Introducing Basic Structural Engineering Concepts through a Web-based Interactive Learning Environment

by

Michalis Aftias

Diploma, Civil and Environmental Engineering
Aristotle University of Thessaloniki, Greece, 1999

Submitted to the Department of Civil and Environmental Engineering and to the Technology and Policy Program
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Civil and Environmental Engineering and
Master of Science in Technology and Policy.

at the
Massachusetts Institute of Technology
June 2001

Signature of Author . . . .
Department of Civil and Environmental Engineering
May 11, 2001

Certified by . . . .
Herbert H. Einstein
Professor of Civil and Environmental Engineering
Thesis Supervisor

Certified by . . . .
Joseph M. Sussman
JR East Professor of Civil and Environmental Engineering
Thesis Policy Reader

Accepted by . . . .
Oral Buyukozturk
Chairman, Departmental Committee on Graduate Studies

Accepted by . . . .
Dan Hastings
Director
Technology and Policy Program

INTRODUCING BASIC STRUCTURAL ENGINEERING CONCEPTS THROUGH A WEB-BASED INTERACTIVE LEARNING ENVIRONMENT

By
Michalis Aftias

Submitted to the Department of Civil and Environmental Engineering and the Technology and Policy Program
in Partial Fulfillment of the Requirements for the Degrees of
Master of Science in Civil and Environmental Engineering and
Master of Science in Technology and Policy.

ABSTRACT

The introduction of Information Technology markedly changed the teaching and learning of structural engineering. The research presented in this thesis focuses on the most basic concepts of structural engineering by developing a set of ***Solid Mechanics Learning Modules*** in a multimedia web-based environment. The goal is to promote intuitive understanding of structural behavior before moving on to analytical expressions.

What is different in our approach is the composition of the audience. On the one side there will be the first year college students in engineering who have no previous specific knowledge of the topic but a background in basic science. On the other side there will be the students in tertiary technical education such as community colleges in the US and the Technikons in South Africa with some practical knowledge but with a weak scientific background. The ***Solid Mechanics Learning Modules*** are part of a multifaceted effort, involving the USAID funded TELP (Tertiary Education Linkage Project), the NSF funded ECSEL (Engineering Coalition for Excellence in Education and Leadership), and I-campus, which is funded by MIT and Microsoft Corporation. The experience and the lessons learned from the early stages of this effort are analyzed.

To ensure cost efficiency and adoption by as large as possible audiences, the final product is designed so that it can become a node within a network of similar products that are or will be developed and that will eventually be linked to form an integrated web-based learning environment for structural engineering education.

Thesis Supervisor: Herbert H. Einstein
Title: Professor of Civil and Environmental Engineering

ACKNOWLEDGEMENTS

I would like to extend my deepest thanks to Professor Herbert H. Einstein, a man of incomparable ethos, for his support and assistance. Working under his guidance has been a great pleasure. I would like to thank Professor Joseph M. Sussman for his constructive comments on my thesis. I also wish express my grateful acknowledgment to Dr. Emma Shepherdson for her valuable support. I am grateful to the Onassis Public Benefit Foundation for their generous financial assistance and encouragement.

Reaching the endpoint of an important stage in my life's trip, I feel that I owe a word of thanks to the following people who have contributed significantly in helping me reach this endpoint.

My family. Mentioning them sounds commonplace and stereotypic but omitting them would be hubris.

Nicholas Houstis, my cousin and friend for his support, patience, and guidance especially in my first difficult steps in the US.

Professor Nicholas A. Ashford, for offering me the most valuable educational experience of my life.

My Professors at the Aristotle University of Thessaloniki in Greece for offering me high-standard engineering education. Particularly, Prof. Christos Anagnostopoulos, Prof. Stavros Bandis, Prof. Eleftheria Papachristou, Prof. Kyriazis Pitilakis, Christos Schinas, and Prof. Stefanos Tsotsos.

Dr. Giorgos Anagnostou, Willy Gehriger, and Nikos Kazilis for their valuable advice and guidance on educational and professional issues.

My friends, and particularly Yannis Chatzigiannelis and Achilleas Tsamis. Certainly, Dionysos must have been repeatedly delighted observing our endless discussions during the numerous gourmet dinners we prepared at our home.

Κι αν δεν μπορείς να κάμεις την ζωή σου όπως την θέλεις,
τούτο προσπάθησε τουλάχιστον
όσο μπορείς: μην την εξευτελίζεις
μες στην πολλή συνάφεια του κόσμου,
μες στες πολλές κινήσεις κι ομιλίες...

Κωνσταντίνος Π. Καβάφης

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

The current research work focuses on introducing the most basic concepts of structural engineering by developing a set of ***Solid Mechanics Learning Modules*** in multimedia web-based environment. Those concepts introduced are the following:

1. The beam as the simplest load-bearing element
2. Loads
3. Horizontal and vertical load-bearing by beams
4. Support types
5. Deformability of the beam
6. Equilibrium conditions.

From an engineering education point of view, the goal is to equip the students with the necessary background before starting to perform simple analytical calculations. The *Solid Mechanics Learning Modules'* goal is to develop the students' intuition by exposing them to the behavior of simple structures. The modules described in this thesis are going be used as a supplement to textbooks and tutoring in order to enhance the learning experience.

The material in this thesis is organized as follows. Firstly, Chapter 2 discusses the importance of a thorough mastering by the students of basic principles in structural engineering. The key features of intuitive engineering thinking as well as the pedagogical issues related to the use of Information Technology as a tool for developing intuitive engineering thinking, are presented. Chapter 3 presents the advantages and disadvantages of using computers, and specifically Information Technology, for introducing basic structural engineering principles. Chapter 4 describes the general framework on which the Solid Mechanics Learning Modules are based. The content, the audience, the educational goals, and the methods used to achieve them are presented. Chapter 5 goes beyond the technical issues related to the design and development of the modules and deals with the broader issue of promoting the use of Information Technology for educational purposes. Specifically, the hands-on experience and the lessons learnt from trying to implement IT-based engineering education in South Africa are described. Lastly, in final Chapter 6 a number of possible improvements of the Solid Mechanics Learning Modules as well as the possible directions of the future research in the field, are discussed.

CHAPTER 2: INTRODUCING THE VERY BASIC PRINCIPLES OF STRUCTURAL ENGINEERING

2.1 Introduction

Explaining the basics of structural engineering at an introductory level is usually considered a trivial task mainly because the few possible questions that the students may have can be answered "in the future". Although this approach seems rational and works indeed in most cases, there are a number of reasons for ensuring a thorough understanding of the very basics of structural engineering.

First, the basis of structural engineering knowledge is strong. A number of questions and doubts can be answered immediately by the student thus reducing the time that he/she spends on clarifying issues or reassuring herself over.

Second, the student's interest is stimulated by his/her own confidence that his/her background is adequate. A common reason for disappointment, poor performance, and eventually the dislike of the subject, is the feeling of lacking confidence in concepts that she/he "should already know".

Information technology provides a new powerful educational tool that can be used to overcome the barriers of conventional teaching methods such as textbooks, in class presentations, and tutoring. The focus of this research is to explore 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. A detailed overview of the material covered within *Solid Mechanics Learning Modules* is presented in chapter 4.

2.2 Teaching priorities – Pedagogical issues

It is important to keep in mind that the goal is to enhance the learning experience. However, when using information technology, the capabilities of the computer should be a means, not an end, and as such are part of a complex system. (Shepherdson 1998)

Although the concepts presented in the *Solid Mechanics Solid Mechanics Learning Modules* are fairly simple, it is important to pay attention to a number of general characteristics of the final product in terms of pedagogy. The following list is a brief attempt to distil from the recent relevant literature the main pedagogical elements of an effective educational software (Perkins 1992), (Bracket 1998), (Shepherdson 2000):

- *Clear Information* - It is important to present all the concepts with clear vocabulary and explanations of the phenomena. Although such a prerequisite seems trivial or self-evident, one should have in mind that there are countless doubts and misconceptions that arise from poor understanding as a result of unclear of even ambiguous explanations. Given that the *Solid Mechanics Learning Modules* introduce basic concepts, the importance of presenting everything clearly, in order to eliminate as much as possible future problems, is even greater.

- *Thoughtful practice* - It is of primary importance to engage the user of such educational software into reflections over the engineering implications of the concepts presented.
- *Informative feedback* – The structure of the *Solid Mechanics Learning Modules* must be such that the students not only get the right answers but at the same time they learn why all the possible wrong answers are excluded.
- *Strong Motivation* – The learning experience must be exciting or at least more exciting than the conventional processes of in-class tutoring or textbook reading. Key element for achieving strong motivation is *visual stimulation.* The design of the onscreen features must be attractive to the user just like commercial web-sites that are designed in such a way that they engage customers in exploring all their links. For educational software this translates to providing an attractive layout which embraces the user and which gives extra information on more advanced topics in case the user feels particularly interested.

A web-based multimedia environment with animations, sounds, links, etc offers the best possible platform for designing educational software with the above characteristics.

2.3 Developing intuition

It is generally accepted that the introduction of computers has revolutionized Structural Engineering by expanding dramatically the capabilities of performing analysis of complex structures with minimal effort and time. However, computers lead to a lot of emphasis on developing the analytical skills of the students in order to perform the required complex analyses. As a result, less effort is put on learning how to predict the physical structural behavior under given loading conditions.

It is very easy to blame computers for this kind of inability of structural engineers to act as real engineers, who can always have in mind the response of structures unrestrained by the results of their analyses. It is however important to recognize that the problem actually is not the computer per se. It is the lack of focus on developing the *intuition* of the students.

In fact, computers provide enormous and worthwhile potential in developing the intuition of the students. Especially when the most basic concepts of structural engineering are taught, as in the case of the *Solid Mechanics Learning Modules*, computers can help a lot in developing as well improving the students' intuition. The key features for achieving the prescribed goal are:

- *Physical representation of structural behavior* – Showing various responses of simple structures to forces, such as motion, deflections, structural failure etc induces the student to think not in terms of numbers or analytical expressions but in terms of structural behavior.
- *Association of structural engineering problems with well-known everyday life examples* - Intuition is reinforced when the student can relate the problem to a phenomenon or a mechanism that he/she is familiar with.
- *Encouragement of intuition by questions over expected structural response* – Intuition may be an inherent ability but there must be enough stimulus to activate it.

2.4 Conclusion

It is the developer's goal to provide users with a tool that has the advantage of offering a one-to-one tutorial experience, which is considered as the most effective form of learning. From a pedagogical point of view one can argue however that software can never be as effective as a real tutor can. It would be arrogant to believe that products like the Solid Mechanics Learning Modules can substitute teachers. In fact, this is far from their objectives. They can however contribute substantially as a complementary tool that will not only improve the effectiveness of the overall learning process but it will, at the same time, reduce the amount of effort required from teachers to achieve their intend.

CHAPTER 3: USING COMPUTERS AND INFORMATION TECHNOLOGY FOR INTRODUCING THE VERY BASIC PRINCIPLES OF STRUCTURAL ENGINEERING

3.1 Introduction

The classic way of teaching structural mechanics with textbooks, in-class presentations, and tutoring, lacks in the fact that something so real and visible in everyday life as structures is described, sketched and simulated with little explicit reference to the real world. The more basic the concepts taught are the more difficult is to relate them explicitly to real word examples that will help the students to grasp those concepts fast and easily. For example how can one explain the concept of a moment reaction?

A very interesting contribution to addressing this kind of "insufficiency" of classic structural engineering teaching on a basic level is done by Professor Dr. O. Kuenzle at ETH. [Kuenzle 1999]. The focus of his work was to construct physical models of simple structures and show their response to various types of loads in conjunction with their properties such as support type, stiffness etc. The goal is to help the student to relate the basic concepts of structural engineering with real world examples that preexist as general knowledge in his/her mind.

The *Learning Modules* aim to go one step further by using Information Technology that not only can replace physical models but can also offer a wide variety of advantages that enhance the learning experience.

