 2

The improvements achieved by students in the test questions associated to Module 2 are summarized in Figures 5.14 and 5.15. These questions correspond to question 2.1 through 2.3 of the pretest and posttest. Figure 5.14 shows the average improvement achieved by students segregated into four groups defined by pretest score ranges. These scores are the percentage of the maximum points available obtained by the student in the questions related only to Module 2. Figure 5.15 presents the average realized improvement for students grouped in four groups also defined by pretest score ranges.

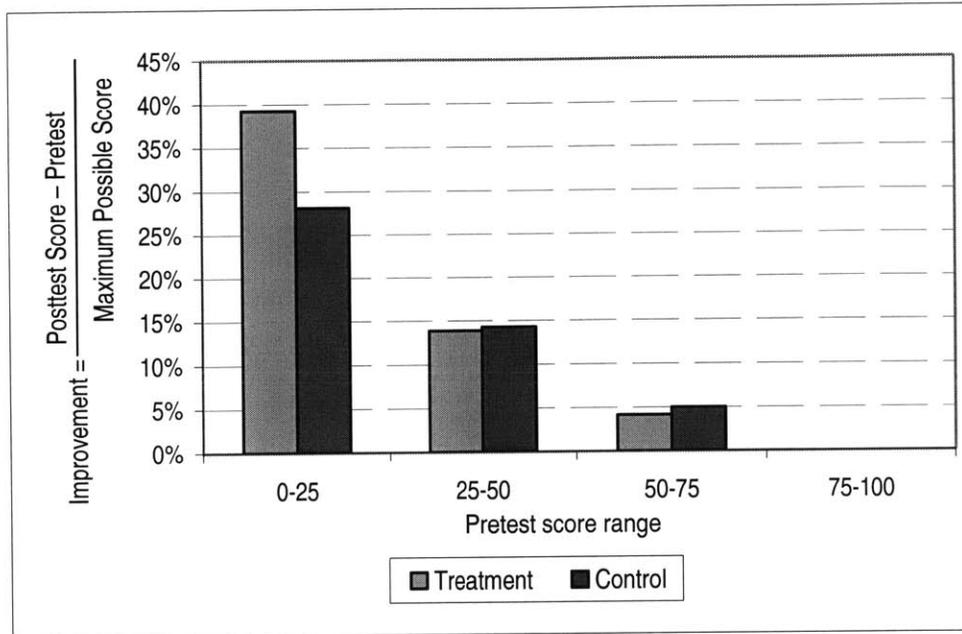


Figure 5.14 Module 2 test score improvement by pretest score range

The two figures show the same tendency observed for the overall test score, where better prepared students consistently improve less than poor performers. The same is observed for the realized improvement, where the lower scorers tend to realize more potential gains in score than the students with better results in the tests. However, the data for Module 2 indicate that there is a benefit of using the module only for students grouped in the lower range, from 0% to 25% in the pretest score. The conclusion can then be drawn that the use of Module 2 did not offer benefits to students who were not having problems with the material presented by the module.

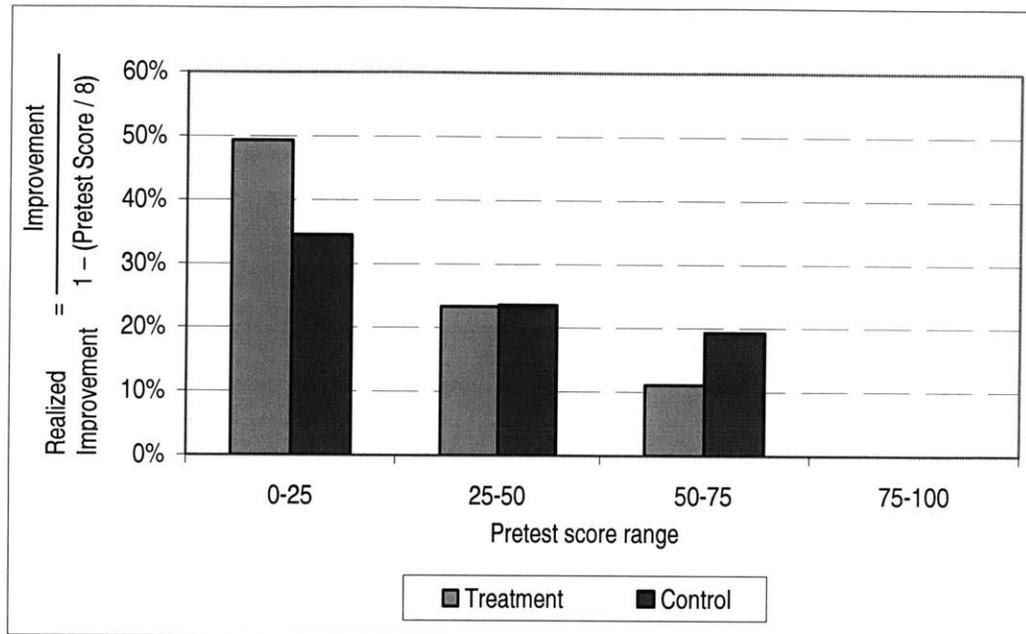


Figure 5.15 Realized improvement in Module 2 test score by pretest score range

Module 3

The data obtained for Module 3, presented in the formats used to present data from modules 1 and 2 does not lead to any conclusions, nor does it show a reasonable trend. The reason for this is that the number of questions asked in the tests related to the material covered by Module 3, questions 3.1 and 3.2, awarded a maximum of three points per test. This low maximum score does not allow one to make reasonable calculations of improvements and realized improvements as defined by Equations 5.1 and 5.2. Subsequent sections will explore the effectiveness of Module 3 with a different approach.

5.3.2.2 Improvement by question set

The design of the pretest and posttest questions allows one to assess the effectiveness of some of the teaching concepts utilized in the modules. In order to perform this assessment, each question set is evaluated by comparing the average improvement

achieved by students in the control and treatment groups in each of the question sets depicted in Table 5.1. Figure 5.16 shows the result of this analysis where each question set is presented separately with the exception of question sets 3.1 and 3.2, which are presented together. This figure shows a consistently larger improvement achieved by the students from the treatment group as compared to that of the students from the control group. It could be argued that the improvement achieved by the control group students should be based from which the improvements attributed to the use of the modules should be derived. In other words, the difference between the two bars for each question set can be credited to the use of the modules. Figure 5.17 presents this difference, labeled relative improvement, where the benefits of the module are clearly different for the various question sets. It is important to keep in mind, when looking at these data, that the improvements presented in the figures are the average improvements of all students involved in the evaluation process (the previous section showed how poor performers in the test benefited more from the modules).

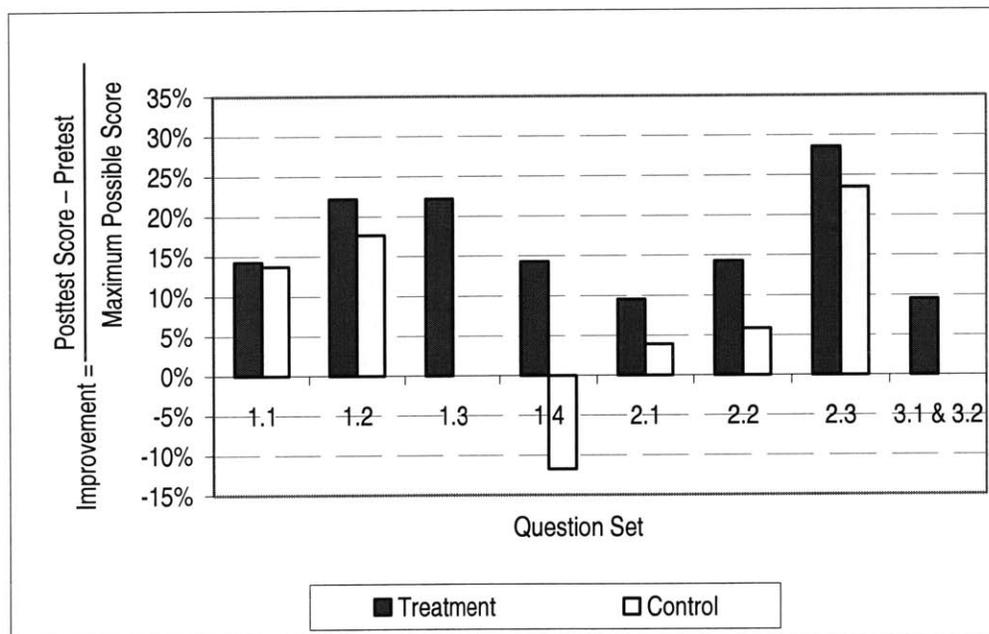


Figure 5.16 Improvement by question set

The results for each of the questions sets will be discussed separately in the following subsections. As reference to the reader, several plots showing the improvement achieved by each student in the posttest with respect to pretest score for each question set have been included in Appendix C .

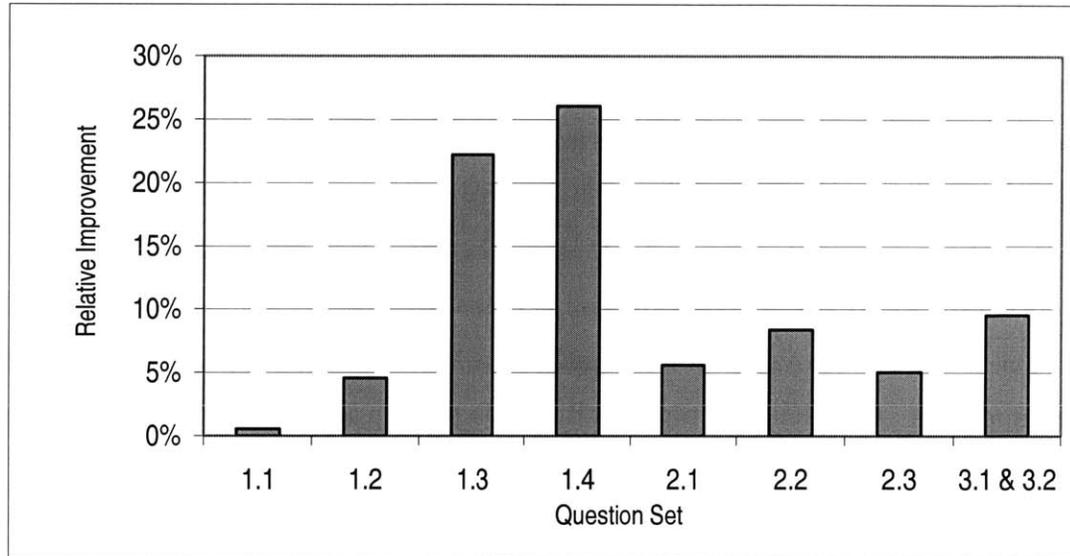


Figure 5.17 Average relative improvement per question set attributed to modules

Question set 1.1 – System stability

Question set 1.1 was the poorest performer of all question sets in the tests with a relative improvement equal to 0.6%. The reason behind this is perhaps explained by the nature of the question itself. This question presented the student with a structural element supported by a combination of supports covered in the module. The student was then asked if the element was stable under any kind of loading. Although Module 1 very briefly presents a case where a beam is not stable under any kind of loading, it does not provide any exercises or animations that reinforce this notion. One of the objectives of this question was to explore how much of the behavior of a structural system did the student understand after having explored the modules. The student should have come

to understand this behavior after a reflective process following the presentation of the necessary basic concepts. This was clearly not achieved by the modules.

Question set 1.2 – Deformed shape

A relative improvement of 4.6% for this question set was somewhat of a disappointment. Module 1 stresses the presentation of the effects that different support configurations for beams have on the deformed shape of these structural elements when subjected to external forces. Although a positive relative improvement can be considered a success in the implementation of the module, the relative improvement that was expected from this question set was higher.

Question set 1.3 – Support reactions

This set represents the second best performer among all question sets with a relative improvement of 22.2%. This result is considered reasonable since Module 1 puts much emphasis on support reactions.

Question set 1.4 – Moments

The question set related to moments is the best performer of the group with a relative improvement of 26.1%. In fact, the concept of moments, as it was previously mentioned, was considered one of the most difficult to present to students due to its abstract nature. The formative evaluation process followed during the development of the modules had a major impact on the presentation of this concept and in the choice of the learning concepts implemented for that purpose.

Question set 2.1 – Rigid body stability

The rigid body stability question set yielded a relative improvement of 5.6%. This question set, despite its apparent good result, is thought to have been misunderstood by students based on a poor formulation of the question on the tests. Its intention was to evaluate the benefits brought by the implementation of the rigid body simulations

discussed in sections 4.1.14.10 and 4.1.14.11. Due to the problem with the question formulation, no conclusion can be drawn regarding this question set.

Question set 2.2 – Determinacy

Students responding to the questions related to determinacy show an average improvement of 8.4%. The improvement in this question set was expected to be somewhat higher, especially when compared to the result obtained in question set 1.3 which deals with a basic concept to establish determinacy in a structural element. However, the determinacy concept is not a concept that is heavily stressed in the modules, it is only mentioned in the narrative content and no learning concept is specifically devoted to determinacy.

Question set 2.3 – Static analysis - equilibrium equations

The question set related to equilibrium equations yielded disappointing results with a relative improvement of only 5.0%, the third worst performer of all question sets. Similarly to the moment concept, the equilibrium equations is a topic that was extensively analyzed during the formative evaluation process and one to which a lot of simulations and animations were devoted in the modules. This disappointment, however, can not be blamed entirely on the failure of the methods utilized by module. Figure 5.16 shows this question set as the one where the most improvement was achieved by the student. How much of this improvement is due to the modules and how much to the maturation effect that the control group might have undergone remains an unknown in the assessment process.

Question sets 3.1 and 3.2 – Internal forces

The sets of questions dealing with the internal forces show a relative improvement of 9.5%, the third best performer among all question sets. These sets evaluate the benefit that students receive by the use of Module 3 since they cover all its content. They also represent the only means to explore the efficacy of Module 3 since the performance of

the improvement evaluation by range of pretest score was not possible; this issue has been discussed in section 5.3.2.1.

Since the control group average did not show an improvement from the pretest to the posttest, it can be assumed, in theory, that all the improvement of the treatment group is due to the gain in knowledge induced by the module.

5.3.3 Survey

The Survey required the students to estimate the time they had spent on each of the modules. More importantly, it also dealt with the student's cognitive behavior by asking them to compare the use of the modules to textbooks and class lectures and to identify their preferred learning mode (see Table 5.4). This comparison was to be expressed by choosing one of seven different levels. The following sections present the feedback from the Survey.

5.3.3.1 Time to complete modules

One of the major complaints from students who participated in the evaluation exercise carried out by Shepherdson (2001) was that the examined module was too long to be thoroughly studied in one session. As a consequence the Mechanics Modules were divided into three separate modules. The input received from students in the Survey regarding the time spent per module, presented in Figure 5.18, shows that the partition of the tool into three modules was successful. This conclusion comes from the fact that the data show an evenly distributed time spent per module, where most of the students spent less than thirty minutes, with most of the students spending between 11 and 20 minutes per module. With this result, the benefits of the presentation of concepts mostly through the implementation of animations, imagery, and simulations is clearly demonstrated, not only improving engineering education, as has been shown in previous sections, but also in reducing time spent in the review and reinforcement of concepts learned in class.

The relatively short period of time typically spent by a student using each of the modules guarantees that the students will benefit from the complete content of each module, avoiding the problem of the student beginning to overlook the last sections of a long module once he/she gets tired and loses concentration.