3.2 Advantages

For the purpose of introducing basic structural engineering concepts, Information Technology offers the following comparative advantages:

a. Motivation

By using attractive graphic design a computer module can be extremely appealing and even eye-catching. Although the graphic interface of the *Solid Mechanics Learning Modules* is not at the desired professional level, with the help of an experienced professional its graphics can be upgraded.

b. Cost effectiveness

The *Solid Mechanics Learning Modules* require relatively few resources to be developed. Most of the cost of such an effort comes from the so-called cost of human capital. Time devoted to research team brainstorming and personal thinking on the content and the structure of the product topic under development, is far more critical than the time required developing the software. The development of Information Technology and its vast expansion in many areas has decreased considerably the cost of the actual development of such sets of *Solid Mechanics Learning Modules.*

c. Responsive environment - Interactivity

One of the most important advantages of Information Technology is that it enables interaction between the user and the program by providing an environment that invites the student to proceed in actions for which he receives a response. Thus, a feeling of personalized learning is developed which engages the student even more in the learning process.

d. Greater potential audience

With the wide expansion of computers and the increasing rates of access to the Internet, a product like the *Solid Mechanics Learning Modules* can have impressively large audiences. In addition, there is great potential to increase such an audience and hence the product's cost effectiveness by linking all other similar efforts in the same field by using the worldwide web.

e. Authentic context

Information Technology offers a good opportunity to use real world images and examples for introducing and explaining the concepts of structural engineering. The multimedia environment with audio, animated pictures and video help to create an implicit link between what is presented in the module and the real world. Presenting structural engineering within an authentic context of real word pictures, case studies, and examples allows the student to grasp the genuine practical implications of the concepts he/she is learning.

f. Intrinsic feedback to the developer

By carefully designing a program like the *Solid Mechanics Learning Modules*, it is possible for the developer to receive feedback, providing assessment of the module that will eventually dictate the necessary improvements. At the current stage of development a feedback mechanism is not part of the *Learning Module*, however this should be one of the very first future steps of the project.

3.3 Disadvantages

a. Lack of personal live interaction

In a computerized module, there is definitely a lack of personal live interaction between the student and the professor. However, the goal of the *Solid Mechanics Learning Modules* is to provide an extra tool that can enhance the learning experience rather than to substitute professors.

b. Limits to interactivity

Although the intention of the developers of the *Solid Mechanics Learning Modules* is to expand the interactive character of the program, it is impossible to predict and answer all possible questions. A truly dynamic response system using artificial intelligence may be a solution to this limitation but for the moment such an innovative work has not been performed in the field of structural engineering. [Viteri 2001]

c. Misuse and underuse of Information Technology

Despite the large and expanding capabilities of Information Technology there is the danger of using it either as an information transfer tool or as a substitute to the professors. A challenge for the *Solid Mechanics Learning Modules* is to go beyond presenting an improved version of a slide show. At the same time, developers conceive their effort within the general framework of improving structural engineering education in which professors have an important supervising role.

3.4 Conclusion – Summary

Information Technology offers a challenging and almost limitless environment for introducing the very basic principles of structural engineering. The capabilities for development are large while at the same time there is a significantly large potential audience that is interested to experiment, to expand and possibly to adopt products like the *Solid Mechanics Learning Modules*.

CHAPTER 4: THE ARCHITECTURE OF THE SOLID MECHANICS LEARNING MODULES

4.1 Introduction

The first part of this chapter, from section 4.2 to section 4.5 , consists of a presentation of the general framework for the *Solid Mechanics Learning Modules*. That framework is the outcome of the following sequential steps, which are also shown schematically in **Figure 4-1**:

1. Definition of the content presented as a part of the Structural Mechanics curriculum,
2. Definition of the audience, namely the "target group" or "users". The audience is studied on the basis of its previously acquired as well as future desirable knowledge. Obviously, by defining the audience the content has to be tailored and adjusted to its specific characteristics. Therefore, there is a dynamic relationship between steps 1 and 2 as shown in **Figure 4-1.**
3. Definition of the educational goals, and
4. Definition of the methods used to achieve them.

The second part, starting with section 4.6 , consists of a detailed description of the actual structural engineering material presented in the *Solid Mechanics Learning Modules.*

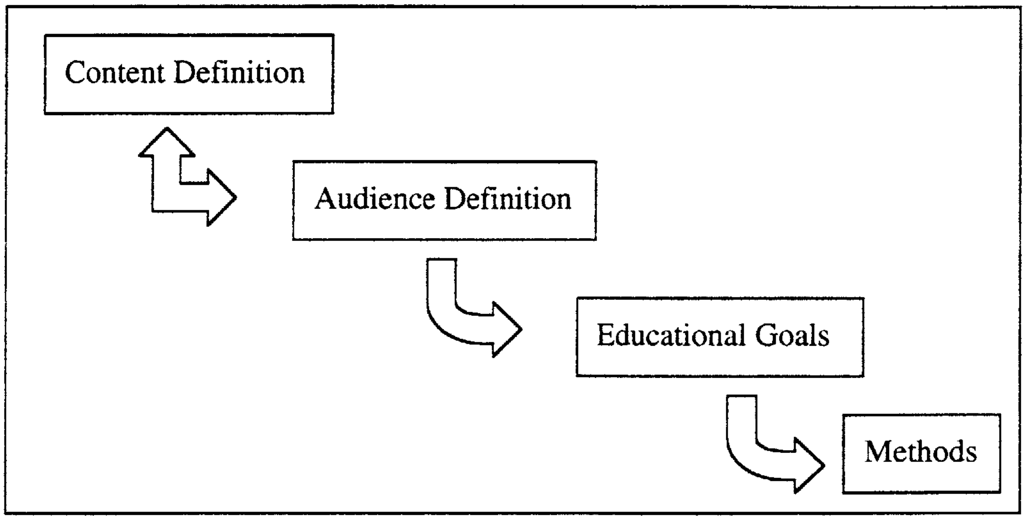

Figure 4-1: Setting the framework of the *Solid Mechanics Learning Modules*

4.2 Defining the content

The idea behind the development of the *Solid Mechanics Learning Modules* is to provide the student with the necessary background in structural mechanics with minimal or even without any required prerequisite knowledge of mechanics. Together with other similar research work done at MIT [Bucciarelli and Shapit 2001], [Shepherdson 1998 & 2001], [Viteri 2001], the *Solid Mechanics Learning Modules* may become part of an IT based library of modules on Structural Mechanics. In such an IT based library the *Solid Mechanics Learning Modules* would most probably be the first "chapter". In order to achieve a smooth transition to more sophisticated modules of the IT based library, the last part of the *Solid Mechanics Learning Modules* will require that the students start performing analytical computations on simple static systems. Hence, the student is introduced to the following concepts:

1. The beam as the simplest load-bearing element
2. Loads
3. Horizontal and vertical load-bearing by beams
4. Support types
5. Deformability of the beam
6. Equilibrium conditions.

All concepts are shown using a single beam, being the simplest possible structure. Although the last two concepts 5 and 6, above, define broad areas, the focus is only on introducing the student to those concepts without attempting to cover the full range of issues related to them.

4.3 The audience

As mentioned above The *Solid Mechanics Learning Modules* will provide basic knowledge in structural mechanics, which can be used by quite different audiences. The product is addressed at the same time to:

- First or second-year University students in the US taking their first structural mechanics class who have been exposed to some physical analysis. For the purposes of this thesis they will be referred to as *Group A*.

- Students in the tertiary technical education such as the community colleges in the US and the Technikons[1] in South Africa, who have some practical background but not much knowledge of physics. For the purposes of this thesis they will be referred to as *Group B*.

Designing the modules for each of the groups separately would present a challenge. In our case, by trying to serve both groups simultaneously, the challenge is dual. There is however common ground based primarily on the following:

1. Both groups have no previous knowledge on the material covered by the *Solid Mechanics Learning Modules,* and
2. The concepts introduced are limited to a basic level.

In the following sections 4.3.1 and 4.3.2 , each group's prior knowledge is presented in relation to the skills and knowledge required to achieve optimum results from the use of the *Solid Mechanics Learning Modules.* The characteristics of the two groups are presented by focusing only on those characteristics that have been taken into account during the development of the *Solid Mechanics Learning Modules.*

4.3.1 Group A: The first and second-year university students

We assume that the preparatory knowledge characteristics of *Group A*, regarding the use of the *Solid Mechanics Learning Modules* are the following:

[1] Tertiary technical/technician universities in South Africa. For a more detailed description see Chapter 5

1. Ability to read and write
2. High school physics and particularly kinematics
3. Some degree of familiarization with computers and web-based software.
4. Access to web-based computer facilities

Although nearly all students of Group A have more or less the same language and physics skills, the degree of familiarization as well as ease and quality of access to computers are not evenly spread among high school graduates around the world. Given that the *Solid Mechanics Learning Modules* are intended to be part of a larger group of modules that will be available through the Internet, it is very important that their web-design be as simple as possible both in terms of its user interface as well as in terms of system requirements.

4.3.2 Group B: The Students in the tertiary technical education

We assume that the knowledge characteristics of *Group B*, regarding the use of the *Solid Mechanics Learning Modules* are the following:

1. Basic reading and writing skills
2. No previous knowledge of physics
3. Possibly some exposure to construction practice that has developed some degree of intuitive understanding of structural behavior
4. Some access to web-based computer facilities at training centers

The relatively lower literacy skills of *Group B* compared to that of *Group A*, combined by the variation of quality of access to computers, require that *Solid Mechanics Learning Modules'* language and web-design be as simple as possible both in terms of its user interface as well as in terms of system requirements. Although the students in the tertiary technical education of *Group B*, may seem to have the advantage of hands-on experience, it is very probable that their misconceptions will be more difficult to be overcome, compared to that of *Group A*, whose members start from scratch.

4.4 Setting the educational goals

The main educational goal of the *Solid Mechanics Learning Modules* is to provide a strong basis of structural engineering knowledge. For Groups A and B having such a strong basis does not refer only to mastering the material presented in the modules but also to adopting an "engineering" way of thinking based on a balanced combination of intuitive and analytical skills.

In the following paragraphs the characteristics of the *Solid Mechanics Learning Modules,* which will produce a strong structural engineering background, are presented.

4.4.1 Developing user's intuition

An essential requirement for anyone in the engineering profession, regardless of the type of work is intuitive engineering thinking. Due to the complexity of the problems that professionals are faced with, even in their early college education, they tend to rely more on their analytical capabilities and tools rather than trying to use their intuition. Therefore, their intuitive thinking drops to a latent state or even gets lost. The *Solid Mechanics Learning Modules* are aiming at developing intuition regarding the following specific areas in structural mechanics:

- Identify stability/instability of various structural configurations,
- Predict relative deformations of different structural systems
- Predict the relative magnitude of reactions for different load configurations.

Going one step further in intuitive thinking, it is desirable that the student is able to associate physical observations with structural behavior. The *Solid Mechanics Learning Modules* are aimed at developing such links in the following areas:

- Motion in conjunction with types of reaction forces at the supports
- Relative deformation in conjunction with relative magnitudes of internal forces
- Given the structural and loading conditions have the student identify the most critical location in the structure.

4.4.2 Direct correlation of structural engineering teaching to real world design

For most engineers structural engineering teaching is associated with schematic representations, which have only little similarity with the actual structures. A typical example are the symbols used for the various types of supports. In the *Solid Mechanics Learning Modules* there is a consistent effort to link schematic representations (symbols) to familiar, real-life structures and structural elements. By using Information Technology, the student is concurrently exposed to both the symbols and to sketches that resemble real world structures as well as to pictures of the real world. Furthermore, the student has the chance to get exposed to or to get notions on "advanced" topics that can make the whole learning experience more stimulating and attractive.

4.4.3 Providing the framework for the introduction of analytical expressions

The ultimate stage of development of the *Solid Mechanics Learning Modules* is that in which the student is expected to set up the first basic analytical expressions of force and moment equilibrium for a determinate beam. These expressions are the equilibrium equations both for the beam as a rigid body as well as for the internal forces.

Throughout the sequence of the modules the goal is to ensure that the student masters all those simple concepts that he/she has been introduced to before moving on to analytical relations. First, the student must be able to understand the concept of equilibrium or, as mentioned above, to be able to distinguish between stable and unstable configurations. Second, the student should be able to distinguish between the various types of supports and their implications regarding reactions to a specific set of external forces.

Although some background on physics of kinematics would definitely help the student to set up simple analytical expressions, the goal is to help him/her understand the concept of action-reaction and equilibrium by using interactive animations of physical reality or models. The developers' aim is to lead the student to a discovery path similar to that of a child trying to build a simple structure with his/hers toys.

4.5 The characteristics of the methodology

After identifying what the educational goals are, the next step is to define the methodology that is used to present the material covered within the *Solid Mechanics Learning Modules* (described in detail in section 4.6). The content is gradually unfolded in a linear sequence moving from one subtopic to the other. Interactivity is an essential element of the methodology, demonstrated by the use of multiple choice quizzes and questions. The student is aided in the guidance through the modules by simple control features such as buttons and hyperlinks similar to the ones available in other web-based applications. The aforementioned characteristics are described in detail in the following sections 4.5.1 , 4.5.2 , 4.5.3 , and 4.5.4 .

A graphic representation of the methodology is shown in Figure 4-2.

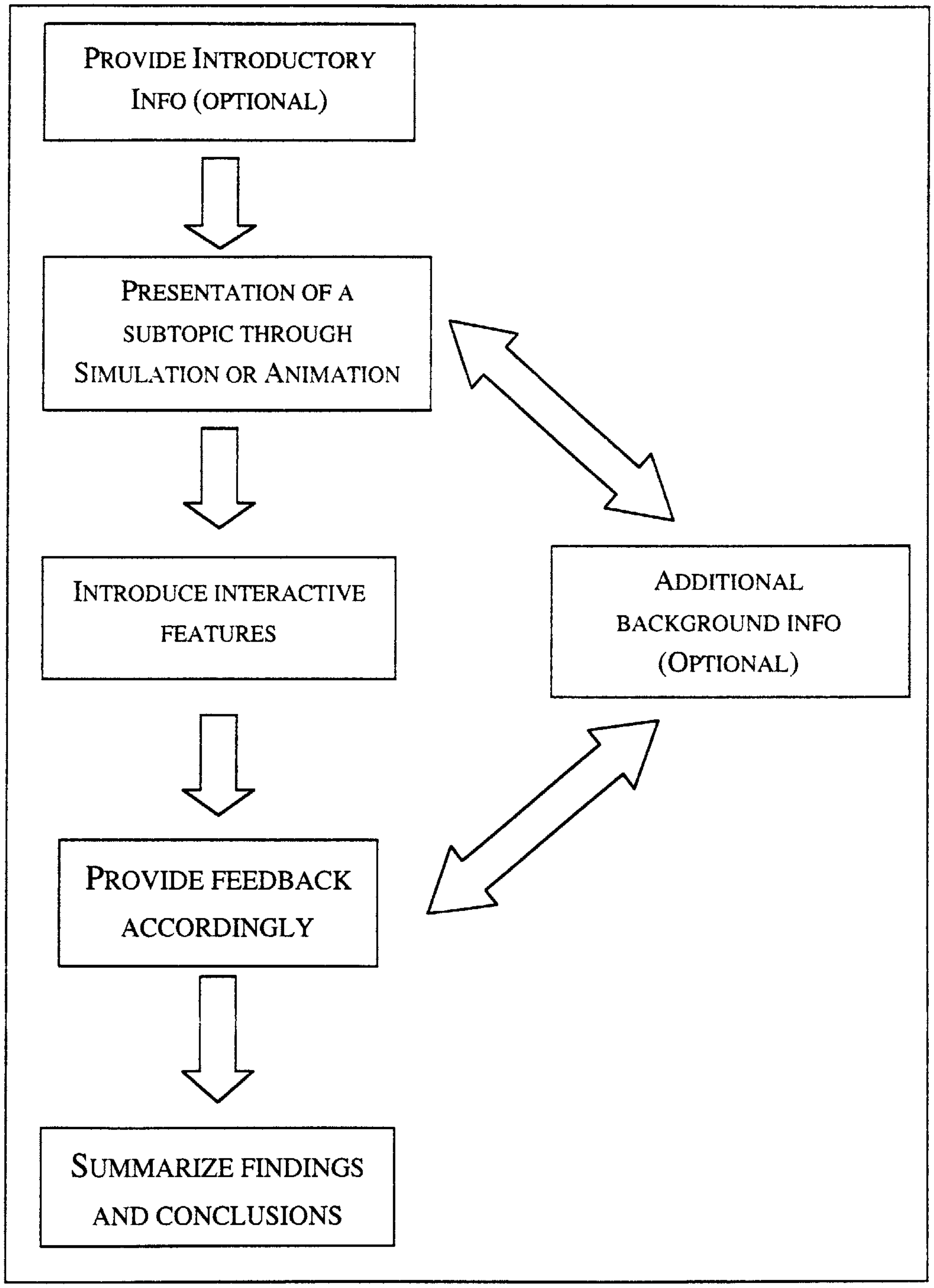

Figure 4-2: Methodology followed in the development of each subtopic

4.5.1 Subtopics

To present the material covered within the *Solid Mechanics Learning Modules* (described in detail in section 4.6) the content is divided into the following conceptual subtopics:

A. Introduction of the beam
B. Load types
C. Load transfer to supports
D. Support Configurations – Stability
E. Support Configurations – Deformations
F. Analytic expressions of equilibrium
G. Internal forces

The subtopics are presented in a linear sequence starting with the simplest one and moving on with increasing complexity. In each subtopic the specific material is covered following the flowchart shown in Figure 4-2. Aside from the "primary" information, that the student will have to access, there are a number of additional optional subsets of information that pop up upon request, from Internet links, other "sub-modules", and other similar applications developed by others in the same curricular area. Depending on the level of understanding or the preferences of the student, he/she can choose to access the supplementary information provided through the sub-modules, which either enhance his/her background knowledge or offer more "advanced" insights.

4.5.2 Interactivity - Multiple choice quizzes

Interactivity is an essential feature for the effectiveness as well as for the attractiveness of the *Solid Mechanics Learning Modules.* In order to engage the student with the introduced concepts, multiple choice quizzes are posed in the various subtopics of the modules. Interactive feedback is designed in such a way, that it reinforces the knowledge gained while keeping the student on the right track by explaining why his/her answers are right or wrong.

A difficult challenge in designing an efficient interactive process is the phrasing of the quizzes. Phrasing is not restricted to designing the questions but includes also the various answers. Both of them must stimulate the student's reflective thought. The answers are tailored in such a way that they clarify as many misconceptions as possible. A step towards greater efficiency would be the use of Artificial Intelligence [Viteri 2001]. Such a step however, goes beyond the scope of this first stage of development of the *Solid Mechanics Learning Modules.*

4.5.3 Control

The control of the "flow" of the *Solid Mechanics Learning Modules* is relatively simple. Any student would have to go through the same subtopics with small changes based on the answers to the small interactive quizzes. A schematic representation of such a simple control path is given in Figure 4-3. Simple control buttons such as Back, Forward Go to Start/End combined with hyperlinks are used for the navigation through the modules. In many cases hyperlinks are used to provide the additional information either within the modules or in separate pop up windows and web-browsers, as mentioned in section 4.5.1 .

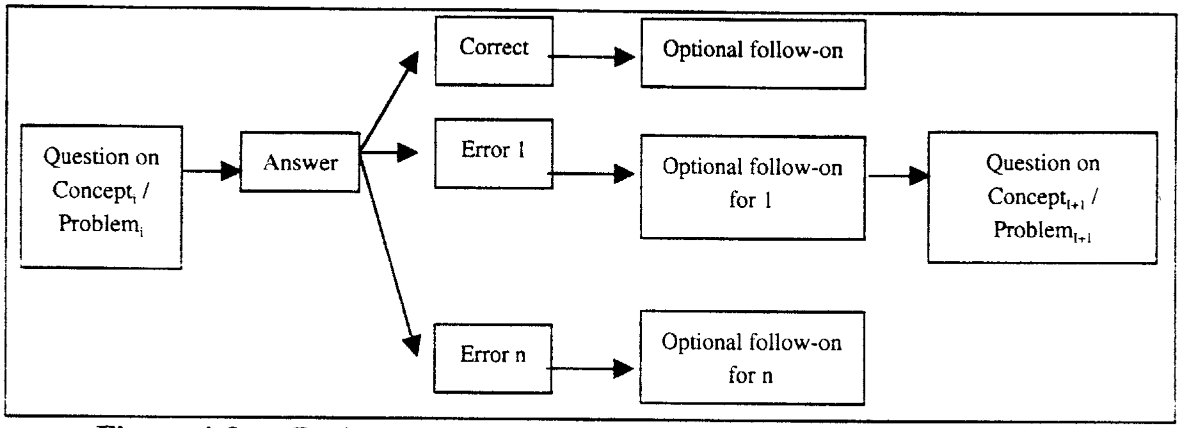

Figure 4-3: Basic control path (based on Figure 4.2 Shepherdson 2001)

4.5.4 The software platform

For the development of the *Solid Mechanics Learning Modules* the commercial software Macromedia Director® was used. The technology involved in the development is "hidden". That is, the user has access only to the final product, which has a web-format. The basic output type is a Shockwave® movie with HTML, JavaScript, Flash, and Java applications incorporated within the movie. Shockwave® movies are made by a combination of text, graphics, sound, animation, and video, creating a multimedia experience.

Director® creates a very user-friendly environment with easy to handle navigational features. The output movie is displayed in a scalable web-browser window and therefore, the user can select the desired display zoom without having to scroll up and down to view the full window. For the design of the movies, Director® apart from its built-in functions, has its own incorporated object oriented programming and scripting language, Lingo®, which allows one to control and customize script manipulation of the text, audio, and video elements.

The modules have a size of less than 1.5Mb and can be accessed through the web by any standard web-browser like Netscape® provided that the Shockwave® plug-in has been installed. Although most browsers have Shockwave® preinstalled, it is available for free on the web and is easy to install and configure. A great plus for Director® movies is the fact that they are platform-independent. (They work on UNIX, Mac OS, Mac OS X, Linux, Windows etc.) Thus, simplicity and ease of access -even with low-performance computer systems (Internet connection by modem, low-speed processors and low-RAM)- are among the major advantages of the technology used.

4.6 The content of the Solid Mechanics Learning Modules

In section 4.5.1 the subtopics into which the content is divided were shown. In this section the content of each subtopic is presented in a detailed fashion, accompanied by a rationale supporting the inclusion or the exclusion of certain concepts. The idea is to move "smoothly" from one subtopic to the other so that the student sees the connection to the previously presented material. In order to solidify the knowledge gained in each subtopic and to pave the way for the next one, a brief review with all the observations and findings as well as all the unanswered questions/issues is presented before moving on.

Furthermore, the sequence is such that in the upcoming sections the student uses the previously acquired knowledge allowing him/her to get into progressively more complex concepts. Interactive elements like real world examples and quizzes are included, whenever appropriate, to enhance the learning experience. Characteristic snapshots from such interactive elements are show in Figure 4-4:and Figure 4-5.