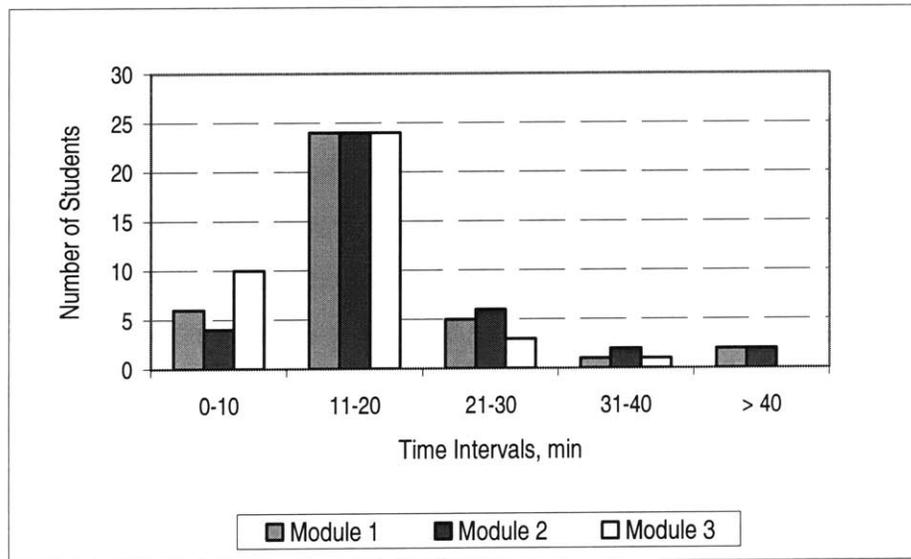


Figure 5.18 Time spent per module

5.3.3.2 Students cognitive behavior

The data collected in this section of the Survey also allows one to draw useful conclusions regarding the development of computer-based teaching tools. In this section, students were required to make comparisons between different learning approaches by rating their level of agreement with proposed statements. This level was indicated by the student on a scale from one to seven, where the former meant a strong disagreement and the latter was chosen for a strong agreement with the proposed statement. Table 5.4 shows the statements given to students and the average level of agreement that resulted from the data analysis. For completeness, the distributions of the answers obtained for each of the questions is presented in Appendix D .

Table 5.4 Survey average results

Proposed Statement	Average Agreement Level
Comparing the Modules that you just explored to Text Books that cover the same material you can say that:	
Modules provide a more intuitive feel for the concepts	5.6
The Modules helped me visualize more that the Text Books	5.8
The Modules were more engaging than Text Books	5.7
The Modules got me thinking more about the actual concepts	5.2
Modules gave me more confidence about a well learned material	4.7
Comparing the Modules that you just explored to Lectures that cover the same material you can say that:	
Modules provide a more intuitive feel for the concepts	4.6
The Modules helped me visualize more that the Lectures	5.0
The Modules were more engaging than Lectures	3.8
The Modules got me thinking more about the actual concepts	4.2
Modules gave me more confidence about a well learned material	4.4
How well do the following descriptions represent how you learn a complex mechanical concept:	
Memorizing the important features	4.2
Establishing a conceptual model (mental model) of how things work	5.9
Drawing a visual representation	5.8
Writing notes phrased exactly as they appear in a text	3.2
Using analogies to make connections between new and known content	5.0

The results of the comparisons between the modules and text books or lectures disclose a positive attitude, in general, of the students towards the use of the modules as teaching instruments. However, it is clear from the data that the preference for the modules over lectures is not as strong as the preference of the modules over textbooks. This observation provides evidence of the importance of the role of the teacher in the classroom.

Based on the results, the more popular methods that students use to learn complex mechanical concepts involve mental models, visual representations, and analogies. It can then be argued that the implementation of these concepts in the mechanics modules follow the student's current learning practices. However, results such as the relative popularity of the method of memorization of concepts and the fact that there was not a

strong disagreement with the method of learning complex mechanical concepts by writing notes phrased exactly as they appear in textbooks should provide good evidence about the diversity of methods employed by students to learn engineering concepts. Clearly, external factors such as the examination methods affect these answers also; this has, however, not been investigated in this survey.

5.4 Summary

This chapter covers the assessment of the teaching tools using general guidelines developed by the educational community to ensure high quality in the collection and analysis of data in educational research. These guidelines cover accepted principles for ensuring the validity of the results. The application of these principles yield what is known in education as a research design. Once these guidelines are presented, the reader is then introduced to the research design chosen for the evaluation of the Solid Mechanics Modules developed in this research project.

The chosen design was a pretest-posttest control group quasi-experiment applied to students enrolled in two undergraduate courses in the Architecture and Civil and Environmental Engineering departments at MIT. The total number of students participating in the exercise was 38, the majority of which were students fitting the criteria for the target audience of the modules. The evaluation procedure for the treatment group included the solution of a pretest followed by the use of the modules, ending with the solution of a posttest and a survey. Students assigned to the control groups solved the pretest and posttest before being given access to the modules. These students answered the survey at the end of the evaluation session.

The analysis of the data collected during the evaluation exercise show encouraging results in regard to the effectiveness of the modules and their potential of improving engineering education. Overall, the data demonstrate that students who are not familiar with the material addressed by the modules were able to dramatically improve their

score in the posttest. On the other hand, students who seemed to know the subject only showed minor improvement after using the modules.

Chapter 6 Summary and Conclusions

The potential of IT to revolutionize education so far has not been fully realized. Methods used by educators have not evolved sufficiently to keep pace with what is available in this new era of rapid technological advance. The dominant educational model is still the transmission model. Teachers have begun to play with digital technologies as a way of meeting the demands of the digital age, but with an approach attached to the transmission model which calls for the use of the lecture as the main means of instruction, the textbook on paper or in electronic form as a reference, and the graded assignment to assess how effectively the student has assimilated the given instruction.

The research work presented in this thesis set out to develop and assess the effectiveness of teaching modules in the area of mechanics that fully take advantage of the adaptive potential of IT through the implementation of a set of learning concepts, extracted from learning theories and pedagogical models. These modules represent an attempt to move away from the transmission model in engineering education by providing the student with an alternative educational instrument that explores non-conventional methods of instruction.

Throughout history, technological advances have improved education in different ways. The early years saw the application of technology innovations for the improvement of

school equipment; elemental implements such as paper, ink, notebooks, etc. became of better quality and more affordable thanks to technology. Advances then shifted their field of application. Technology started to provide better means for teaching; the introduction of apparatuses to improve visualization of phenomena such as maps, textbooks, and the blackboard among others, were all technological innovations that improved the learning environment in classrooms.

The latest stage of technological innovations came with the sophistication of the inventions being introduced into education. Equipment such as the magic lantern, film, radio, television, and ultimately, the computer have appeared over the last one hundred years. Some of these have been more successful than others but all of them have contributed to the improvement of education in general. History has also shown how the appearance of new technological advances in education triggers enthusiasts to predict abrupt changes in education and even the disappearance of the teacher as known today.

The first conclusion that comes from this historical recount is that current development of teaching tools should emphasize the introduction of these tools as an addition to current educational practice. This will allow one to make a smooth transition from the transmission model to a model in which different types of learning are explored by instructional instruments taking advantage of the capabilities of new technologies such as IT. Initially, it should always be a premise to present these tools as an aid to instructors, rather than as their replacement. Teachers should ultimately adapt themselves to new methods of teaching. This practice should also assure that the effort to introduce IT into the classrooms does not fail.

One important aspect of this research project was the consideration of educational theory during the development of teaching tools. This provided the opportunity to the author to experiment with different educational approaches for the presentation of technical concepts. It can be concluded from this, as a recommendation for the

development of larger-scale teaching tools, that it is important to have a team of tool developers who are well trained in the tool's subject matter as well as knowledgeable in educational methods. The scheme of having an educational tool developed by education theorists with technical support provided by a group of experts who do not get involved in the methods of presentation of the subject matter is not recommended. The understanding of the difficulty of different concepts of the subject matter while also having the knowledge of important aspects of educational theory has been essential for the approach chosen here. Part of the success that the tools developed within this research project have shown during their evaluation can be attributed to this combined approach.

Based on what has been discussed above, it was necessary to summarize some of the most relevant learning theories that provide important guidelines for the development of teaching tools. These guidelines have been presented in the form of teaching and learning requirements and an attempt has been made to implement these requirements in the development of the tools. These requirements remain as important components to be considered during the development of future tools.

It was argued before that the teachers will play an important role during the implementation of the teaching tools, since he/she is the ultimate promoter of the developed tools and the last link between the tools and the students. For this reason, the teacher has to be also considered during the development of this type of tools; moreover, in case of IT-based teaching tools, this consideration has to aim for a tool that is as flexible as possible for use by many different types of teacher. This guarantees the dissemination of the developed tool and its ultimate effectiveness in reaching many people through the Internet. This thesis work presents several pedagogical models for the implementation of the teaching tools to be considered during the development process.

Two teaching tools were developed in this research project; a set of modules on basic solid mechanics and one module on the use of the stereonet. The basic solid mechanics tool consists of three modules. The objective of the modules is to introduce undergraduate students to basic principles of structural mechanics such as structural supports, moments, couples, equilibrium equations, and internal forces. The modules are conceived as a supplement to what is taught in a more analytical context in the classroom by the teacher of the course. The modules present concepts through narrative content accompanied by animated imagery and simulations implemented in games aimed to motivate their use by student. The mechanics modules can be implemented in different pedagogical scenarios; the simulations serve the purpose for the use of the computer as an electronic blackboard and as a cognitive tool, while the narrative style and the order of presentation of concepts also fit well a model to use the computer as surrogate teacher. The technology with which the modules have been developed assures that the modules are available for access through the Internet.

The stereonet module is a teaching tool that covers a much more complex problem than that presented in the basic mechanics modules. The module uses imagery as the principal learning concept to present geometric principles that are difficult to understand for a student in a typical classroom environment because it involves analyses in three dimensions. Therefore, the implementation of three-dimensional imagery on the computer screen is the most important element of this module. The design of the module makes it ideal for its application in a pedagogical model that uses the computer as an electronic blackboard and also as a cognitive tool, while its narrative content also facilitates the computer use as a surrogate teacher. Among the principles covered by the module are the construction of stereographic projections, the description of planes in space, and the application of stereographic projections in rock wedge stability analyses. The technology used for the development of this module also allows users to access it through the Internet.

The development of the stereonet module benefited from the experience gained from the development and evaluation of the basic solid mechanics modules. The stereonet module should then be considered a contribution to engineering education made possible by the initial results of this research project. It should also provide the starting point for yet another loop of research in the development and implementation of teaching tools enabled by Information Technology in the engineering curriculum.

An essential aspect in developing any type of teaching and learning tool is to assess its effectiveness. An evaluation of the mechanics modules is presented in this thesis. This evaluation was preceded by a study of different research designs which led to the guidelines for the assessment exercise. Specifically, the evaluation of the three basic mechanics modules consisted of a “pretest-posttest control group quasi-experiment”. This exercise consists on the segregation of the evaluation participants into two groups. A test (pretest) preceding the exposure to the teaching tools is given to students of both groups. Only one of the groups, the treatment group, is then given access to the modules. Both groups are then again tested (posttest) after the treatment group has been exposed to the modules. The results of the posttests are compared and the benefit of using the tools is analyzed. The group that does not receive the treatment is called the control group.

Additionally, a Survey was conducted at the end of the assessment exercise in which students were asked to compare aspects of the modules with the used textbooks and lectures in the subject. Students were also asked to rate their agreement or disagreement with a number of statements describing methods to learn complex mechanics concepts.

This evaluation exercise was conducted on the students enrolled in two courses at MIT; one in the Architecture Department and one in the Civil Engineering Department. The total number of participants was 38 students. The evaluation for each course was carried on different dates and each course was divided into treatment and control groups according to the exercise procedure.

The analysis of the test scores reveals the benefits obtained from using the tools. Two conclusions can be drawn from this analysis; the first is that the use of the tools improves the students' comprehension of the subject matter covered by the mechanics modules. This is shown by the greater improvement achieved by students of the treatment groups as compared to that of the control groups in both evaluated courses.

The second conclusion that can be drawn is that there is a tendency for students who performed the worst in the pretest to show the most improvement after exposure to the teaching tools. Based on this observation, the benefit obtained from the use of the modules by a student who is having problems with the subject is to increase the student's confidence and interest in the subject.

The results of the Survey disclose a positive attitude, in general, towards the use of the modules as teaching instruments. The data show a clear preference for the modules over textbooks. They also show that while there is some preference of modules over lectures, students still prefer some aspects of lectures when compared to those of the modules. This observation reinforces the idea of proposing a change in the transmission model but keeping some of its good aspects such as the personal relation between the teacher and the student.

The results obtained in the section of the Survey in which students are asked to comment about methods commonly used to learn complex mechanics concepts, confirmed the assumptions made during the planning stages of the modules. Specifically, animations, models, and simulations appear to be the most effective methods of instruction. However, this section also revealed the diversity in the student's learning styles.

In summary, this research project developed two teaching tools that move away from the transmission model typically used in engineering education. This development based on concepts of educational theory led to improved education by presenting

knowledge through a more effective experience to the student. These concepts were implemented in the tools in the form of complex imagery, specialized feedback, animations, and simulated games that improve understanding by interaction between the computer and the student. This approach was then assessed, where its effectiveness was demonstrated and its benefits were shown. The developed tools remain as important contributions to engineering education and provide a sound basis to encourage development of similar tools that represent an alternative to the transmission model.

Chapter 7 Recommendations for Future Work

This chapter discusses recommendations for future research work related to the topic of this thesis. The recommendations can be grouped into three categories: 1) recommendations on the future improvements and usage of the teaching tools developed in this thesis; 2) recommendations for developing new teaching tools; and 3) recommendations on how to assess teaching tools.

Recommendations on the future improvements and usage of the teaching tools developed

Although the tools developed in this research project are fully functional, and their effectiveness in a classroom environment has been demonstrated, there is still room for their improvement. The mechanics modules require the enhancement of their navigational capabilities. They can also be improved by replacing some of their narrative content with more interactive elements to take them even farther from the framework of the transmission model. This recommendation particularly refers to the improvement of the presentation of analytical derivations, which, it is thought, still lack the desired level of interaction and level of achievement in generating a mental model in the student that facilitates understanding.

The stereonet modules are to be improved by the addition of interactive elements represented in simulated games that challenge the student and represent the

implementation of learning concepts such as feedback and reinforcement and problem-solving. In particular, the instruction of the equal angle stereographic projection would be enhanced through a game where students are asked to draw the projection of a given plane. This game would provide feedback of the student's input. The presentation of the stability analysis methodology also provides an opportunity for the improvement of the module, where more interactivity, perhaps in the form of feedback to student's response to questions, could be implemented.

The effort put into the development of the teaching tools presented in this thesis would be lost without their dissemination and implementation in the classroom. So far, there is evidence of the tools' effectiveness in improving engineering education; however, this evidence is useless if the modules are not used. It was observed during the development process that students were influenced by their teacher's reaction towards the modules. A teacher who is enthusiastic about it would lead students to rely on their use and be confident that the material presented would be useful for their learning experience. During the evaluation process, many students expressed their approval towards the modules but regretted that they were not part of the recommended support material for their course and, therefore, their use would be limited. This is a clear example of how the preparation of the modules itself does not guarantee their successful application. The modules need to be adopted by a teacher and promoted in class, be it through their use during class presentations (use of the computer as an electronic blackboard) or by recommending their review after class as a supplement to what has been covered.

The notion of a library of modules still needs to be pursued. Specifically, the basic solid mechanics modules developed in this project are part of a series of modules developed on the subject matter. These modules are iBeam (Viteri, 2003), FrameWorks (Sthapit, 2002), TrussWorks (Sthapit, 2002) and the Steel Profile Database (Nguyen, 2002). Although the content of these modules complement each other, there is not an implemented connection between them that allows a student to move from one module

to the other, making the student's learning experience more effective through the use of tools that have a broader spectrum of teaching concepts. An effort should be made to achieve this connection between modules.

The evaluation performed on the mechanics modules, though it follows a scientific approach, is somewhat limited to the setting of an educational institution such as MIT, where the academic performance of students may be higher than that of the average potential users of the modules. The performance of additional assessment of the mechanics modules, and the first evaluation of the stereonet module, including assessments outside of the MIT setting, would allow one to generalize the results obtained in this research.

Recommendations for developing new teaching tools

As discussed before, the development of future teaching tools should be undertaken by a team in which developers are well trained in the tool's subject matter as well as people knowledgeable in educational methods. This scheme guarantees that the developers understand the difficulty of different concepts of the subject matter and are also knowledgeable in important aspects of educational theory. In addition, the developing team should include, or at least receive ongoing feedback from a teacher of the subject matter. The teacher's experience in presenting concepts in class is a valuable resource when identifying difficult concepts.