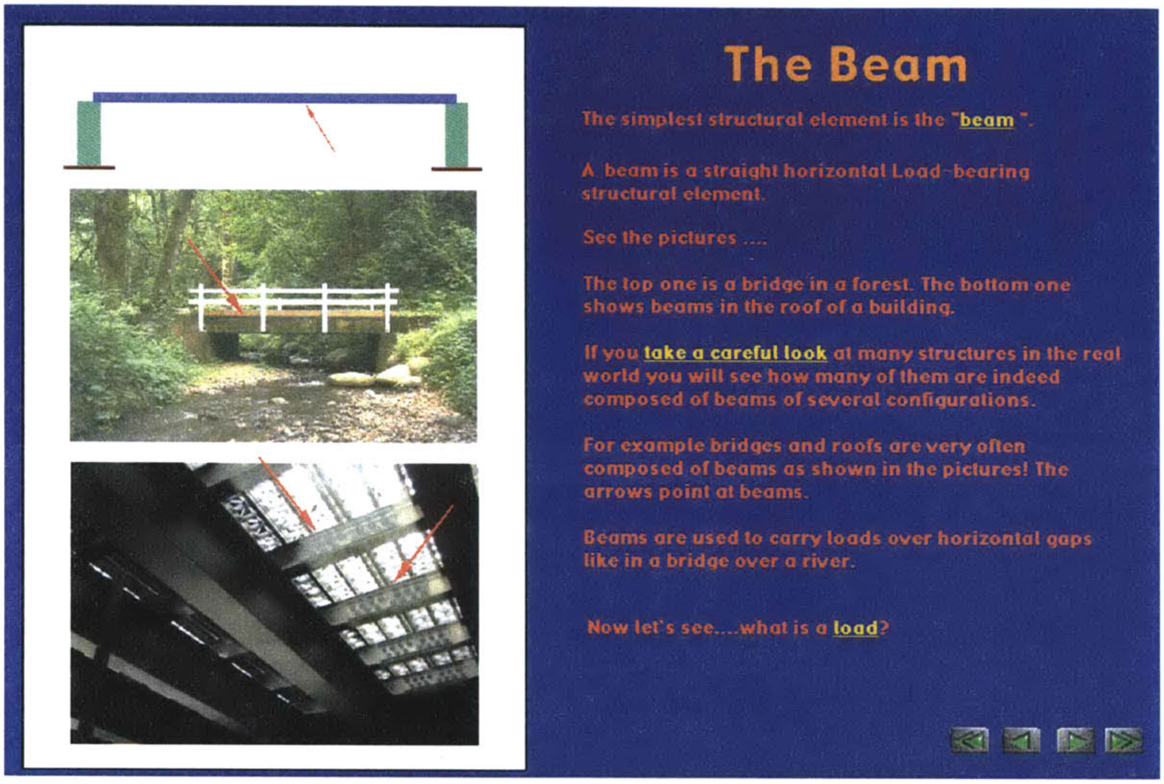

Figure 4-4: Real-world pictures incorporated within the Solid Mechanics Learning Modules

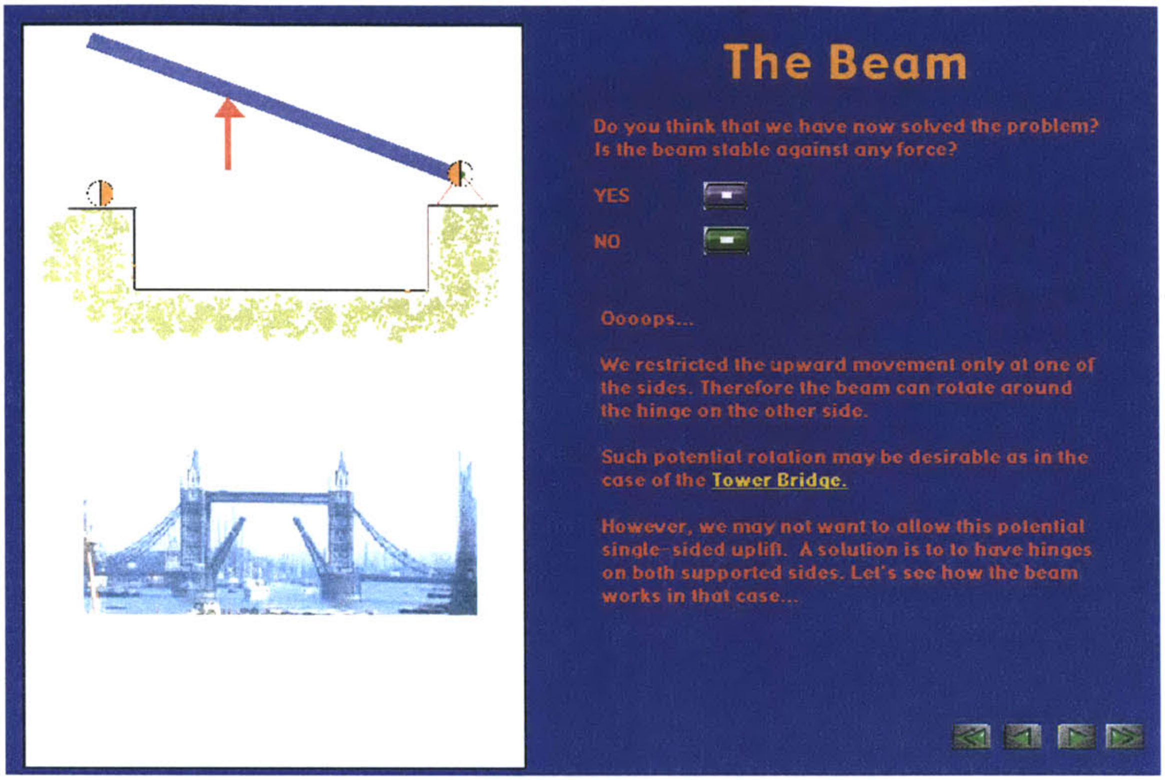

Figure 4-5: A typical quiz layout

A general graphic outline of the content of the module is presented in a storyboard[2] format in Figure 4-6. More detailed parts of the storyboard are presented in separate graphs in the Appendix.

---

[2] Term used by Emma Sepherdson for graphs of that type.

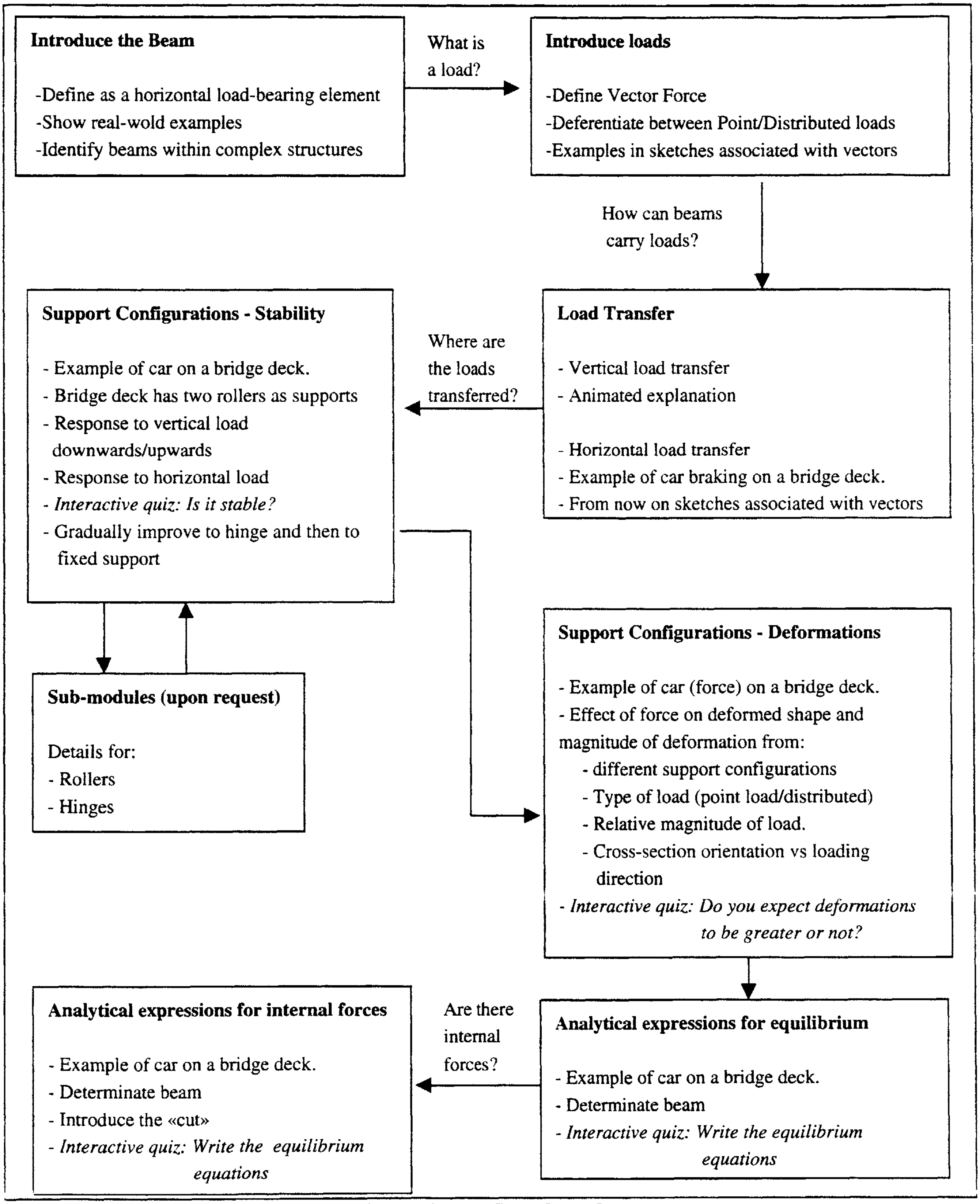

Figure 4-6: Storyboard

4.6.1 Introduction of the beam

Given that the assumed background knowledge for the use of *the Solid Mechanics Learning Modules* is minimal, the first concept introduced is that of the beam as a structural element. Apart from simple schematic representation of a beam, real life pictures of beams incorporated into structures, such as bridges, and roofs are presented. (See Figure 4-5.) Those are shown in order to create a connection to real life examples as well as to help the student start identifying the structural elements in real structures and associating them with schematic representations.

4.6.2 Load types

The concept of load as a vector force is introduced while point loads and distributed loads are differentiated. Cartoon examples of point and distributed loads are linked together with vector force representations as in Figure 4-7. From that point on, cartoon-type sketches are accompanied by vector representations for forces, wherever applicable.

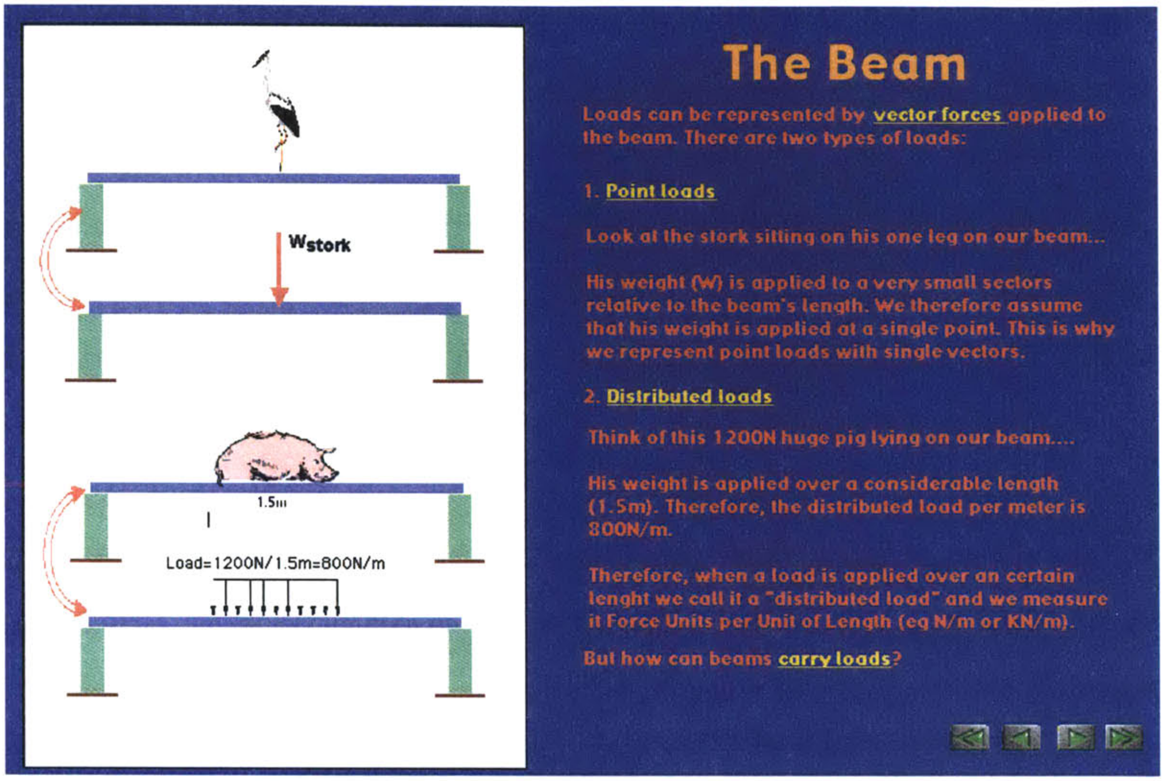

Figure 4-7: Schematic representations linked with vector forces

4.6.3 Load transfer to supports

In this subtopic the main goal is to explain to the student how a load that is applied at any point of the beam is transferred to the sides of the beam and is carried by the supports.