Educational tools should not take a student longer than 45 minutes to cover the material, or should be equipped with navigational elements that allow the student to clearly divide his/her work into sessions of such duration. Navigational elements should also allow students to identify their advance within the module and to come back to a specific section if necessary without having to go through a lot of material previously covered.

New tools should consider the application of the teaching concepts discussed in this work but their development should always consider the search for new concepts that help students understand the specific theory covered while taking advantage of what technology offers at the time.

A last recommendation for the development of teaching tools, is to always consider that the success of each tool is associated with how well accepted the tool is by the academic community. With this in mind, each tool should be developed in such a way that it adjusts itself to various pedagogical models that different teachers may be willing to use.

Recommendations on how to assess teaching tools

The procedure followed in testing the students yielded the positive results that students improve after having learned with the modules. However, it is recommended that future evaluation exercises, similar to the one undertaken in this research project, be performed in shorter sessions. Ideally, an evaluation session should be performed for each tool which, as has been recommended, should not take longer than 45 minutes to study. This practice should guarantee that the evaluation participants are focused on the tool for the entire evaluation time making its results more reliable. Students working in longer sessions tend to lose attention towards the end of the evaluation.

One aspect that showed flaws in the evaluation performed in this project was the number of questions asked and the fact that no partial credit could be awarded to students for their answers. This defect was most evident when analyzing the results obtained from section three of the evaluation. This section awarded only 3 points in each test, from which trends and improvements could not be disclosed accurately. It is recommended that questionnaires are prepared so that a sufficient number of questions are asked and that partial credit can be awarded in those questions. This results in a larger grade spread and allows for the observation of better trends and the disclosure of real improvements attributed to the use of the tools.

Non-statistically validated evaluations such as the survey conducted here should not be overlooked. The feedback provided during these surveys and other methods such as focus groups are powerful and may lead to important contributions during the development of a tool. Furthermore, listening to comments and reactions directly from the users discloses information that is otherwise impossible to obtain from a numerical assessment.

Appendix A Equal Angle Projection Derivation and Programming

This appendix presents the derivation of the equations along with the Lingo code associated with the simulation that allows the user to observe in real time how the equal angle projection of a plane behaves according to changes in the dip of the plane.

Figure A.1 shows a plane dipping at an angle i and its corresponding equal angle projection. The simulation draws lines similar to lines AD and AE to represent the projection of the intersection of the plane with the lower hemisphere of the reference sphere. C and B are the intersection points between the referred lines and the horizontal plane. The derivation focuses on defining the length (d) and angles α and γ' for each line. Additionally, the x,y coordinates for the point of intersection of each line with the horizontal plane is defined. The simulation draws one line for every 10° -increment in the value of the γ angle, from -90° to 90° . This results in 19 lines drawn. Since Lingo does not allow for real time manipulation of the circle arc representing the projection, this arc is portrayed by the simulation as a series of cylinders connected by their ends. Each cylinder end is located at the point where each projecting line intersects the horizontal plane, in other words, points such as C and B in Figure A.1 are to be connected by a

cylinder for the representation of the plane projection. Since the coordinates of these points have also been calculated, the location and orientation of the cylinders making up the projection is easily determined. The Lingo code included in this appendix corresponds to the instructions that handle the response of the module to the user handling the slider rule that modifies the dip angle of the plane in the model.

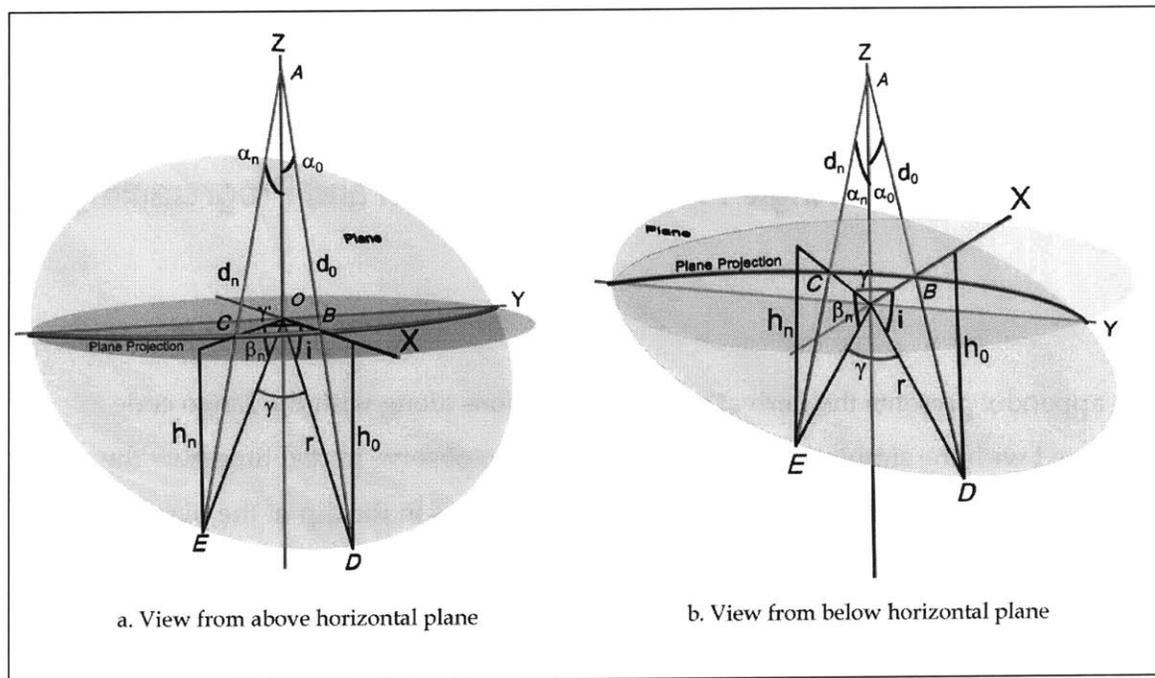


Figure A.1 Equal angle stereographic projection derivation

From the geometry shown in Figure A.1:

$$h_n = r \cos \gamma \sin i$$

Where:

r : radius of reference sphere

i : plane dip

γ : angle between dip line (OD) and line OE

$$\sin \beta_n = \frac{h_n}{r}$$

Where:

β_n : apparent dip

$$\alpha_n = 45 - \frac{\beta_n}{2}$$

$$d_n = \frac{r}{\sin \alpha_n} \sin[90 + \beta_n]$$

The distance from O to C , defined as a is then:

$$a = \frac{r}{\sin(90 - \alpha_n)} \sin \alpha_n$$

γ' is defined as the angle between lines OB and OC . Its expression with respect to γ and the dip angle is:

$$\tan \gamma' = \frac{\tan \gamma}{\cos i}$$

The (x,y) coordinates of point C can now be defined as:

$$x = a \cos \gamma'$$

$$y = a \sin \gamma'$$

Lingo code:

```
global rotationX
global rotationY
global rotationZ
global pMember
global inclina
global align
```

```

on mouseDown (me)
  the floatPrecision = 3
  repeat while the stillDown
    set the locH of sprite me.spriteNum to constrainH(me.spriteNum - 1, the mouseH)
    slidX = the locH of sprite me.spriteNum
    barX = the locH of sprite (me.spriteNum - 1)
    rotationXPlane = 90 * (slidX - barX) / ((the width of sprite (me.spriteNum - 1)) / 2)
    currentX = pMember.model("Rotating Plane").transform.rotation.x
    toRotate = rotationXPlane - currentX
    pMember.model("Rotating Plane").rotate(vector(toRotate, 0, 0), #self)
    dip1 = rotationXPlane * pi() / 180

    rotateFan(dip1)
    drawProjection(dip1)
    inclina = rotationXPlane
    if (align > 0) and (align < 90) then
      if inclina < 0 then
        buza = " NE"
      else
        buza = " SW"
      end if
    else
      if (align > 90) and (align < 180) then
        if inclina < 0 then
          buza = " NW"
        else
          buza = " SE"
        end if
      else
        if (align < 0) and (align > -90) then
          if inclina < 0 then
            buza = " SE"
          else
            buza = " NW"
          end if
        else
          if (align < -90) and (align > -180) then
            if inclina < 0 then
              buza = " SW"
            else
              buza = " NE"
            end if
          end if
        end if
      end if
    end if

    if pMember.number = 2 then buza = ""
    if rotationXPlane = 0 or abs(rotationXPlane) = 90 then buza = ""

    put abs(rotationXPlane) & buza into member "Dip Angle"
  end repeat
end on mouseDown

```

```

    updateStage
  end repeat
end mouseDown

```

```

on rotateFan(dip)
  rotateRay(dip, 1)
  rotateRay(dip, 2)
  rotateRay(dip, 3)
  rotateRay(dip, 4)
  rotateRay(dip, 5)
  rotateRay(dip, 6)
  rotateRay(dip, 7)
  rotateRay(dip, 8)
  rotateRay(dip, 9)
  rotateRay(dip, 10)
  rotateRay(dip, 11)
  rotateRay(dip, 12)
  rotateRay(dip, 13)
  rotateRay(dip, 14)
  rotateRay(dip, 15)
  rotateRay(dip, 16)
  rotateRay(dip, 17)
  rotateRay(dip, 18)
  rotateRay(dip, 19)
end rotateFan

```

on rotateRay(dip2, which) -- Procedure called for each line showing the plane projection

```

stringProj = "Seg" & string(which)
stringRay = "Ray" & string(which)
gamma = ((which - 10) * 10) * pi() / 180
h = 100 * sin(abs(dip2)) + 100 * (cos(abs(gamma)) - 1) * sin(abs(dip2))
if (h = 100) or (h = -100) then
  beta = pi()/2
else
  beta = atan((h / sqrt(100 * 100 - h * h)))
end if
alfa = pi() / 4 - beta / 2
if alfa = 0 then
  d = 200
else
  d = (100 / sin(alfa)) * sin(pi() / 2 + beta)
end if
k = which / 10
mult = 1 - 2 * k
if (dip2 = (pi() / 2)) then
  gammaPrima = mult * pi() / 2
else
  gammaPrima = atan(tan(gamma) / cos(abs(dip2)))
end if
xPrima = (d / 2) * sin(alfa) * sin(gammaPrima)

```

```

yPrima = (d / 2) * sin(alfa) * cos(gammaPrima)
zPrima = (d / 2) * cos(alfa)
if (dip2 < 0) then
  pMember.model(stringRay).transform.rotation.x = alfa * 180 / pi() - 90
  pMember.model(stringRay).transform.position = vector(-xPrima, yPrima, -zPrima)
else
  pMember.model(stringRay).transform.rotation.x = -alfa * 180 / pi() + 90
  pMember.model(stringRay).transform.position = vector(xPrima, -yPrima, -zPrima)
end if
pMember.model(stringRay).transform.rotation.z = gammaPrima * 180 / pi()
pMember.modelResource(stringRay).height = d

```

--Projection Rotation: locates and rotates the cylinders making up the projection

```

if (which < 19) then
  a = (100 / sin(pi() / 2 - alfa)) * sin(alfa)
  gammaNext = ((which - 9) * 10) * pi() / 180
  hNext = 100 * sin(abs(dip2)) + 100 * (cos(abs(gammaNext)) - 1) * sin(abs(dip2))
  if (hNext = 100) or (hNext = -100) then
    betaNext = pi()/2
  else
    betaNext = atan((hNext / sqrt(100 * 100 - hNext * hNext)))
  end if
  alfaNext = pi() / 4 - betaNext / 2
  aNext = (100 / sin(pi() / 2 - alfaNext)) * sin(alfaNext)
  gammaPrimaNext = atan(tan(gammaNext) / cos(abs(dip2)))
  x1 = a * sin(gammaPrima)
  y1 = a * cos(gammaPrima)
  x2 = aNext * sin(gammaPrimaNext)
  y2 = aNext * cos(gammaPrimaNext)
  xBar = (x1 + x2) / 2
  yBar = (y1 + y2) / 2
  dc = sqrt((x2 - x1) * (x2 - x1) + (y2 - y1) * (y2 - y1))
  rotZ = atan ((y2 - y1) / (x2 - x1))
  if (dip2 >= 0) then
    pMember.model(stringProj).transform.rotation.x = 90 - rotZ * 180 / pi()
    pMember.model(stringProj).transform.position = vector(-xBar, -yBar, -100)
  else
    pMember.model(stringProj).transform.rotation.x = -90 + rotZ * 180 / pi()
    pMember.model(stringProj).transform.position = vector(-xBar, yBar, -100)
  end if
  pMember.modelResource(stringProj).height = dc
end if

```

end rotateRay

Appendix B Tests for Evaluation of Mechanics Modules

B.1. Pretest Control Group

Survey Type 3

User ID: _____

Department you are enrolled in:

Civil Engineering Architecture Mechanical Engineering Aeronautics Not listed here

Year enrolled:

Freshman Sophomore Junior Senior Graduate Instructor

Your gender:

Male Female

Number of courses taken that you think are related to the subject:

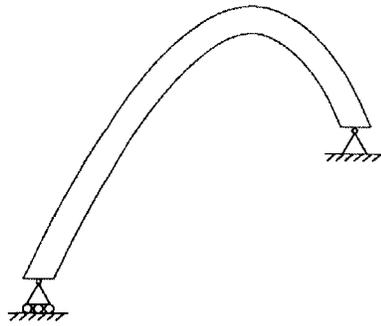
None 1 2 3 4 More than 4

Please answer the following questions. Remember, this is a study oriented to assess the effectiveness of alternative teaching methods, it is not intended to evaluate your knowledge in the subject nor will it be considered in your term's grade. It is important that you mark the answers that you are convinced are the correct ones. Try not to guess the answer. You can leave blank the answers that your are not sure about, there is nothing wrong in doing so.

Section 1

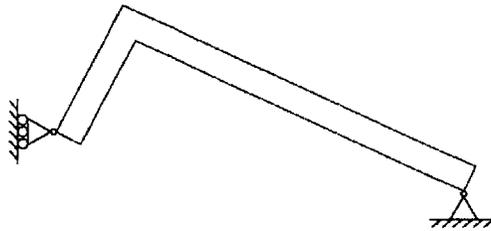
1.1 Select TRUE if you think that the following structural elements are stable under any kind of loading. Select FALSE if you do not believe so.

1.1.a



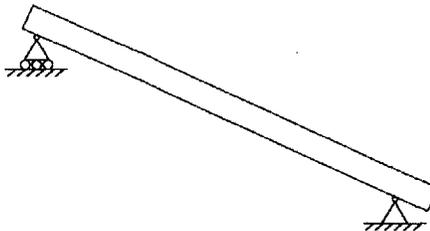
True False

1.1.b



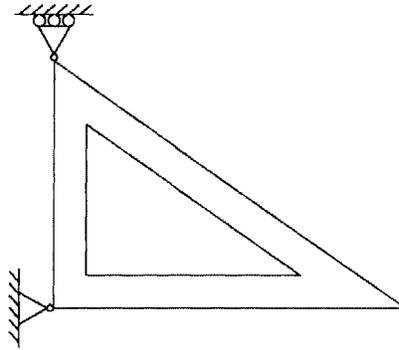
True False

1.1.c



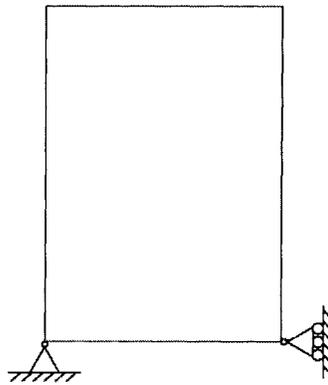
True False

1.1.d



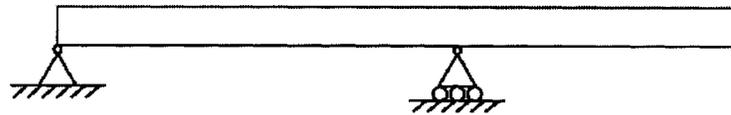
True False

1.1.e



True False

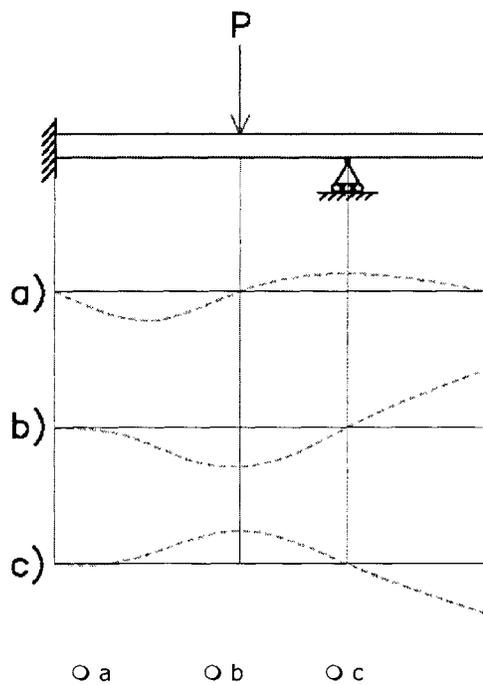
1.1.f



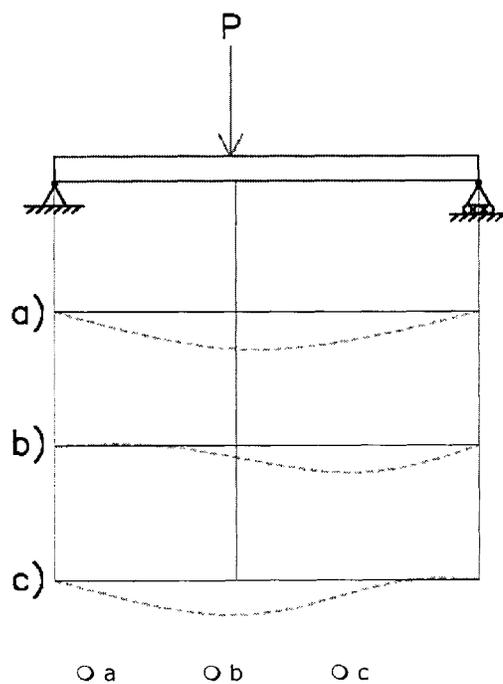
True False

1.2 Indicate which is the correct deformed shape for the arrangement shown.

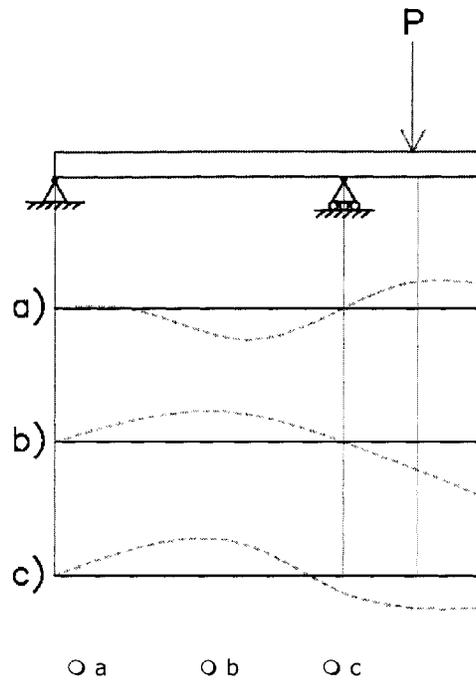
1.2.a



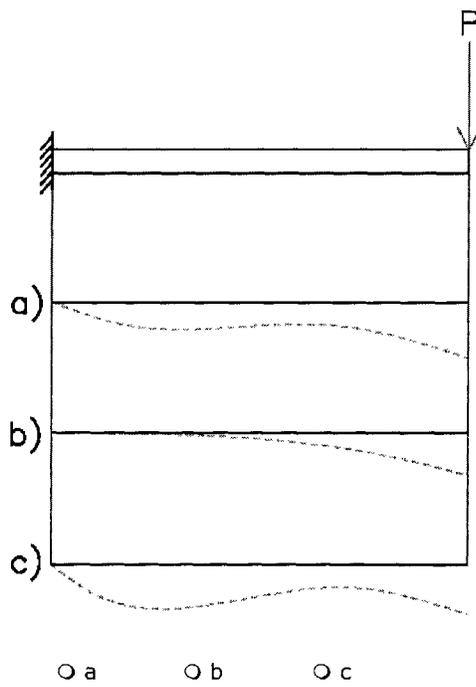
1.2.b



1.2.c

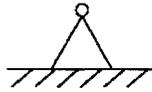


1.2.d



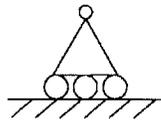
1.3 Determine the number of reactions that each of the support elements represented below can provide.

1.3.a



0 1 2 3 4

1.3.b



0 1 2 3 4

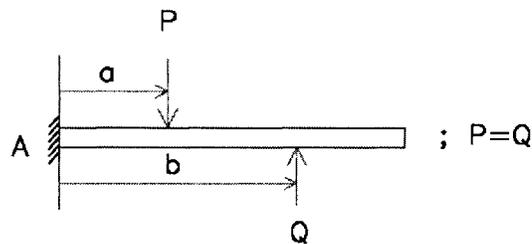
1.3.c



0 1 2 3 4

1.4 Write down the expression for moments at A and indicate the sense of this moment (clockwise, counterclockwise)

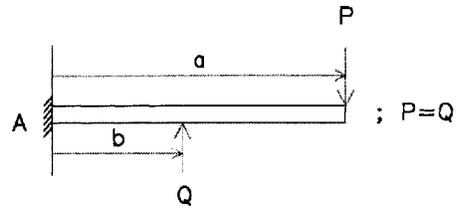
1.4.a



$M_A =$ _____

Clockwise Counterclockwise

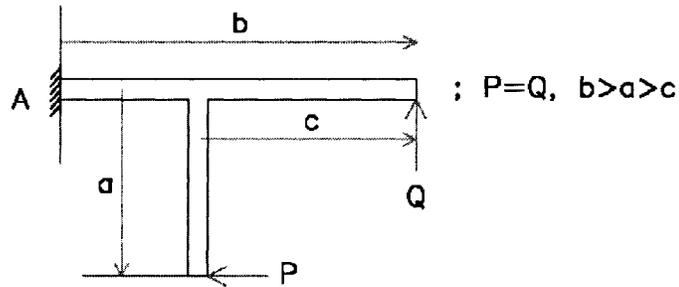
1.4.b



$M_A =$ _____

- Clockwise Counterclockwise

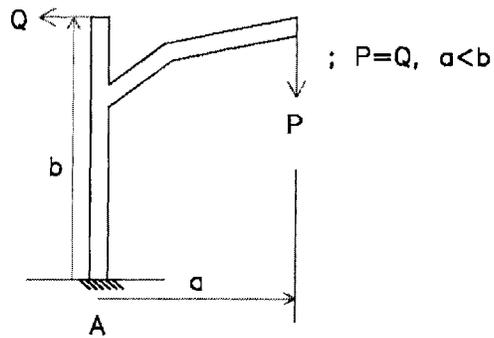
1.4.c



$M_A =$ _____

- Clockwise Counterclockwise

1.4.d



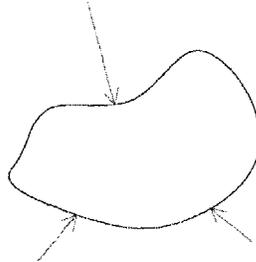
$M_A =$ _____

- Clockwise Counterclockwise

Section 2

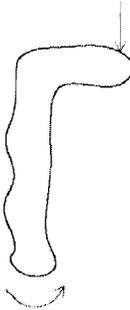
2.1 Choose TRUE if you think that the following free bodies appear (estimate - no exact calculations) to be in equilibrium, choose FALSE if you don't think so. Note that supports are not being used in this case, only the shown forces are being applied on the free bodies.

2.1.a



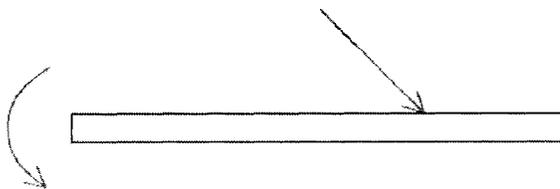
True False

2.1.b



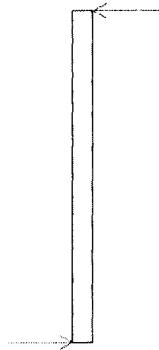
True False

2.1.c



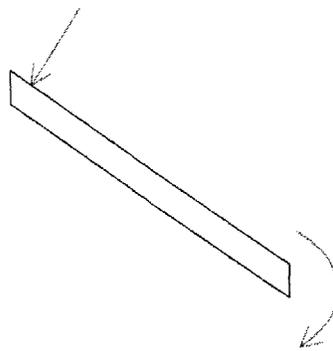
True False

2.1.d



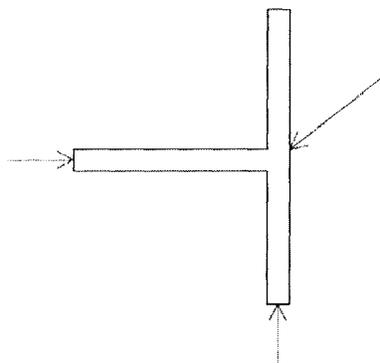
True False

2.1.e



True False

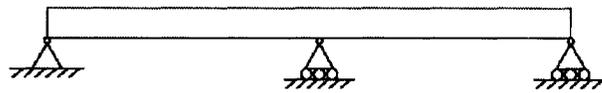
2.1.f



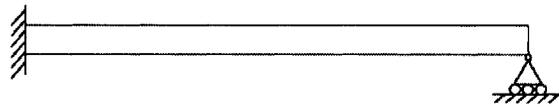
True False

2.2 Determine if the body is statically determinate or not

2.2.a



- Statically Determinate Statically Indeterminate



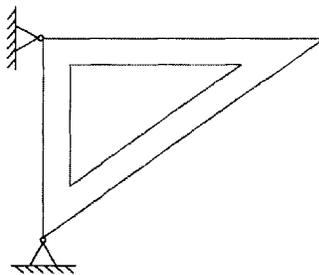
- Statically Determinate Statically Indeterminate

2.2.c



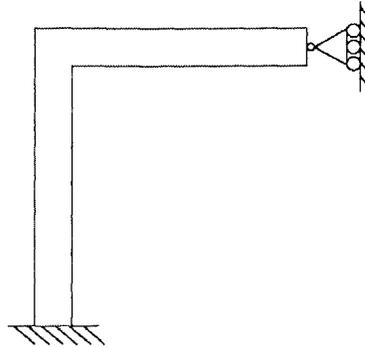
- Statically Determinate Statically Indeterminate

2.2.d



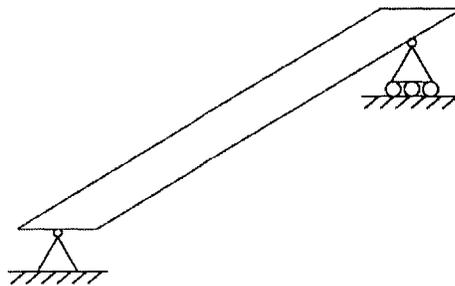
- Statically Determinate Statically Indeterminate

2.2.e



- Statically Determinate
- Statically Indeterminate

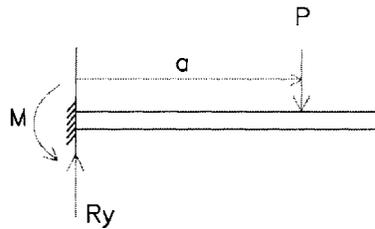
2.2.f



- Statically Determinate
- Statically Indeterminate

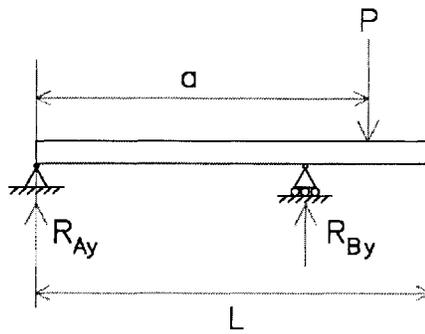
2.3 Pick the correct expression for a reaction

2.3.a



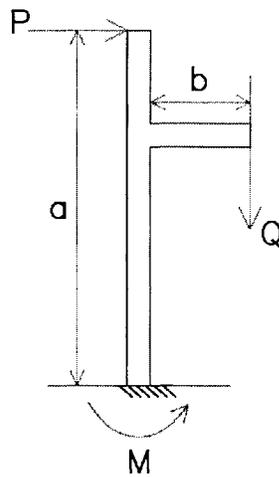
- $M = P \cdot a$
- $R_y = P \cdot a - M$
- $M = R_y \cdot a - P \cdot a$
- None of the above

2.3.b



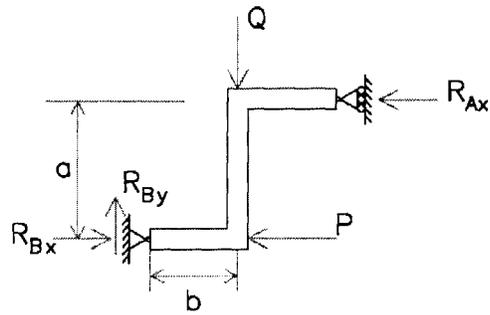
- $R_{Ay} = (P \cdot a) / (L - a)$
- $R_{By} = (P \cdot L) / a$
- $R_{By} = (P \cdot a) / L$
- None of the above

2.3.c



- $M = Q \cdot a - P \cdot b$
- $M = Q \cdot b + P \cdot a$
- $M = P \cdot a/2 + Q \cdot b/2$
- None of the above

2.3.d

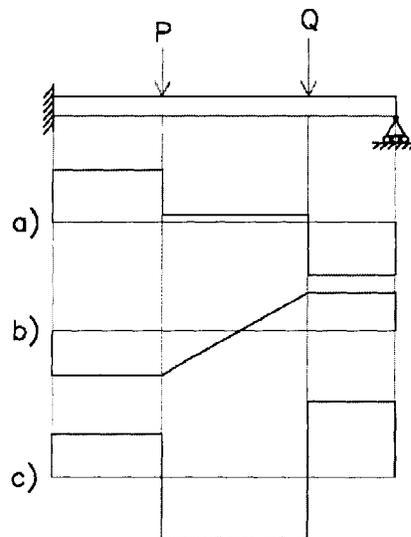


- $R_{bx} = P$
- $R_{bx} = R_{ax}$
- $R_{ax} = Q \cdot (b/a)$
- None of the above

Section 3

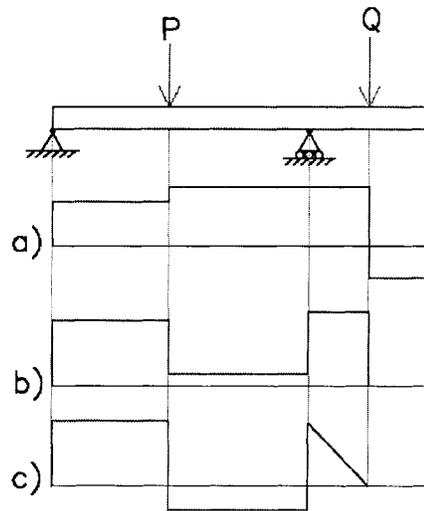
3.1 Determine the correct shear diagram for each case