First, the transfer of vertical loads is presented. It is assumed that for the student it is easier to picture the case where one single reaction is acting at the same point as the single action. This helps the student to link this easily conceivable phenomenon with the case where a vertical load *F* acting in the middle of the beam produces two vertical reactions R_{yA}, R_{yB}. We start by having a single reaction *R* right at the middle of the beam which is then "split" into two separate vectors that are transferred internally to the sides as shown in Figure 4-8. Although such a process is instant and can not easily be explained, it is expected that by introducing a pseudo-time dimension through the animation, the whole phenomenon becomes easier to understand.

Second, the transfer of horizontal loads is presented. The same notion of internal transfer to the supporting side is used. A car braking on a beam exerts a horizontal force by friction on the beam. Again the cartoon-type sketch is accompanied by simultaneous parallel vector representations.

The size of both the acting force F_h as well as the reaction R_x, are increasing as the car is about to come to a complete halt. Although there is no explicit comment, such a detail potentially puts the student into thinking more broadly about the actual phenomenon.

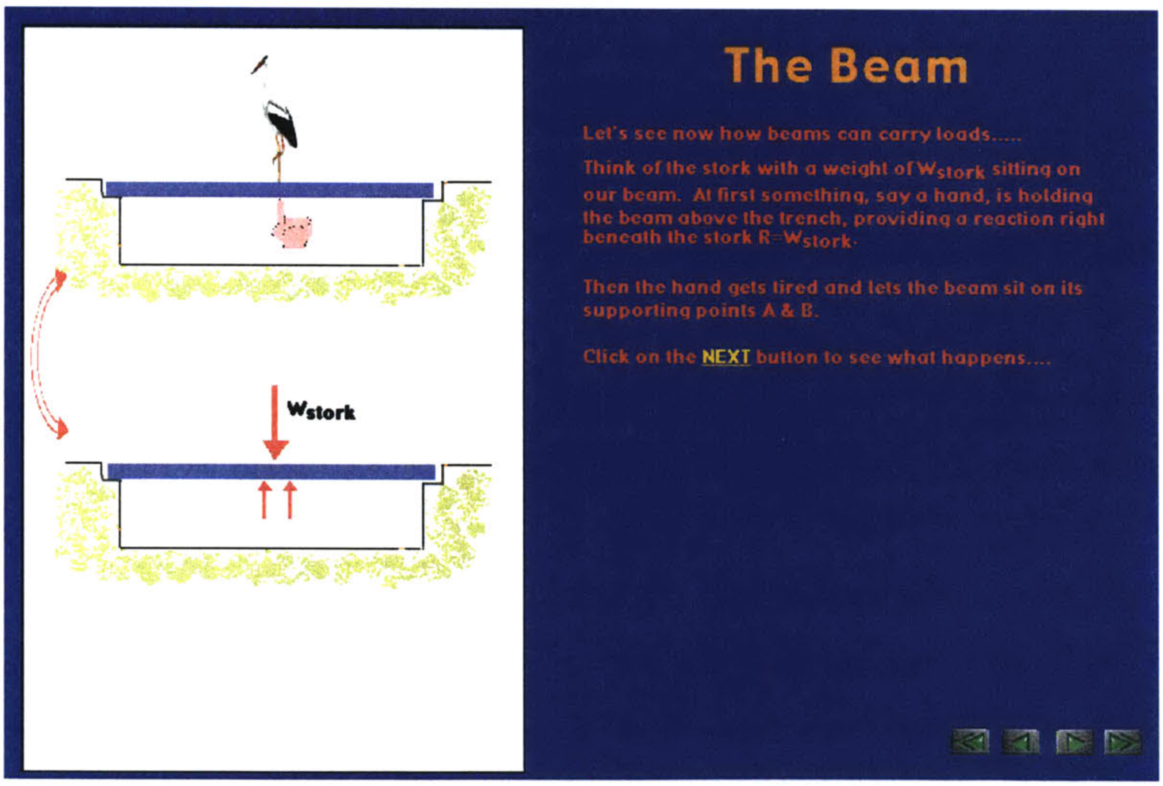

Figure 4-8: Load transfer

4.6.4 Support Configurations - Stability

Having shown that reactions to external forces act on the supporting points a more detailed exploration of what a support is and what it does follows. The primary goal of supports, holding the structures in place, is examined. At first the roller, is introduced on both sides. Then by showing the system's reaction to horizontal forces the need for at a more stable support is demonstrated. Various gradual "improvements" to the roller lead to the introduction of the hinge and then to the fixed support. (See Figure 4-9:

Gradual improvements, from a roller to a hinge).

For representing the rollers and the hinges the symbol of the cylinder shown in Figure 4-10, introduced by Kuenzle [Kuenzle 1999], is used.

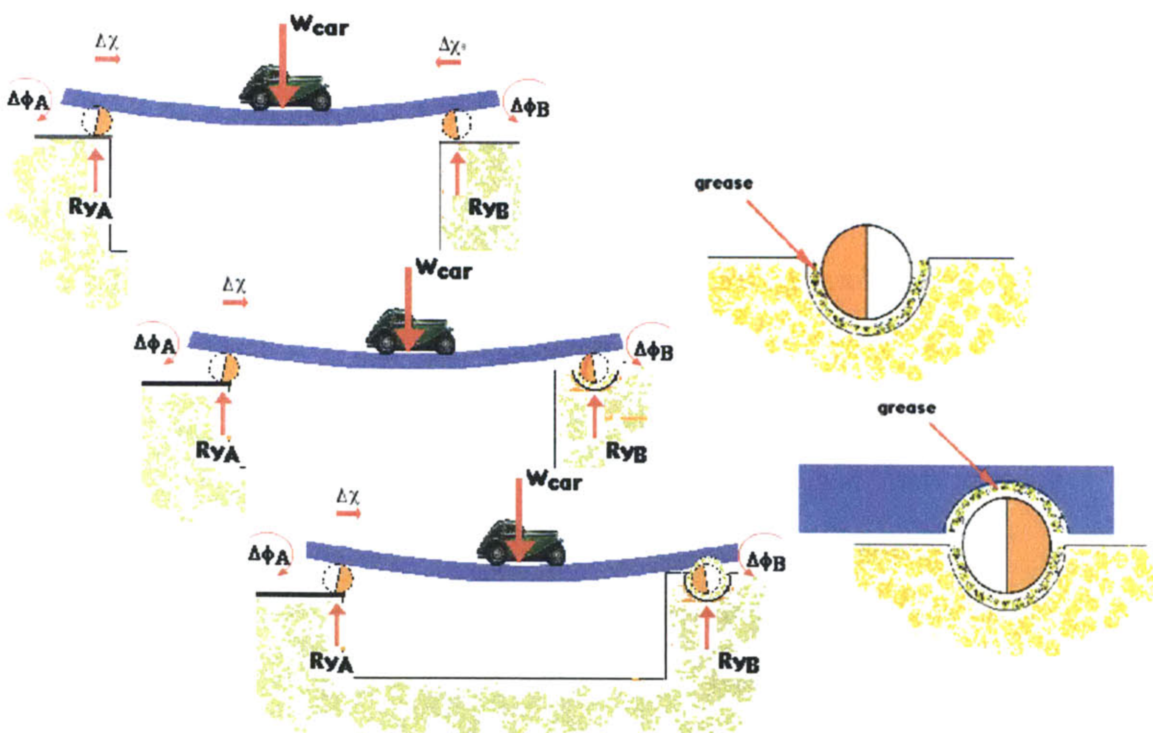

Figure 4-9: Gradual improvements, from a roller to a hinge

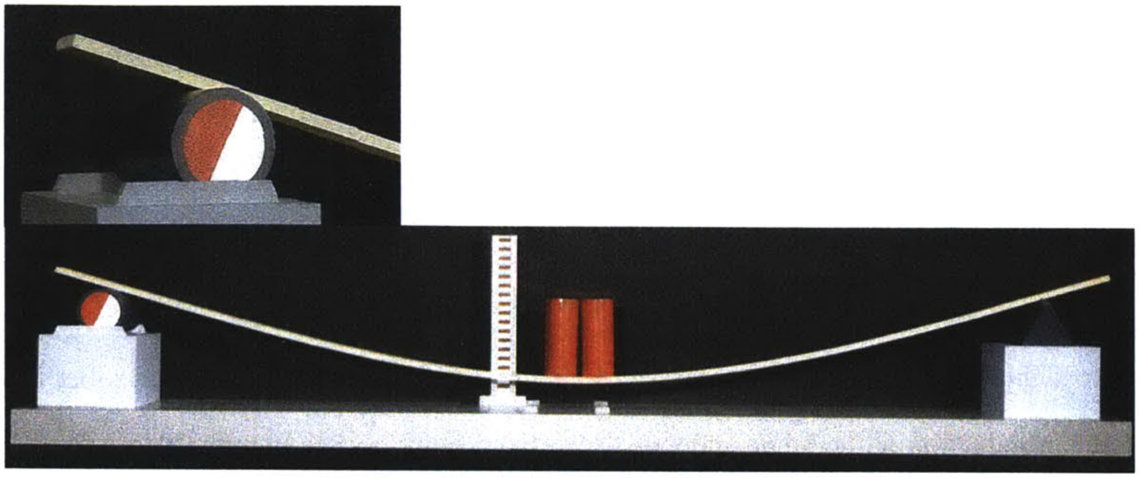

Figure 4-10: Kuenzle's idea for representing a roller

Rather than asking the student to learn what the various support types do and not do, we let him/her to discover the rationale behind the decision to use one type or another. Each support configuration for the beam provides an increasing stability for certain loads.

For each type of support, rollers, hinges, and fixed supports, a separate sub-module is available upon request as a pop up window, from which the student can learn more details in a narrative format (See Figure 4-11). In each of these sub-modules for every type of support the following information is provided:

- Real world pictures,
- Their characteristics,
- The symbols used to represent them in sketches,
- Why they are used, and
- Examples of their use

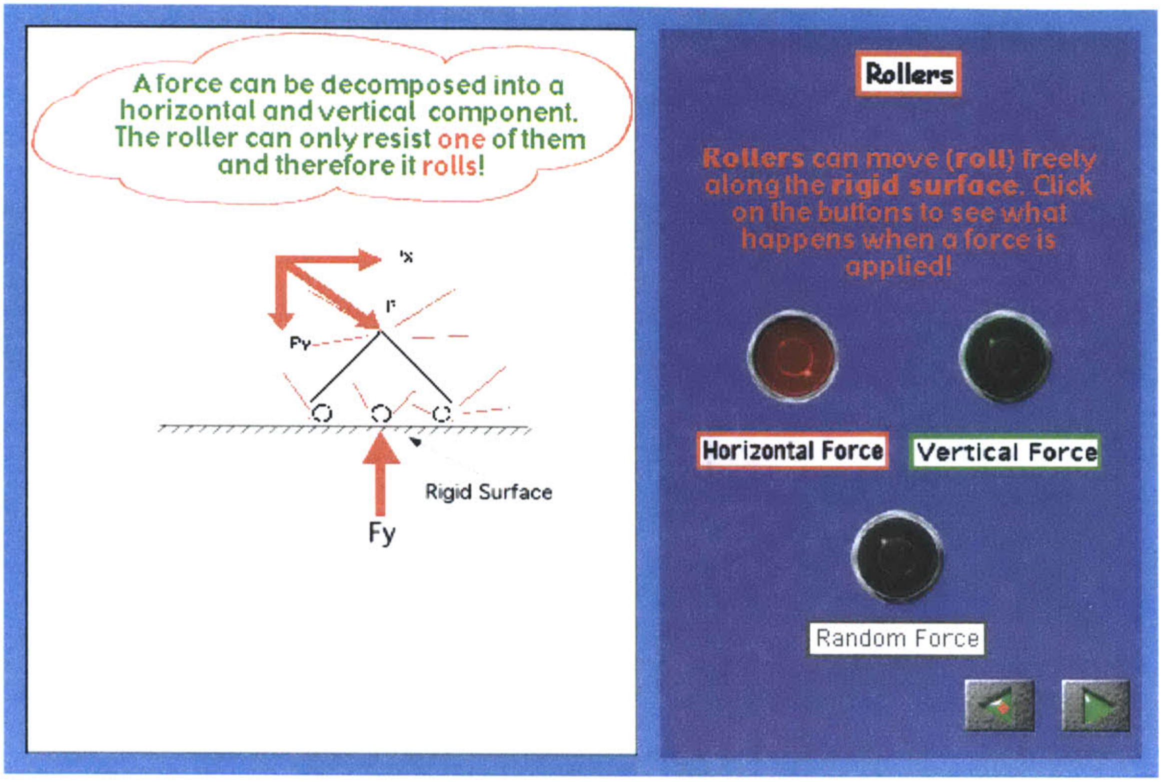

Figure 4-11: A typical window of a submodule

4.6.5 Support Configurations – Deformations

After becoming familiar with all support types, the effect of various support configurations on deformation characteristics of a single beam are studied. The focus is purely qualitative. Deformed shapes and the relative magnitude of deformations are shown. Simple animations are presented in order to show the various stages that a beam undergoes when loaded. The last stage of such animations are shown in Figure 4-12.