3.1.a



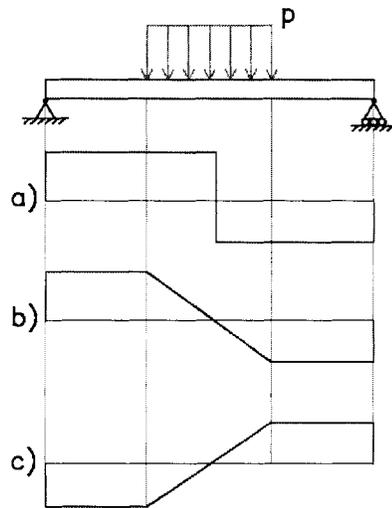
- a
- b
- c

3.1.b



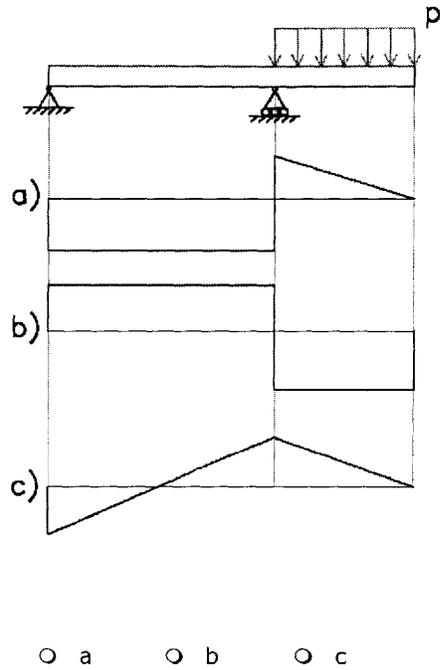
- a b c

3.1.c



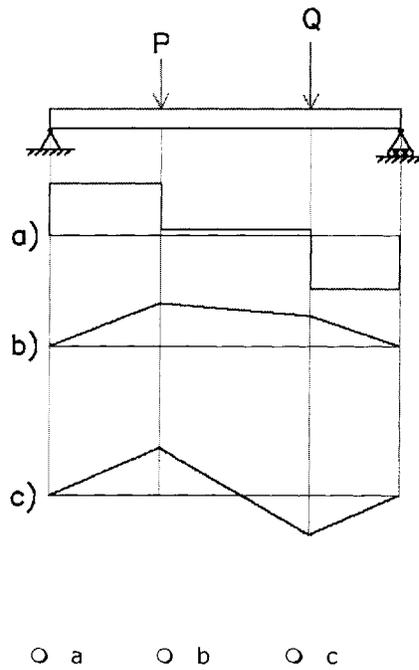
- a b c

3.1.d

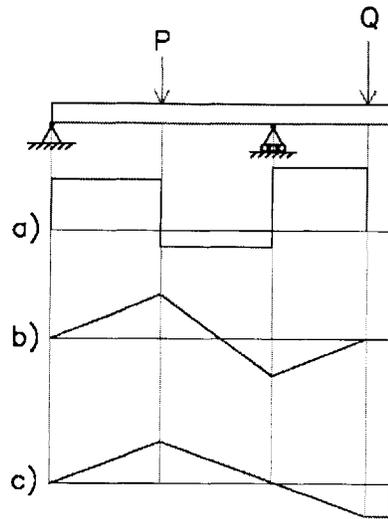


3.2 Determine the correct moment diagram for each case

3.2.a



3.2.b



- a b c

The End!
Please press the Submit button.
Thank you for your cooperation!

B.2. Survey

User ID: _____

Please use the same User ID you used for the first survey.

How much time (in minutes) did it take you to complete each of the modules:

Module 1: _____ minutes

Module 2: _____ minutes

Module 3: _____ minutes

To what degree do you agree with the following statements?

Mark 1 for a strong disagreement and 7 for a strong agreement. Use the full scale in between.

1. Comparing the Modules that you just explored to Text Books that cover the same material you can say that:

a. The Modules provide a more intuitive feel for the concepts.

1 2 3 4 5 6 7

- Strongly Disagree Strongly Agree
 b. The Modules helped me visualize more than the Text Books.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 c. The Modules were more engaging than Text Books.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 d. The Modules got me thinking more about the actual concepts.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 e. The Modules gave me more confidence about a well learned material.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree

2. Comparing the Modules to Lectures on the subject you can say that:

- a. The Modules provide a more intuitive feel for the concepts.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 b. The Modules helped me visualize more than the Lectures.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 c. The Modules were more engaging than Lectures.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 d. The Modules got me thinking more about the actual concepts.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 e. The Modules gave me more confidence about a well learned material.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree

3. How well do the following descriptions represent how you learn a complex mechanical concept.

- a. Memorizing the important features.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 b. Establishing a conceptual model (mental model) of how things work.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 c. Drawing a visual representation.
 Q1 Q2 Q3 Q4 Q5 Q6 Q7
- Strongly Disagree Strongly Agree
 d. Writing notes phrased exactly as they appear in a text.

Appendix C Personal Improvement Charts per Question Set

Figures C.1 through C.8 present each student's improvement for all question sets.