Going one step further, the effect of the following parameters on the deformed shape and magnitude of deformation of a beam are examined:

- Type of load –point or distributed,

- Relative magnitude of load, and
- Shape of cross-section versus direction of loading

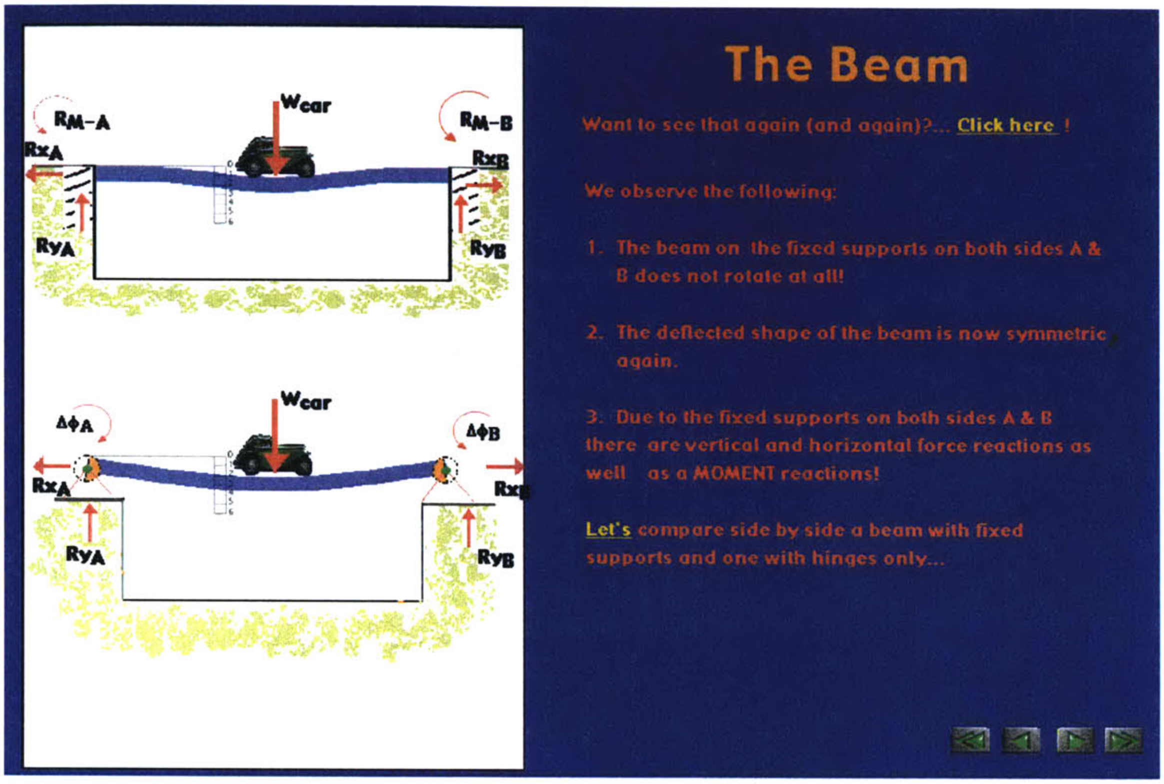

Figure 4-12: Deformed shapes and relative magnitude of deformations

4.6.6 Analytical expressions of equilibrium

The "ultimate" educational goal of the current stage of development of the *Solid Mechanics Learning Modules* is the gradual transition from qualitative observations to basic analytical calculations. With that in mind, the concept of (in)stability and equilibrium was presented earlier in the module, through animations and interactive quizzes, in order to serve as background knowledge.

In order to introduce the student to analytical expressions gradually, at first, the overall equilibrium is presented. For simplicity the equilibrium is studied only for a statically determinate beam. The student is then asked to input the components of the equilibrium equations. In order to guide the student, entries for the required equations for equilibrium –force and moment equilibrium- are shown. (See Figure 4-13) The challenge is to fill-in the three editable fields correctly. A filtering algorithm checks the users' entries and provides a right/wrong message accordingly[3].

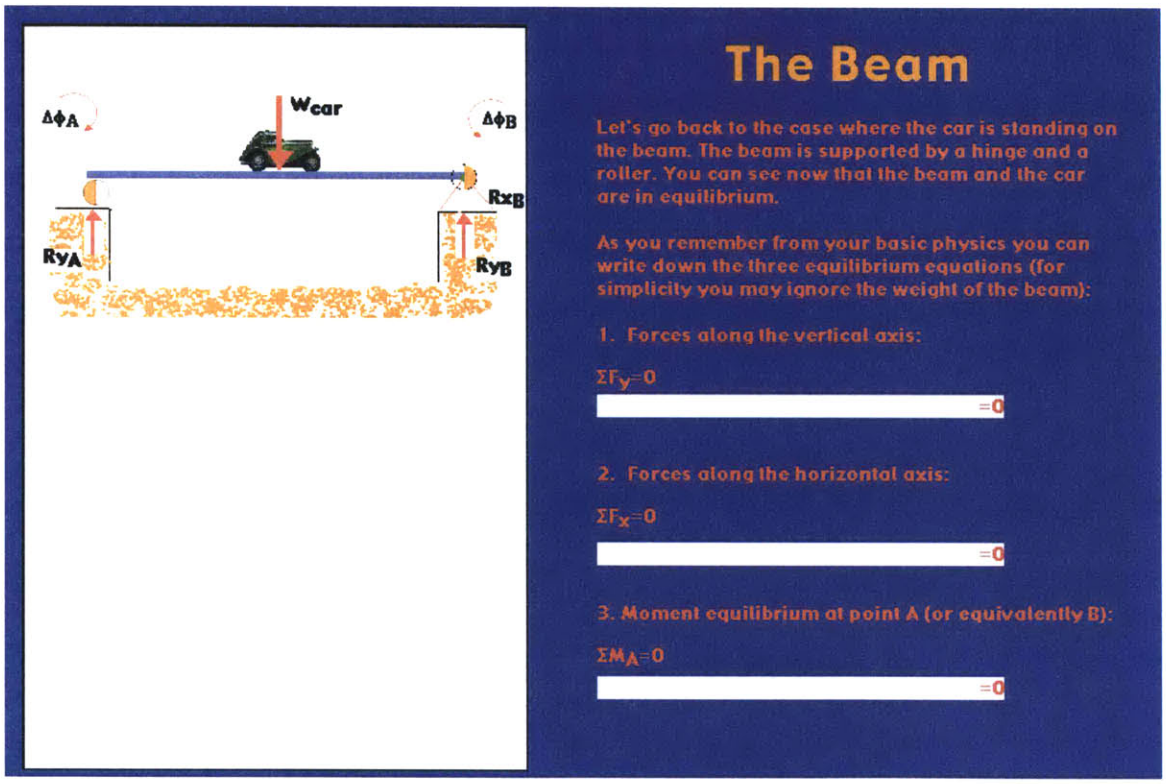

Figure 4-13: The graphical user interface for the analytical expressions of the overall equilibrium

[3] The filtering algorithm has not been incorporated.

4.6.7 Internal forces

Moving one step further with analytical expressions, the concept of internal forces is introduced. In order to help the student to "picture" internal forces, the classic "cut" is used. The concept of "load transfer", presented in section 4.6.3 , helps the student to realize that internally, in every single point of a structural element, forces act and prevent the structure from moving or collapsing.

The existence of internal forces is presented as a result of the fact that every piece resulting from any random theoretical cut must be in equilibrium. Again, in a similar format as for the overall equilibrium equations, the student needs to fill-in the editable fields for the three equations of equilibrium. (See Figure 4-14) A filtering algorithm checks the entries and provides a right/wrong message accordingly[4].

---

[4] The filtering algorithm has not been incorporated.

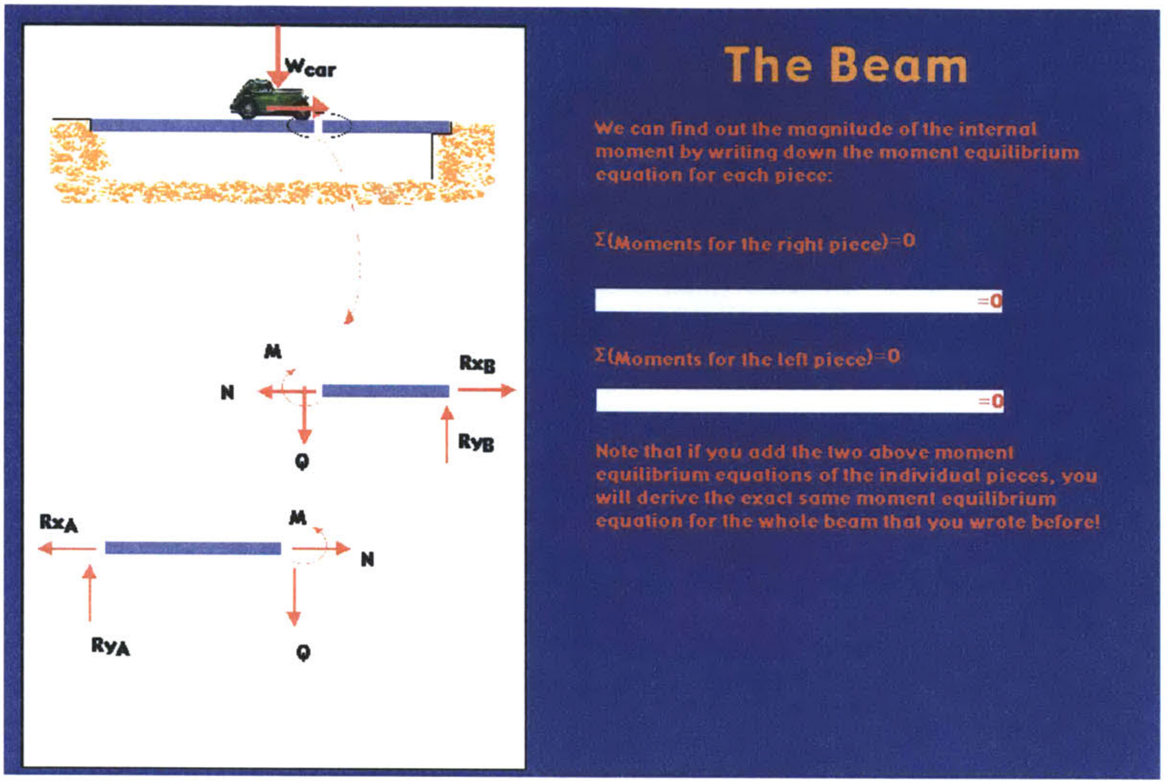

Figure 4-14: The graphical user interface for internal force equilibrium equations

4.7 Conclusion

In this chapter the rationale underlying the *Solid Mechanics Learning Modules* together with their actual content are presented. Although the concepts of structural mechanics presented are fairly simple, a great deal of "hidden" work was involved. This however, is by no means a guarantee for the efficiency of the *Solid Mechanics Learning Modules*. The developer believes that there is certainly room for improvements. Some of them are already identified and will be presented in Chapter 6.