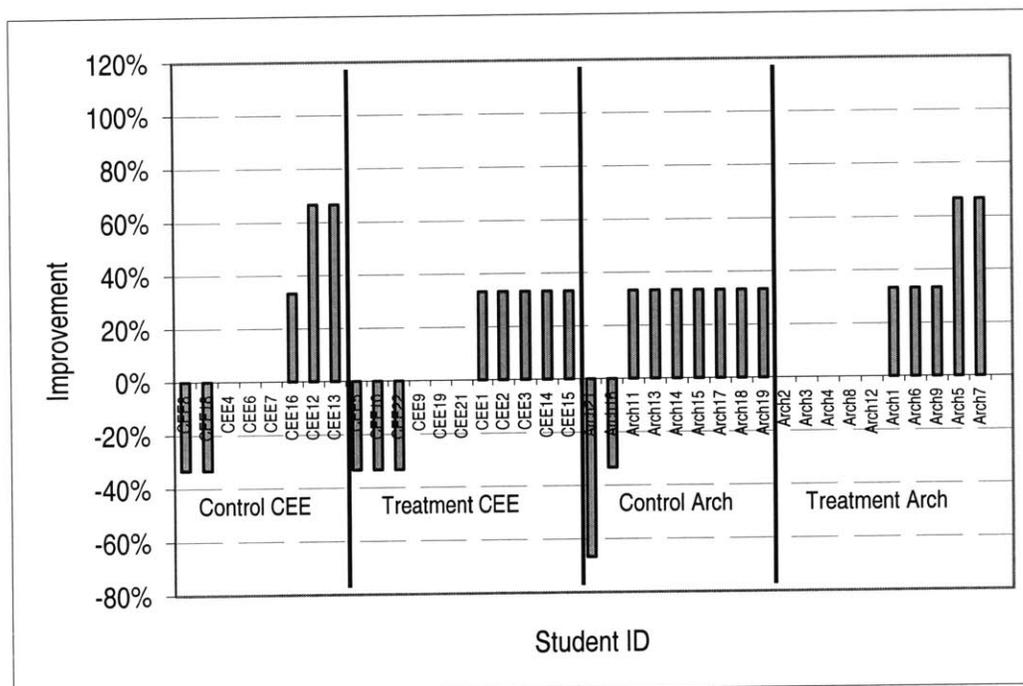


Figure C.1 Personal improvement in question set 1.1

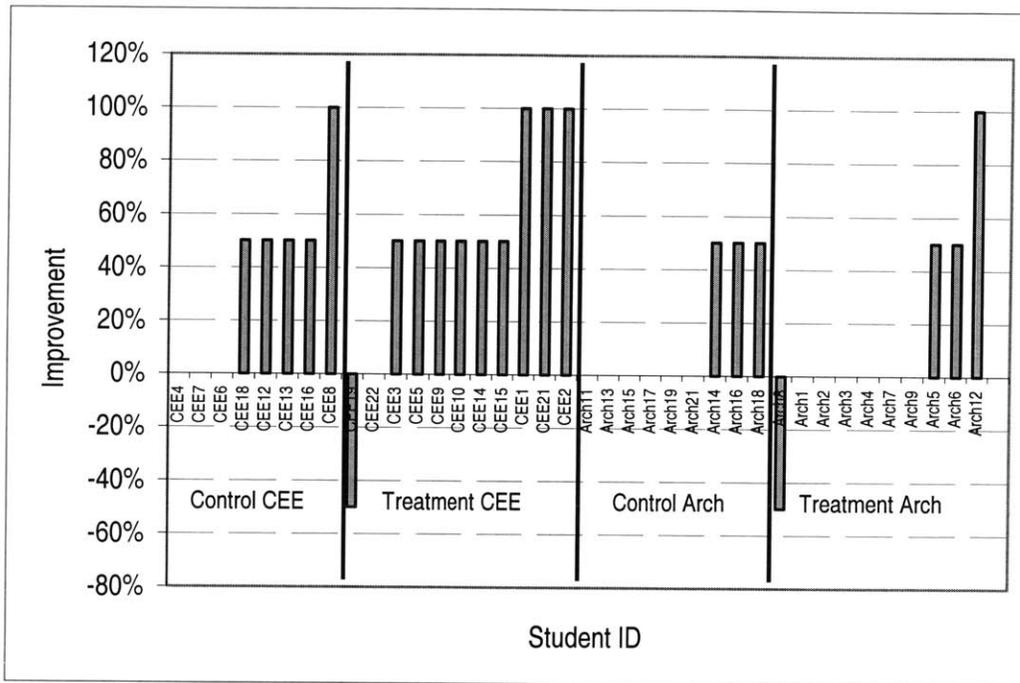


Figure C.2 Personal improvement in question set 1.2

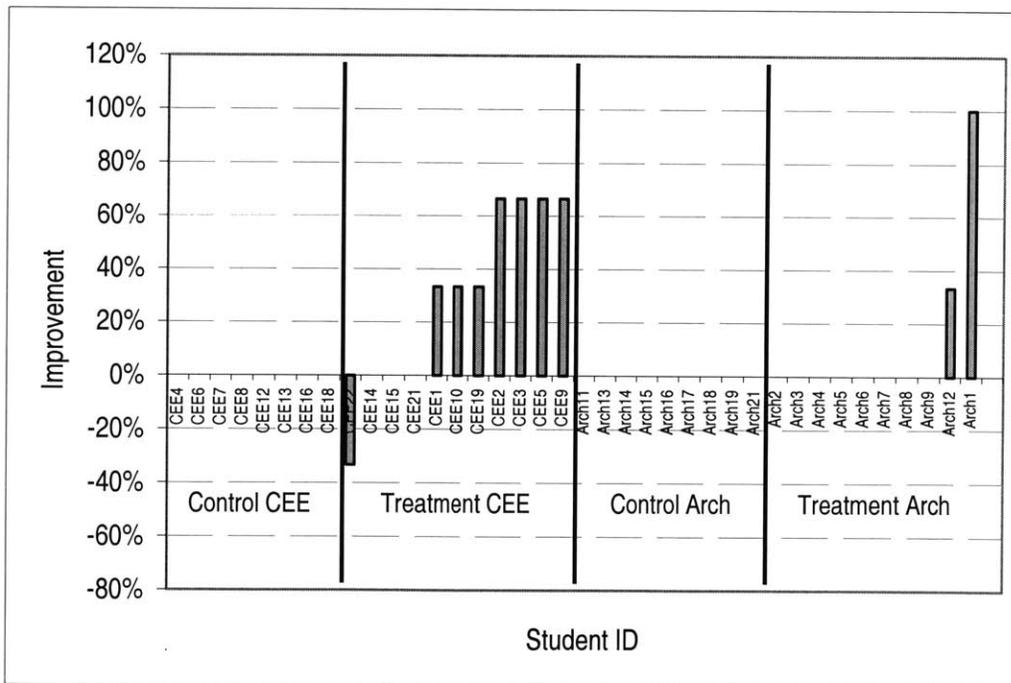


Figure C.3 Personal improvement in question set 1.3

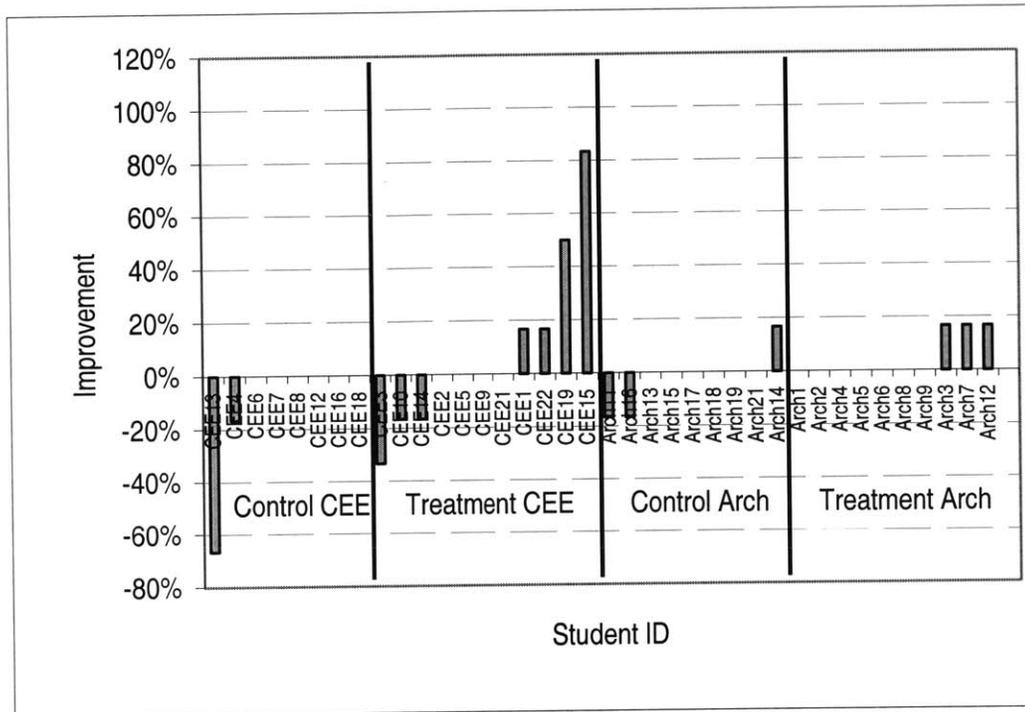


Figure C.4 Personal improvement in question set 1.4

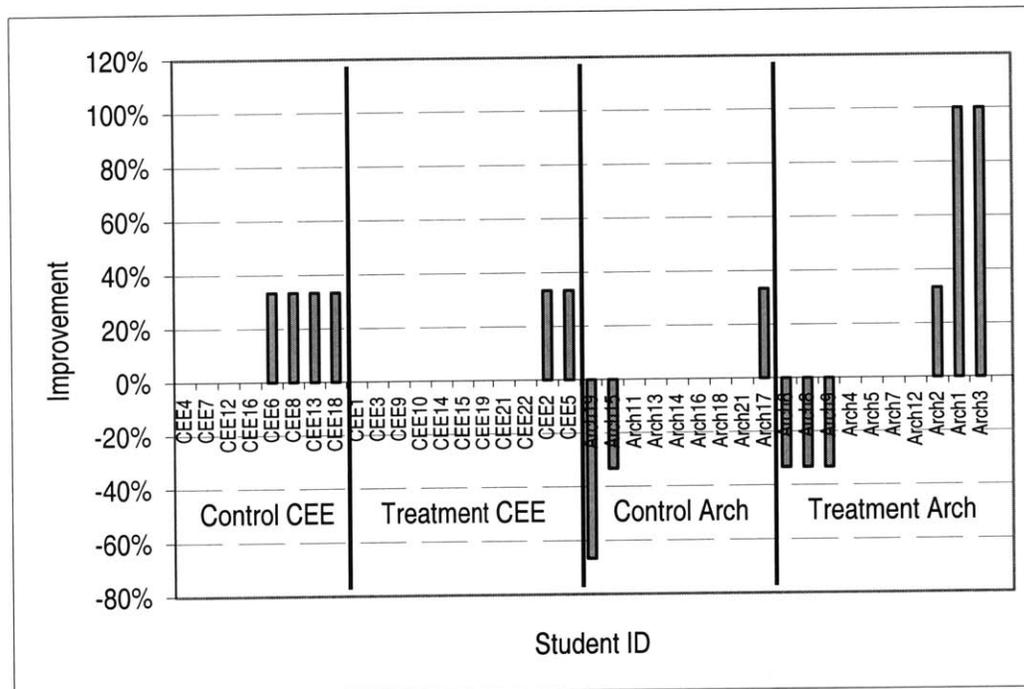


Figure C.5 Personal improvement in question set 2.1

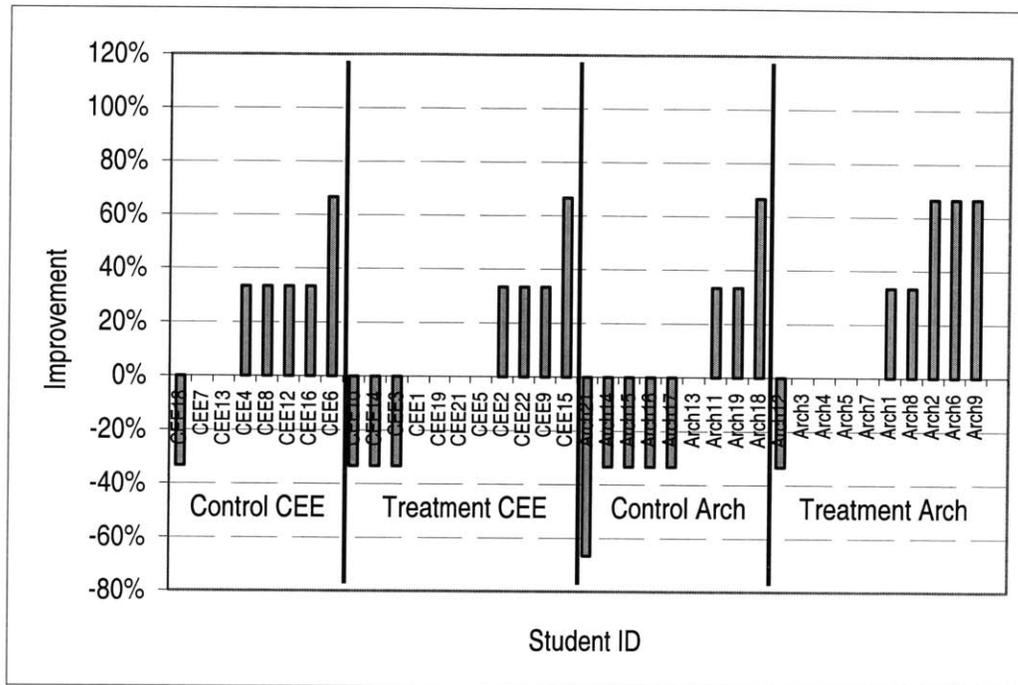


Figure C.6 Personal improvement in question set 2.2

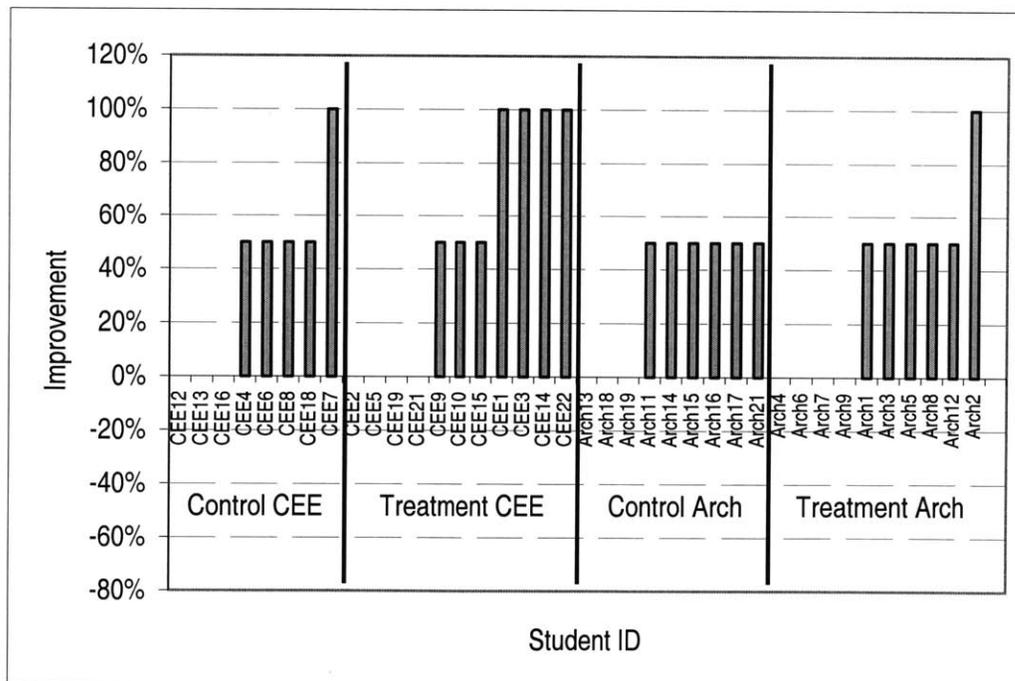


Figure C.7 Personal improvement in question set 2.3

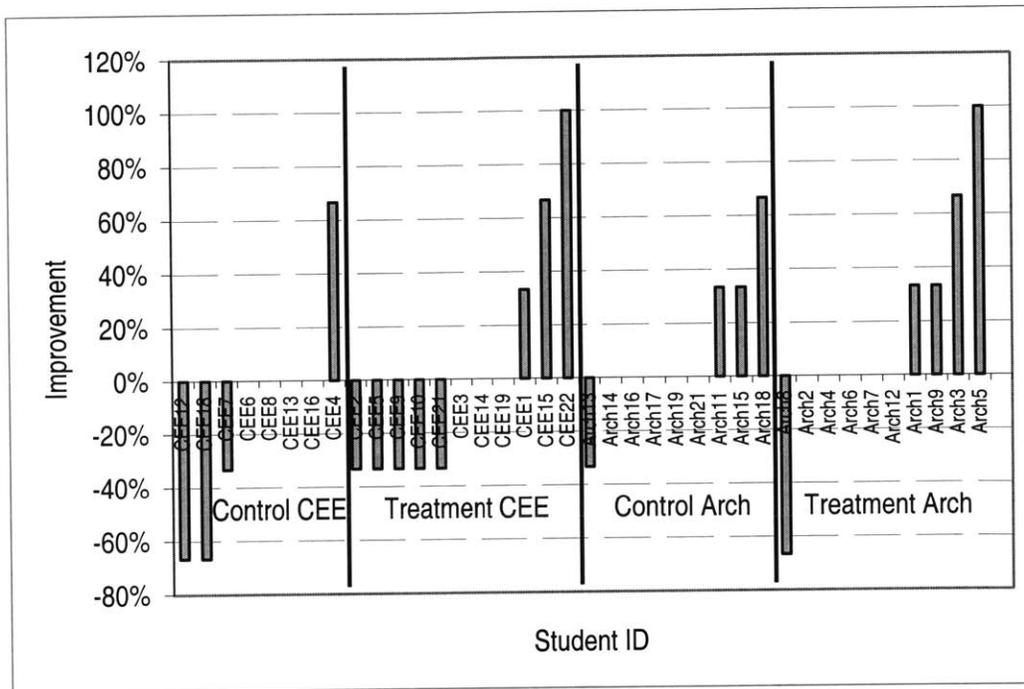


Figure C.8 Personal improvement in question sets 3.1 & 3.2

Appendix D Survey Results

The following charts present a distribution of the number of students and their level of agreement with the proposed statement.

The statements formulated in figures D.1 through D.5 compare the modules against text books that cover the same material, while figures D.6 through D.10 compare the modules against lectures. Lastly, figures D.11 through D.15 show the level of agreement of students when asked how well the suggested descriptions represent how they learn a complex mechanical concept.

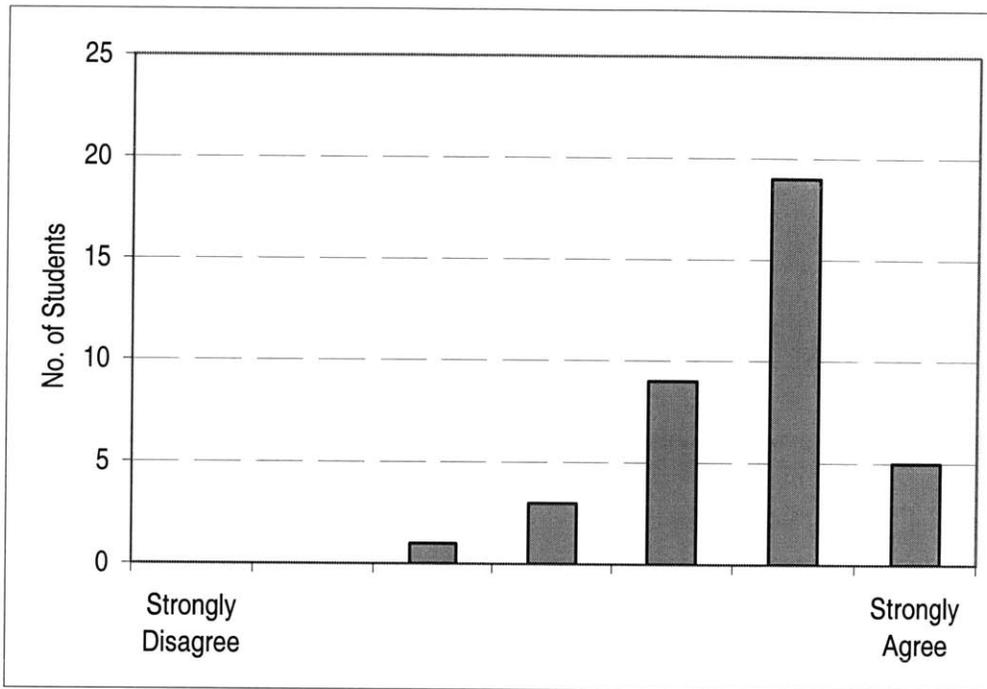


Figure D.1 Response to "The Modules provide a more intuitive feel for the concepts"

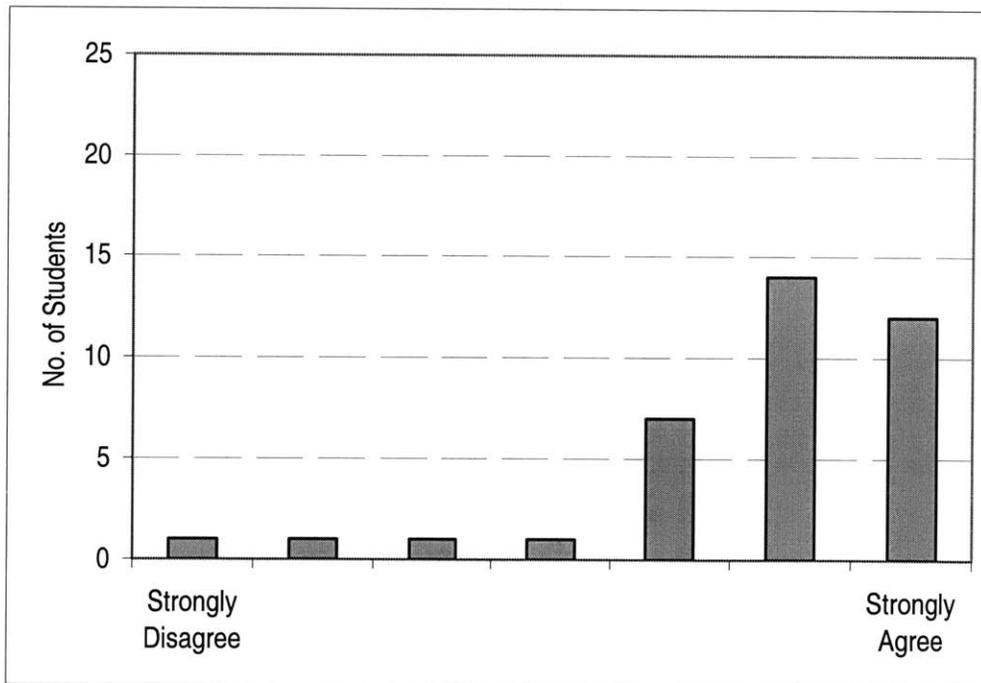


Figure D.2 Response to "The Modules helped me visualize more than the Text Books"

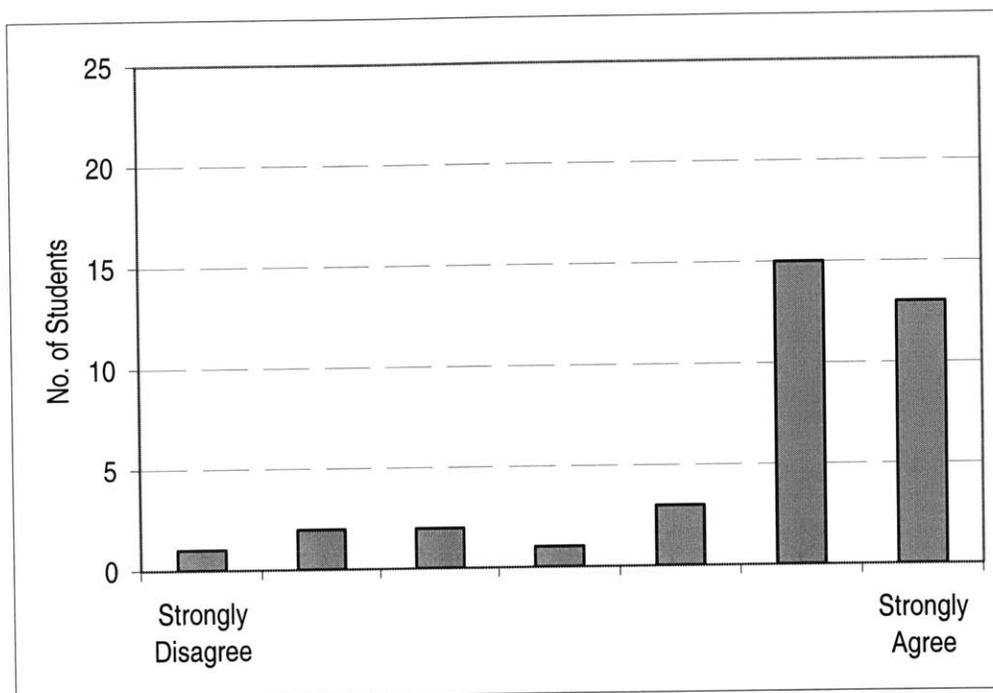


Figure D.3 Response to "The Modules were more engaging than Text Books"

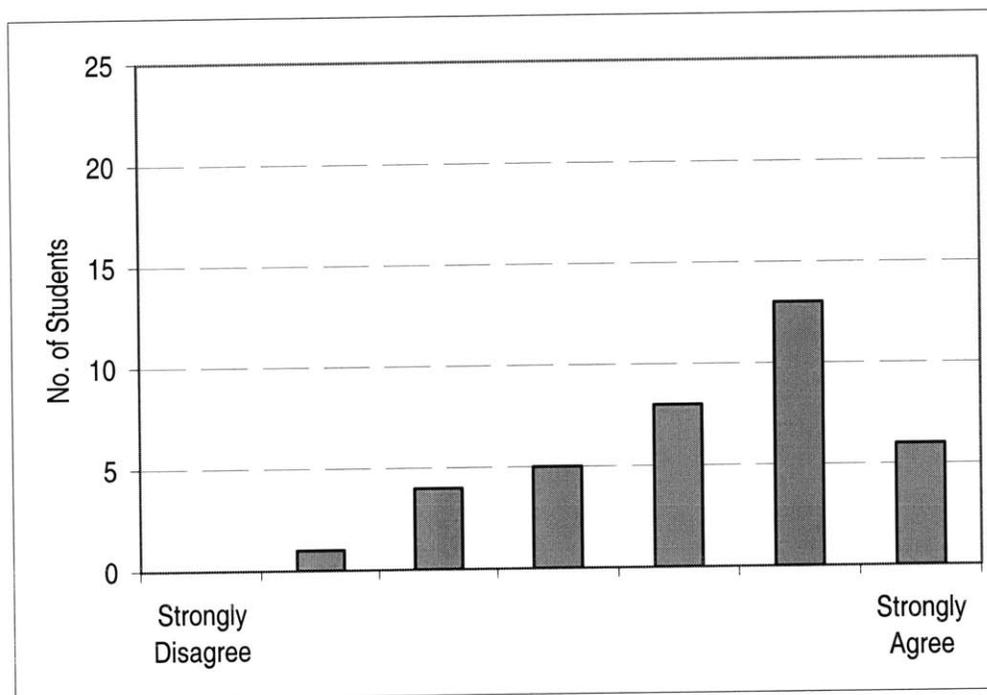


Figure D.4 Response to "The Modules got me thinking more about the actual concepts"