CHAPTER 5: THE TECHNOLOGY-EDUCATION INTERFACE

5.1 Introduction

Working on the development of IT-based educational material brings up the broader issue of the Technology-Education interface. Using IT is not a question of simply placing existing educational material into different media. It poses a number of challenges from many points of view; pedagogical, psychological, economical, social and so on. IT is gradually reshaping a wide variety of endeavors and is now affecting education as well.

In this chapter, an attempt is made to go beyond the narrow technical aspects of an engineering educational tool. The possibility of leapfrogging education in developing countries by using IT is examined.

A hands-on experience from promoting IT for educational purposes in such countries has been gained from the *Integrated Technical and Tertiary Education and Economic Development for South Africa* project (*ITTEEDSA*). A key feature for that project, which started in 1995 and which was externally funded by the US Agency for International Development, has been the development of *New Educational Approaches and Programs for Engineering Education* at the Technikon schools of South Africa (technical universities similar to the US community colleges). The *Solid Mechanics Learning Modules* developed and described in this thesis, will eventually be applied in the South

African prototype project and therefore, studying the evolution of the aforementioned project as well as the economic, political and educational context, within which it is being developed, will provide valuable lessons.

5.2 Combining education and economic development in developing countries – The case of South Africa[5]

Implementing a major political and social revolution by overturning apartheid in 1994, South Africa found itself faced with the challenge of balancing its fragmented economic development across all racial and ethnic groups. South Africa's social and racial problems are relatively well known. While a small fraction enjoys higher living standards than the average US citizen, a significant fraction (43%) of the South African population of over 40 million, still has an income below minimum living standards.

However, South Africa has the "unique" competitive advantage of having an existing high-tech industry, that is comparable to that of the developed countries and on which the country counts considerably in the future. Therefore, its infrastructure development effort has to be planned in such a way that will ensure that both the current needs for technically trained labor as well as the future needs for high-tech personnel will be fulfilled.

[5] Integrated Technical and Tertiary Education and Economic Development for South Africa. Proposal to the US Agency for International Development.1995.

In order to address the problem, the new government launched the ambitious "Reconstruction and Development Program (RDP)" whose key goals are:

- Meeting basic needs,
- Developing Human Resources,
- Building the Economy,
- Democratizing the State and Society, and
- Implementing the RDP

In pursuing the aforementioned goals it was realized that the top three of them are closely linked because of the following:

- There is a lack of low and medium skilled technicians to carry out the reconstruction program. In order to meet the demand for labor with technologist/technician education, the graduation rates will have to increase from 3000 in 1995 to 10,000-15,000 per year by the year 2010. The non white community had been systematically excluded from technical and scientific education.
- Educating people without providing jobs is both unacceptable and would create social and political unrest.

The solution proposed in form of a proposal submitted in 1995 to the US Agency for International Development (USAID) by a group composed of several US universities, ORT International, and the Technikon Partnership[6], was to solve both problems through

[6] The US Universities: MIT, Howard, University of South Carolina Research Authority, York Technical College.

an integrated approach, by combining engineering education and economic development. In other words, developing infrastructure and attracting industry while simultaneously ensuring that the required number of adequately educated people is available.

Specifically, the solution proposed within the context of the project named *Integrated Technical and Tertiary Education and Economic Development for South Africa* (*ITTEEDSA*) had the following objectives:

- Assessment of the technical manpower needs in South Africa.
- Create the nation-wide "Institute of Technology" involving industry/business, labor, Technikons, universities, and government. This "virtual" institute would optimally coordinate all physical and human resources.
- Create a link between economic development and education by establishing local economic centers in combination with the Technikon learning centers.
- Modernization of technician education by introducing distance learning programs based on the Technikon learning centers. **The key elements of these learning centers would be the linkage to the Technikons through distance education and particularly the extensive use of Information Technology based education.**
- Create staff development programs
- Create economic missions that would initiate pilot programs for educational and economic efforts.

Technikon schools: Technical Schools in South Africa (similar to the US community colleges)
ORT International: Non-Profit private training organization. Home page: http://www.icd.ort.org/

There was a great deal of excitement about the innovative and pioneering concept of the project. The combination of economic development through engineering education by using the modern tools of IT promised a breakthrough. However, as the project was discussed amongst the South African Technikons, a number of practical problems emerged:

- Particularly, several of the historically disadvantaged Technikons lacked basic equipment essential for their operation that had to be provided first. Statements such as "we do not have even enough paper and pencils" were made.
- There were wide differences in the level of the various Technikons for historical and political reasons, which prevented the use of IT at some participating schools.
- In 1995 access to e-mail and the Internet was highly problematic for many of the participating South African faculty members. This resulted into serious communication problems.

In light of these limiting conditions the role of IT as a driving force for the success of the *ITTEEDSA* project became questionable. Nonetheless, the need to push engineering education particularly for the group of people who had no access to it was considered to be very important. This was recognized by the historically disadvantaged Technikons, their US partners, and USDAID and lead to a somewhat differently oriented effort.

5.3 The Textbook Effort

The five disadvantaged Technikons in cooperation with a slightly different set of US universities (Howard, MIT, Clark Atlanta, and North Carolina State University), reconsidered the objectives of their initial proposal to the USAID and came up with a new set of targets. The revised set of efforts focused on the following:

- The writing and production of engineering textbooks
- Development of the Technikons' curriculum, and
- Enhancing staff development.

This proposal was approved by the USAID and was started in 1997 with the aim of producing 8 (eventually 9) textbooks. The way in which the textbooks were written was very innovative and simultaneously served the staff development. Each textbook was developed by groups of four project members. A Technikon faculty member was the designated author assisted by three moderators, two other Technikon faculty members and one from the US team. The involvement of Technikon faculty was particularly important since most of them were first-time authors.

The interaction of authors and monitors initially occurred exclusively at semi-annual workshops and through exchange by postal mail. Increasingly this exchange took place electronically but still included a workshop close to the end of writing of each book.

Overall nine textbooks were printed in the period 1997-1999 in the following areas:

1. Physics for Engineering,

2. Introductory Digital Systems,
3. Mechanical Engineering Drawing,
4. Mechanics for Civil Engineering
5. Construction Methods for Civil Engineering
6. Construction Materials for Civil Engineering
7. Drawing for Civil Engineering
8. Drawing for Engineering
9. Basic Circuit Analysis for Electrical Engineering

The textbooks, which are on paperback, were immediately very successful. Much of this can be associated with the low price (less than $10/book) but given that the textbooks were adopted by schools not involved in their development it appears that they are also technically a success.

5.4 The CD-ROM Effort

After the successful completion of the textbooks, the "follow on" to the project created somewhat of a dilemma to the members of the consortium. The dilemma was whether to develop more advanced textbooks or to improve the existing ones. However, a third concept was initiated, and further developed, namely, the creation of CD-ROMs as a supplement to the textbooks.

The intent was to avoid duplicating the textbook material in the CD-ROMs but instead, to use unique IT features to enhance the textbooks. Furthermore the "follow on" project is seen as a chance:

- to introduce and expose both faculty and students to the use of computers and particularly IT in learning,
- to improve the efficiency of the engineering curriculum with visual resources, simulations, graphics etc, and
- to produce more creative use of the faculty's contact with the students.

Specifically, aspects which are difficult if not impossible to convey in text and printed figures will make use of the CD-ROM. Examples are:

- Relation between the 3-D reality and 2-D representation, (in "Drafting" textbook)
- Simulation of physical processes (in "Electrical Circuit", and "Physics" textbooks)
- Visualization of construction processes (in "Construction" textbooks)

The Solid Mechanics *Solid Mechanics Learning Modules,* described in this thesis, which combine simulation and animation, become part of the CD-ROM of the "Mechanics" textbook.

Also the development of the CD-ROMs is intended to lead to a more complete buy-in to IT. Nevertheless, this current IT oriented phase of the project is still far from the initial and ambitious goal of the *ITTEEDSA* project for using IT as a tool for combined education and economic development. In the following section 5.5 , a more detailed attempt to analyze the lessons learned from such a hands-on experience is presented.

5.5 The experience gained from the ITTEEDSA and the "follow on" projects

Looking back in the case of the *ITTEEDSA* project and the "follow on" one can conclude that the message regarding the success of the implementation of Information Technology was mixed. Initially there was excitement and relatively high hopes about the power of Information Technology since it was expected to play a major role in assisting the economic development through engineering education. However, reality proved to be different, and as a result, more conventional and "down to earth" efforts were pursued first before the idea of introducing IT became gradually feasible. The *ITTEEDSA* effort by being one of the first projects where IT was to be used for educational purposes in a developing country on such a large scale, offers valuable experience and lessons for the future.

The experience of the *ITTEEDSA* project and its "follow on", showed that it was unrealistic to speak about Information Technology in a sector that was lacking basic means such as simple office supplies, paper and pencils. Although it was certainly innovative to propose the restructuring of the technical education by using IT, the actual timing for the implementation of IT was far different than the one planned. In fact, it took the group of the Technikons and the US universities five years to start including IT within their set of tools. Moreover, the evolution from addressing basic needs to the development of CD-ROMs came as a more natural sequence, which gave the developers more confidence regarding the success of their moves.

An important parameter relative to the possible implementation of IT was the reluctance of the participating members of the *ITTEEDSA* project to accept IT as a major tool for what they were seeking to achieve. Such reluctance may have occurred due to the lack of experience and familiarization of a number of the participating members with IT. Even if the possible benefits were demonstrated to them, the cultural "buy-in" takes time to occur. Particularly, at the time that the *ITTEEDSA* project was supposed to start, the Internet, even in the US, had not expanded significantly, while in South Africa it was very unevenly distributed.

One may argue that had the project started in the year 2000, things would have been much different regarding the extent and the timing of implementation of Information Technology. It is not only a matter of cultural acceptance but also a matter of the level of the available technology. Developments like file-sharing and the lowering of the cost of satellite communications have changed the scene and have pushed the limits of the applicability of Information Technology even in areas where there is barely any land based telecommunication infrastructure available.

There is also another parameter that has to be taken into account when entirely new ideas are proposed for similar projects. Confidence in success is not only related to experience and knowledge of the proposed ideas but it is also related to the perception of the participating members regarding efficient use of the available funds and resources. Risky and avant-garde ideas are less likely to be realized whenever there is a fear of wasting resources that are not easily replaceable. In the case of the *ITTEEDSA* project, risking the availability of funds or, even worse, experimenting with USAID's funds rather than spending them on something everybody could relate to, appeared to be unacceptable.

The physical presence of a person capable and responsible for running and supporting the system on a permanent basis would also make things much easier. Even users familiar with IT need support mechanisms such as help centers. The physical presence of such a person based permanently in South Africa would have:

- Increased the confidence of the local professors in accepting solutions that seem too avant-garde up to that time. Simply from a psychological perspective, having such an expert available would have a major impact.
- Facilitated the application of IT by providing expertise as well as by transferring his/her knowledge to the local faculty member who would later take over.

The above measure could be applied in parallel with the training and education on IT of a South African faculty member in a US university so that there would be no delay in providing the local project team with an expert based in South Africa.

The problems encountered in the introduction of *ITTEEDSA* project's innovative and ambitious primary goal of for using IT in combing engineering education and economic development may have also been associated with the project's scale. Applying the project at one Technikon instead of five and subsequently in a considerably smaller pilot area in the countryside may have actually worked even from the time back in 1995. Creating a local cluster, where the concept could be actually implemented on a pilot scale, it would have made possible to:

- Show feasibility of the concept
- fine tune of the project,
- gain experience on solving the same particular problems that would eventually be encountered in full scale,
- lower cost thanks to learning effects,
- lower associated risk and consequences of a possible failure by decreasing at a first stage the geographic scope of the project, etc.