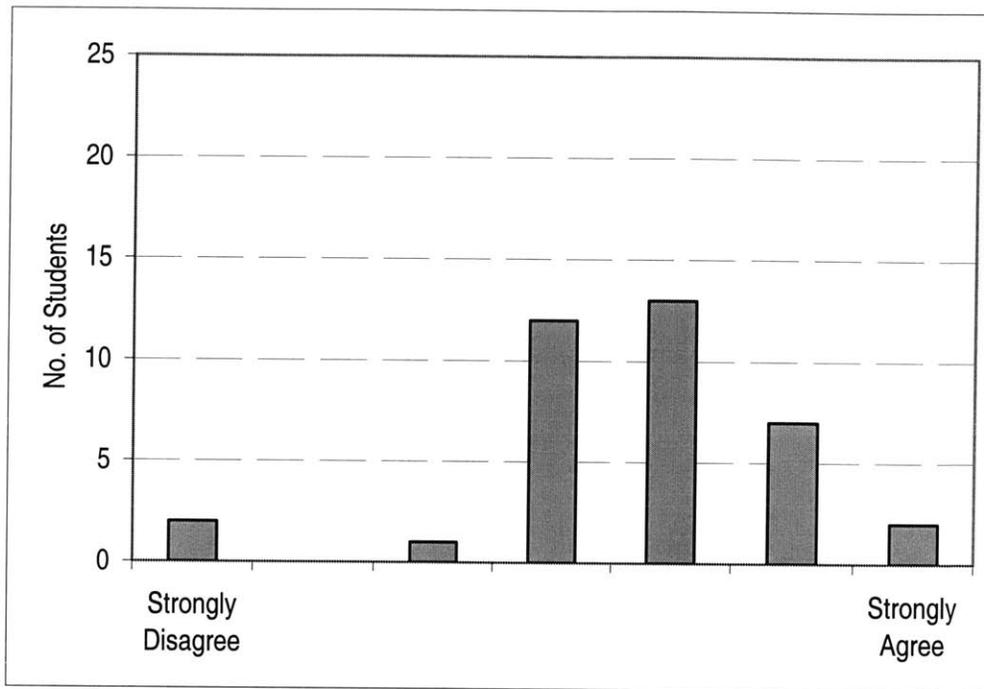


Figure D.5 Response to "The Modules gave me more confidence about a well learned material"

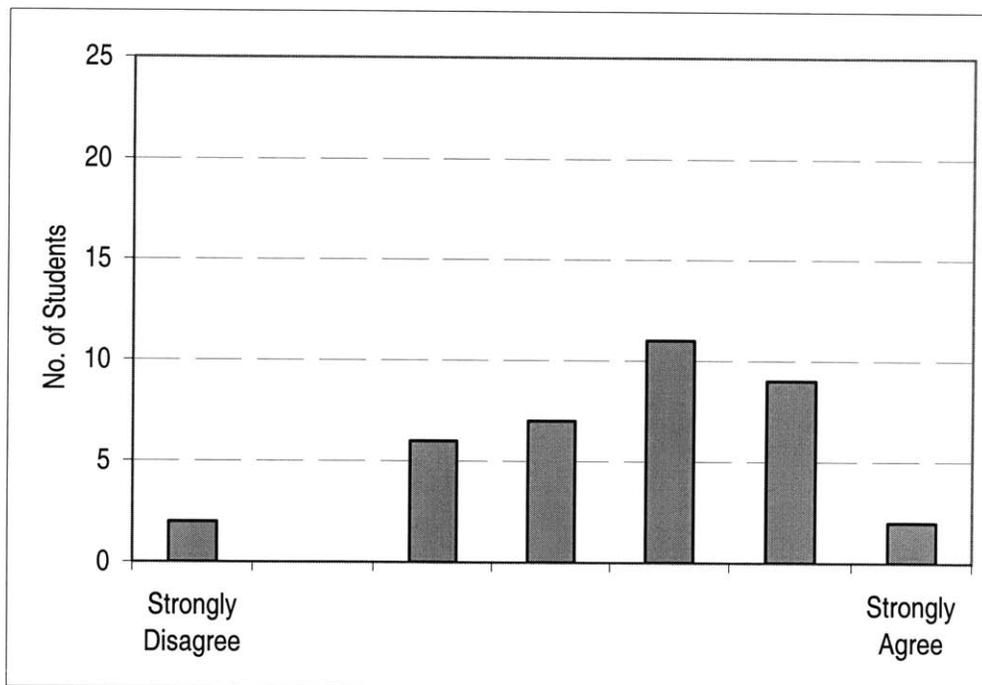


Figure D.6 Response to "The Modules provide a more intuitive feel for the concepts"

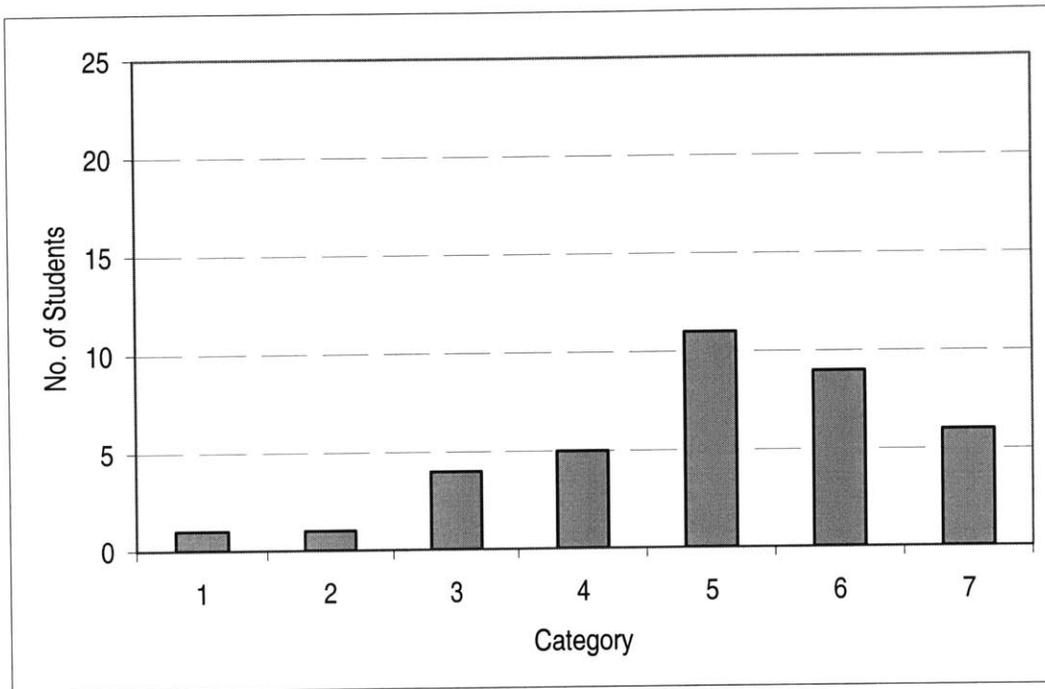


Figure D.7 Response to "The Modules helped me visualize more than the Lectures"

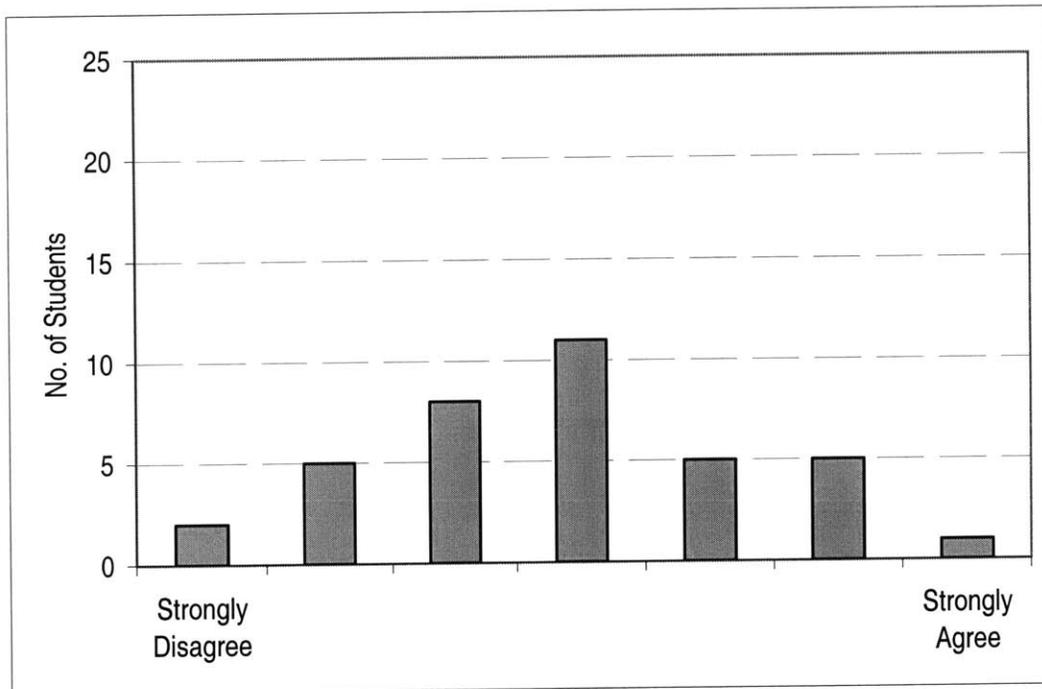


Figure D.8 Response to "The Modules were more engaging than Lectures"

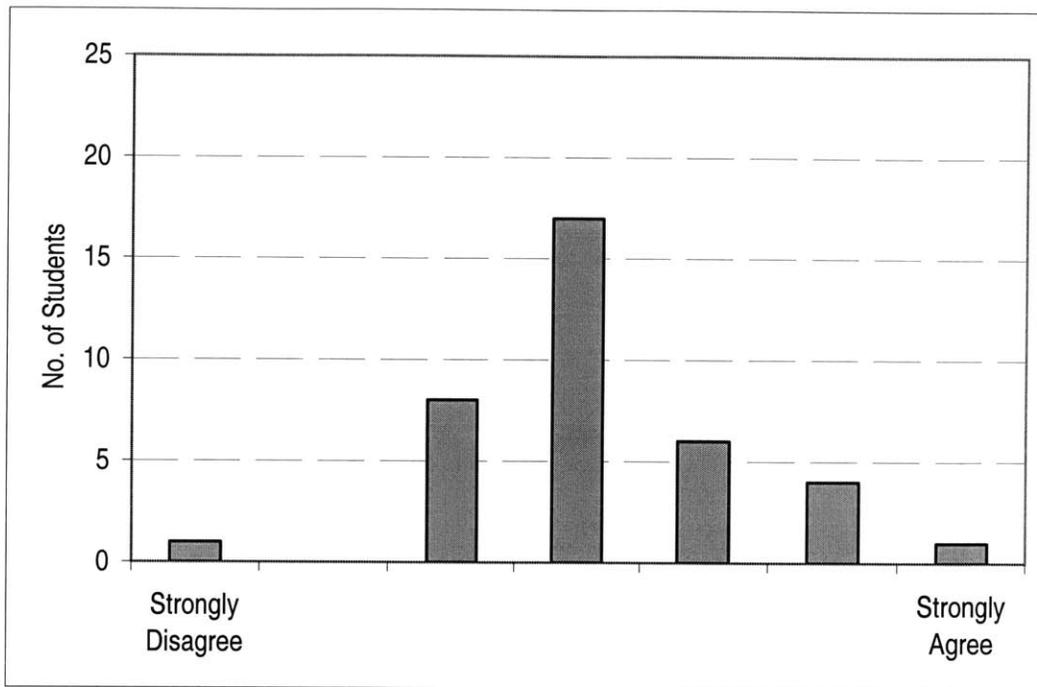


Figure D.9 Response to "The Modules got me thinking more about the actual concepts"

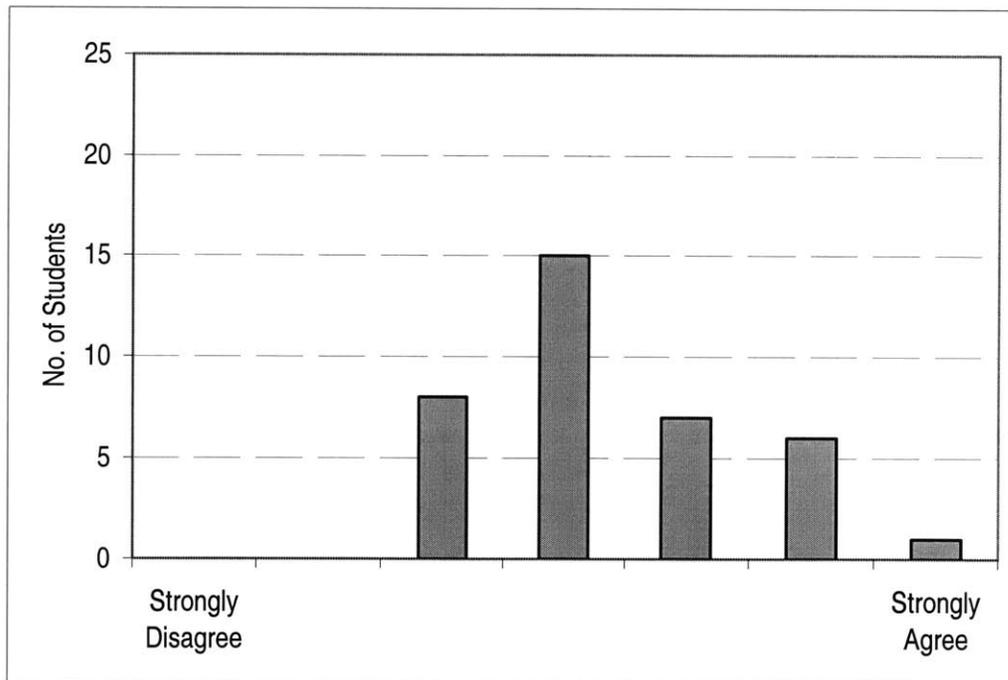


Figure D.10 Response to "The Modules gave me more confidence about a well learned material"

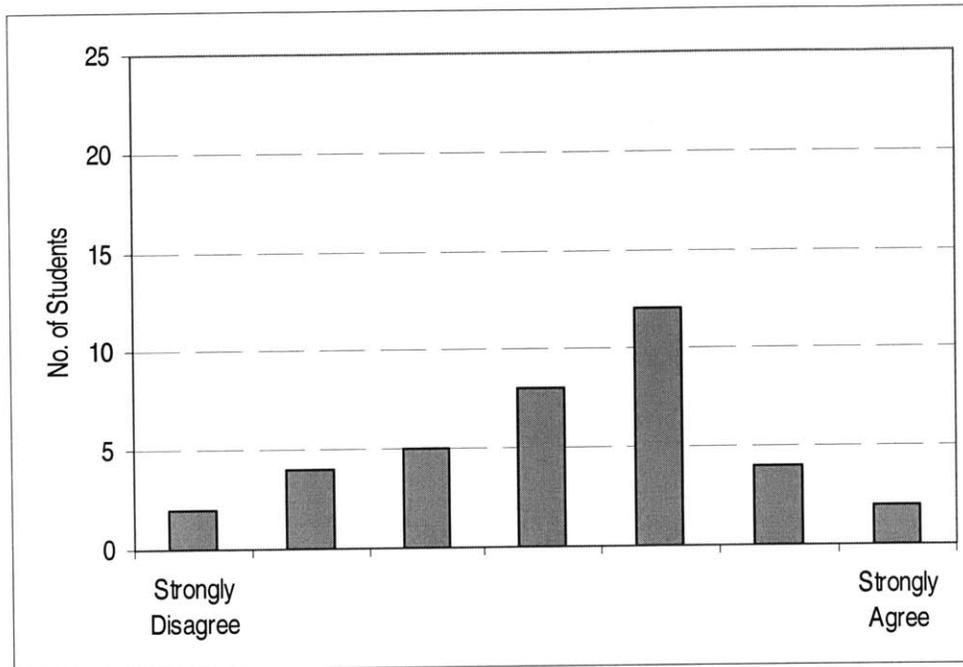


Figure D.11 Response to "I learn complex mechanics concepts by memorizing the important features"

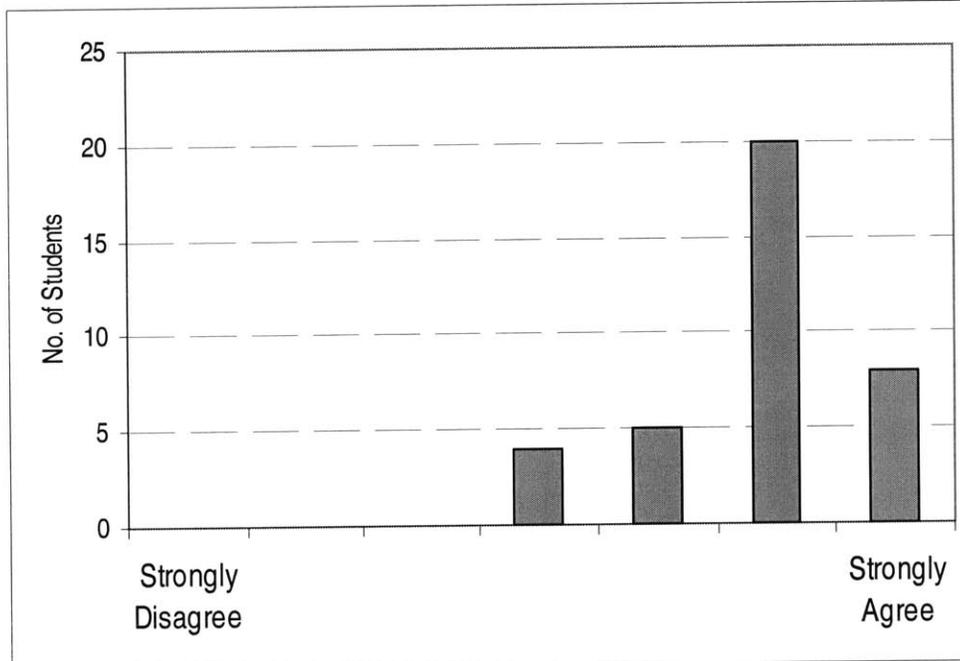


Figure D.12 Response to "I learn complex mechanics concepts by establishing a conceptual model (mental model) of how things work"

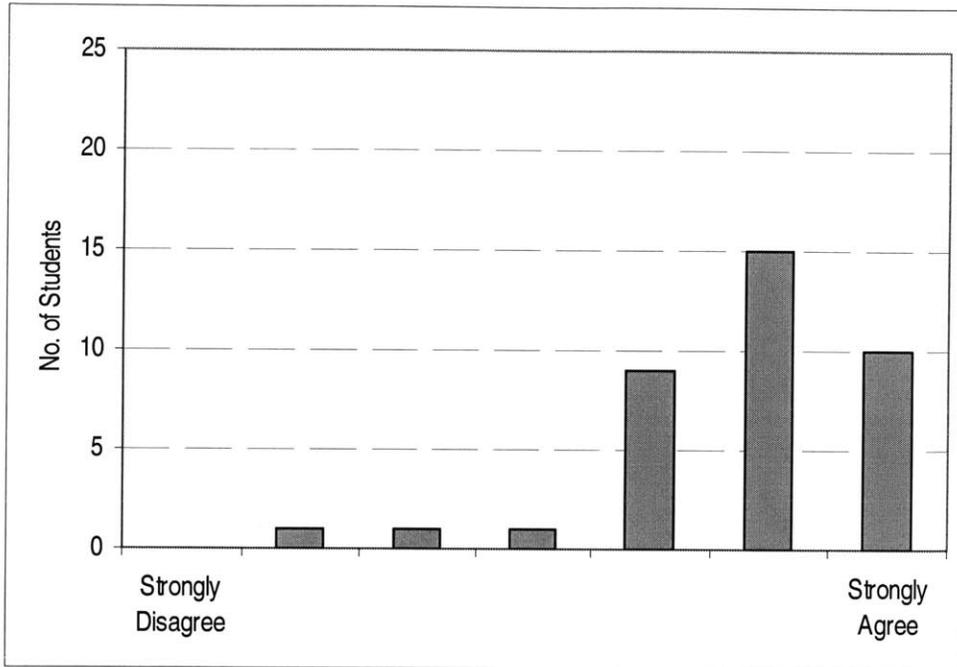


Figure D.13 Response to "I learn complex mechanics concepts by drawing a visual representation"

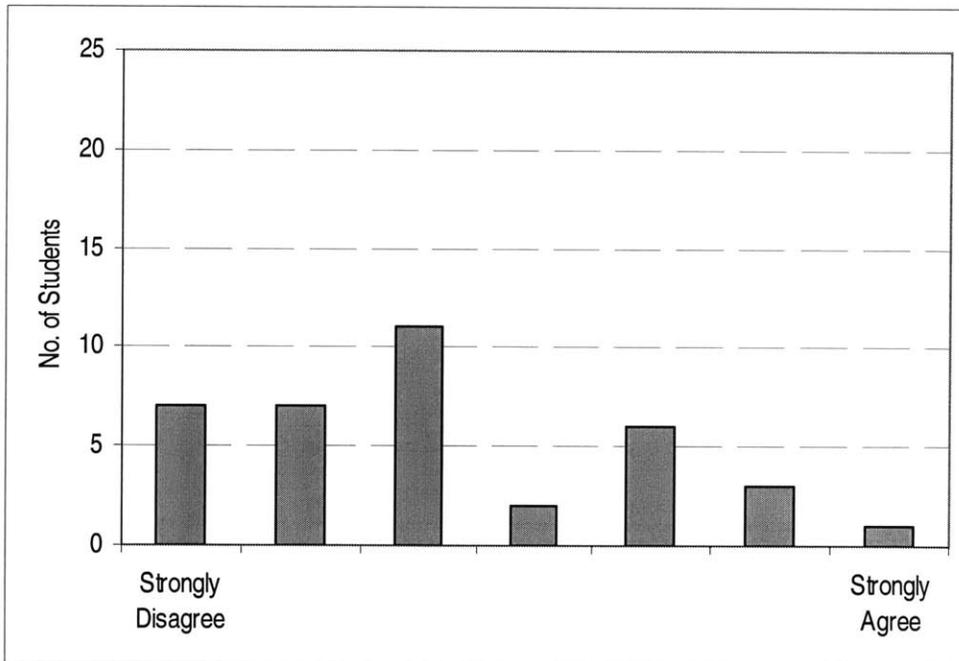


Figure D. 14 Response to "I learn complex mechanics concepts by writing notes phrased exactly as they appear in a text"

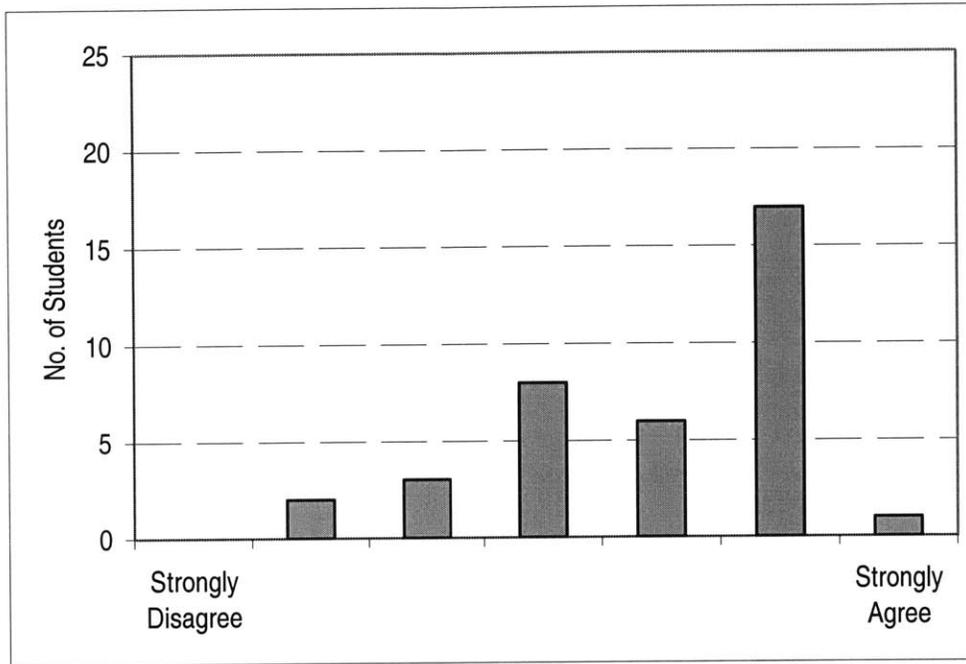


Figure D.15 Response to “I learn complex mechanics concepts by using analogies to make connections between new and known content”

References

- Adams, W. J. (1830). "Lecture on the construction and furnishings of school rooms; and on school apparatus". Boston, MA: *American Institute of Instruction*
- Aftias, M. (2001). *Introducing basic structural engineering concepts through a web-based interactive learning environment*. MIT Thesis C.E. S.M.
- American Journal of Education*, Vol. 1. 1856
- American Journal of Education*, Vol. 16. 1886
- American School Apparatus Company (1867). *Improved School Furniture*, New York, NY
- American Textbook Publishers Institute (1949). *Textbooks in Education*. Chicago, IL: The Lakeside Press
- Anderson, C. (1962). *Technology in American Education 1650 – 1900*. Washington, DC: US Department of Health, Education, and Welfare.
- Ausubel, D. (1968). *Educational psychology: A cognitive view*. New York: Rinehart and Winston.
- Ausubel, D. P. (1963). *The psychology of meaningful verbal learning*. New York: Grune and Stratton.
- Brewster, D. (1856). *The Stereoscope: Its history, theory, and construction with its application to the fine and useful arts and to education*. London: John Murray.
- Bruner, J. (1966). *Toward a Theory of Instruction*. Cambridge, MA: Harvard University Press.

- Bumstead, J. F. (1841). *The blackboard in the primary schools*. Boston, MA: Perkins & Marvin
- Caine G. & Caine R. (2001). *The brain, education, and the competitive edge*. Lanham, MD.: Scarecrow Education.
- Campbell, D.T. & Stanley, J.C. (1963). *Experimental and Quasi-Experimental designs for research*. Washington D.C.: American Educational Research Association.
- Carroll, J. B. (1963). A model of school learning. *Teachers College Record*, 64, 723-733
- Collins, A. (1989). *Cognitive apprenticeship and instructional technology* (Technical Report No. 474). BBN Laboratories, Cambridge, MA. Center for the Study of Reading, University of Illinois
- Collins, A., Brown, J. S., & Newman, S. E. (1987). *Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics* (Technical Report No. 403). BBN Laboratories, Cambridge, MA. Center for the Study of Reading, University of Illinois
- Cook, T. D. & Campbell, D. F. (1990). *Quasi-experimentation: Design & analysis issues for field settings*. Boston: Houghton Mifflin Company.
- Cuban, L. (1986). *The classroom use of technology since 1920*. New York: Teachers College Press
- Cuban, L. (2001). Ch. 6, Are computers in schools worth the investment?. In *Oversold and underused*. pp. 176-197. Cambridge, MA: Harvard University Press.
- Darrow, B. (1932). *Radio: The assistant teacher*. Columbus, OH: R. G. Adams
- Dede, C. (2001). Testimony to Congress.
<http://www.house.gov/science/research/reshearings.htm>
- Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York, NY : Basic Books
- Gentner, D. & Stevens, A.(1983). *Mental Models*. Hillsdale, NJ: Erlbaum.
- Godbole. (1953). *Manufacture of lead and slate pencils*. India
- Illustrated catalog of school merchandise*. Chicago, IL: 1881, Andrews & Co.
- Johnson, D.W. et al. (1983) Interdependence and Interpersonal Attraction Among Heterogeneous Individuals: a Theoretical Formulation and a Meta-Analysis of research. *Review of Educational Research*, 53, 1, 5-54.
- Kerlinger, F. N. & Pedhauzer, E. J. (1997). *Multiple regression in behavioral research (3rd ed.)*. Stamford, CT: Wadsworth Publishing Co.

- Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Englewood Cliffs, NJ.: Prentice-Hall
- Laurillard, D. (1993) *Rethinking University Teaching. A Framework for the Effective Use of Educational Technology*. Routledge, London.
- Laurillard, D. (2001) *Rethinking University Teaching in the Digital Age*. Forum for the Future of Universities. Aspen, Colorado.
- Lave, J. & Wenger, E. (1990). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press
- Macromedia, Inc. (2001). *Macromedia Director (Ver. 8.5)* San Francisco, CA
- Macromedia, Inc. (2004). *Shockwave technology: Shockwave Player (Ver. 10)* San Francisco, CA
- Maher, ML & Gu, N (2002) *Virtual Worlds = Architectural Design + Computational Elements, Proceedings of ANZAScA*, Deakin University.
- Malone, T. (1981). Towards a theory of intrinsically motivating instruction. *Cognitive Science*, 4, 333-369.
- McCarthy, B. (1987). *The 4MAT system: teaching to learning styles with right/left mode techniques*. Barrington, IL. EXCEL
- Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97
- Morsell, W. F. (1893). The lantern in the school. *Education*, XIII, 558-564.
- Nguyen, H. P. (2002). *Web-base online tools for a shake table laboratory*. MIT Thesis C.E. S.M.
- Paige, R. (2002) *Introduction to 2020 Visions Transforming Education and Training Through Advanced Technologies*. US Department of Commerce. Washington D.C.
- Perkins, D. (1992). Ch. 3, Teaching and learning: Theory One and beyond. In *Smart schools*. pp. 43-72. New York: Free Press.
- Piaget, J. (1969). *The Mechanisms of Perception*. London: Rutledge & Kegan Paul.
- Pulsifer, W. E. (1921). *A brief account of the educational publishing business in the United States*. Atlantic City, NJ
- Puntambekar, S. (1999) *An integrated approach to individual and collaborative learning in a*

web-based learning environment. In Proceedings of the Computer Support for Collaborative Learning (CSCL 1999) Conference. (eds. C.M. Hoadley & J. Roschelle) pp. 458-465. Stanford University, Palo Alto, CA.

Redfield, D. & Sivin-Kachala, J. (2003). *Scientifically based research: A guide for educational publishers and developers*. Washington D.C.: Software & Information Industry Association.

Seattler, P. (1953). *A history of instructional technology*. New York, NY: McGraw Hill

Shepherdson, E. F. (2001). *Teaching concepts utilizing active learning computer environments*. MIT Thesis C.E. Ph.D.

Sthapit, A. (2002). *An object oriented approach to matrix analysis of structures*. MIT Thesis C.E. S.M.

Viteri, V. (2003). *Experiential learning environments for structural behavior*. MIT Thesis C.E. Ph. D

Vygotsky, L.S. (1978). *Mind in Society: the development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Waterman, R. Jr. (1894) Educational exhibits at the Columbian exposition. *Educational Review* New York:NY, VII

Wiersma, W. (2000). *Research methods in education: An introduction (7th ed.)*. Boston: Allyn & Bacon.

Wild, M. (1996). A perspective on mental models and computer modelling. *Journal of Computer Assisted Learning*, 12(1), 10-21.

Wiske, M.S. (1998). Ch. 3, What is teaching for understanding?. In *Teaching for understanding*. pp. 61-86. San Francisco: Jossey Bass.

Yin, R. (1994). *Case study research: Design and methods (2nd ed.)* Beverly Hills, CA: Sage Publishing.