Instead of "going small" with a pilot program the exact opposite could also be a solution. Applying IT from scratch in such an ambitious goal as infrastructure development for a whole country requires a much more vigorous support. Therefore, incorporating the development of IT for engineering education within a general effort for the promotion of IT in all sectors of the economy could have given the required momentum to the *ITTEEDSA* project. Moreover, incorporating IT within a broader effort such as the "Reconstruction and Development Program" of South Africa might have decreased the costs for individual projects such as the *ITTEEDSA* project while helping the diffusion of IT in many other sectors of the economy where IT is equally useful. After all, IT is becoming an essential tool for multiple sectors of the economy, and sooner or later an investment in IT will be required in all those individual sectors for countries like South Africa.

5.6 Conclusion

The intended use of IT for the combined promotion of engineering education and economic development in South Africa provides valuable experience for future projects in other developing nations and communities. Most importantly, the South African experience shows that there are constructive ways to enhance engineering although the initial plan was not implemented as conceived. The following thoughts, originating from the South African experience, may be useful for future efforts using IT in engineering education.

One may blame the South African project's innovative approach and/or its scale for the delay in reaching its initial goal of deploying IT in engineering education. Probably both of them were beyond their optimum levels given the general context of the project. However, this does not imply that ambitious projects, of large scale and scope should not be planned. To the contrary, such projects should be brought up given that they can actually be very rewarding due the challenges involved.

Certainly, deciding upon the scale and the scope of the project beforehand is important. An oversized project may discourage its participants, particularly when the scope is relatively wide. In the case of the South African project a small group of professionals and academics formulated a promising and pioneering proposal, which required the cooperation of individuals and organizations from a wide array of disciplines, ranging from education and technology to economics and public policy, in order to be fully and successfully implemented. However, the organizational and the institutional framework that supported the effort were .

By looking back at the South African project, one may identify a number of possible synergies that could have been explored for the benefit of the effort, so that the project could proceed as initially planed, eliminating the need for a pilot phase or reductions in scale and scope. Given the wide range of IT applications, it would have been advantageous to explore other sectors, or prospective partners who may have common interests regarding IT, in order to share costs, expertise, and possibly new ideas that may developed be in the course of the collaboration.

Finally, as almost in every project, the cultural, economical, and political peculiarities of the country in which a project is running have to be acknowledged in order to adapt the goals and the methods accordingly.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This thesis describes a first version of the *Solid Mechanics Learning Modules,* a set of IT-based of modules developed for teaching basic structural engineering concepts to first year university and technician college students. The educational goal of the *Solid Mechanics Learning Modules* is to have them used as a supplementary material to textbooks and lectures, such that the students will gain intuitive understanding of structural behavior. This will be facilitated by animated schematic representations and qualitative examples. Moreover, the students will be assisted in developing the necessary background for performing basic analytic calculations.

In terms of content, the modules start by introducing the student to the concepts of a beam and loads on the beam, followed by vertical and horizontal load transfer to the supports. The effect of various support configurations on the stability and the deformation of a beam subjected to a single load acting in various directions is studied. Finally, the student is introduced to simple analytical expressions of equilibrium of external and internal forces for a determinate beam.

In this thesis, a hands-on experience of applying IT in enhancing engineering education at the Technikons in South Africa is described. The innovative approach and the project's scale may be blamed for the limited the use of IT and the delay of its implementation for the benefit of the project. However, the message derived from the South African experience is that there are constructive ways to enhance engineering education using IT in the context of similar ambitious large-scale projects. Implementing pilot phases, exploring possible synergies within other sectors of the economy for sharing costs and ideas, and respecting the peculiarities and culture of the people involved and affected by the project, were identified as key-parameters for mitigating the problems associated with such large-scale projects in the educational domain.

As mentioned above, in this thesis, the first version of the *Solid Mechanics Learning Modules* was described. As in every first effort, there is still plenty of room for improvements, additions, and possibly, some corrections as well:

Possible improvements:

- Evaluating users' answers to questions in analytical questions,
- Enhancement of the graphics of the *Solid Mechanics Learning Modules,* and
- Expansion of the interactive elements of the *Solid Mechanics Learning Modules.*

The development of an algorithm that can evaluate user's input is required for the completion of the existing version of the *Solid Mechanics Learning Modules*. The challenge is to allow the algorithm to accept all combinations of user input in order to avoid rejecting a correct input if it is written in a somehow "unexpected" way. In order to simplify the process and avoid "unexpected" misspellings, the components of the equations (all signs and all vector-force components) could be available in a draggable menu, from which the student-user will pick the ones he/she thinks are needed by using the "drag and drop" feature of Director.

The focus during the development of the *Solid Mechanics Learning Modules* has been on improving the actual content rather than designing the most attractive, professional-level user interface. The developers therefore, acknowledge that there is plenty of room for improvement of the appearance of the *Solid Mechanics Learning Modules*, particularly in the design of graphics and animations so that the final version meets the highest standards for web-based educational products.

Most of the material in the *Solid Mechanics Learning Modules* is presented in a narrative format with relatively few interactive elements. The latter are primarily in form of simple questions and quizzes. Rather than adding more quizzes, which may annoy the student-users if there are too many of them, interactivity can be enhanced by prompting the student-user to proceed to on-screen actions such as to “drag and drop”, to enlarge or to move elements and then see what kind of results his actions trigger.

Future research:

- Use of Artificial intelligence for greater interactivity,
- Evaluation scheme for the *Solid Mechanics Learning Modules,* and
- Enlarge the *Solid Mechanics Learning Modules* and include them in a library of modules,

A very promising field that could contribute substantially to the development of similar educational software is Artificial Intelligence. Creating “personalized” tutoring based on the individual responses of the student-user could provide another dimension to such educational software. Work along these lines in elementary solid mechanics is currently under development by Viteri. [Viteri 2001]

Given that the *Solid Mechanics Learning Modules* are a product, which has been developed essentially in the lab without direct input and feedback from their prospective audience, the design of an effective evaluation scheme would help the developers to improve substantially the content and the quality of the modules. By taking advantage of the relatively large audience that the CD-ROMs, described in chapter 5, will be addressed to, the evaluation can be done both effectively and within a relatively short period of time. The evaluation should be designed in a way that can provide information on the following:

- The relative success of its educational goals,
- Ease of access and user-friendliness of the interface,
- Weaknesses pointed out by the students together with their thoughts and suggestions for possible improvements

Including the *Solid Mechanics Learning Modules* in a library of learning modules based on the idea proposed by Shepherdson [Shepherdson 1997] is among the future steps of research. By combing a large set of modules, in a complete set of material available through the Web, the potential audience will increase dramatically and hopefully its impact to engineering education will do so as well. Apart from designing the material to be included into such a library, it is equally important for the future developers to consider a number of technical, legal, and economical/marketing issues so that the library can reach its maximum potential.

BIBLIOGRAPHY

1. Bucciarelli, L.L., Shapit A. 2001. The Electronic Companion to the textbook "Engineering Mechanics for Structures" (http://web.mit.edu/1.04/www)
2. Einstein, H.H 1996-1998. Physical Geology Tutor. http://cfd4.mit.edu/PGTprivate
3. Einstein H.H. 1999. IT Enrichment of Engineering Education Through Active Learning, Simulation of Large Engineering Systems, and Assessing and Improving of IT-Enabled Learning. Project proposal.
4. Integrated Technical and Tertiary Education and Economic Development for South Africa (ITTEEDSA). Proposal to the US Agency for International Development (USAID/Pretoria). 1995.
5. Kuenzle, O 1999. Demonstrationen an Tragwerksmodellen. HBT, ETH Zuerich.
6. Miller, G.R., Cooper, S.C. 1998. Visual Mechanics – Beams and Stress States. PWS Publishing, Boston, MA.
7. Norback, J.S. 1998. Literacy Skills Analysis for Job Training. Technical Report. NCAL. Graduate School of Education. University of Pennsylvania.
8. Perkins, D. 1992. Smart Schools – From training to educating minds. The Free Press New York, NY 1992.
9. Reder, S., 1998. Learning to earn: Direct incentives for work-based literacy learning. Technical Report. NCAL. Graduate School of Education. University of Pennsylvania.
10. Reynolds, S.A, 1999. Education at Technikon – Access to US Expertise. Final Report, phases 1 & 2.
11. Shepherdson, E. 1998. Teaching Structural Behavior through an Interactive and Complete Environment. Masters Thesis MIT.

12. Shepherdson, E. 2001. Teaching Concepts Utilizing Interactive Learning Computer Environments. Ph.D. Thesis MIT http://moment.mit.edu/thesisemma/startHere.htm

13. Viteri, V. 2001. Teaching Structural Behavior: Implementing dynamic assessment and valuation capabilities to simulation-based learning environments. (To be published)

14. Williams, R. Tollet, J. 1997. The non-designer's Web book: An easy guide to creating, designing, and posting your own web site. Peachpit Press, Berkeley, CA.

APPENDIX: STORYBOARDS OF SEVERAL SUBTOPICS[7]

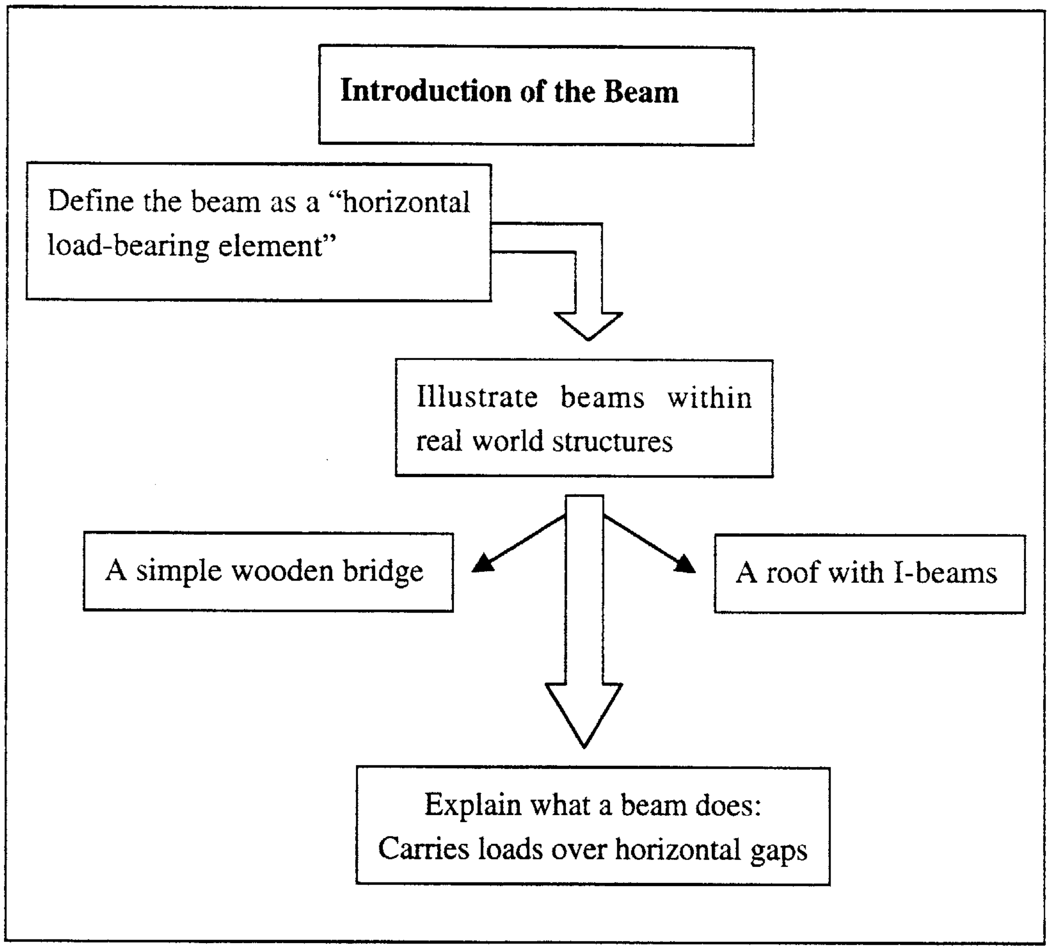

Figure A-1: Subtopic 1 – Introduction of the beam

[7] See page 36

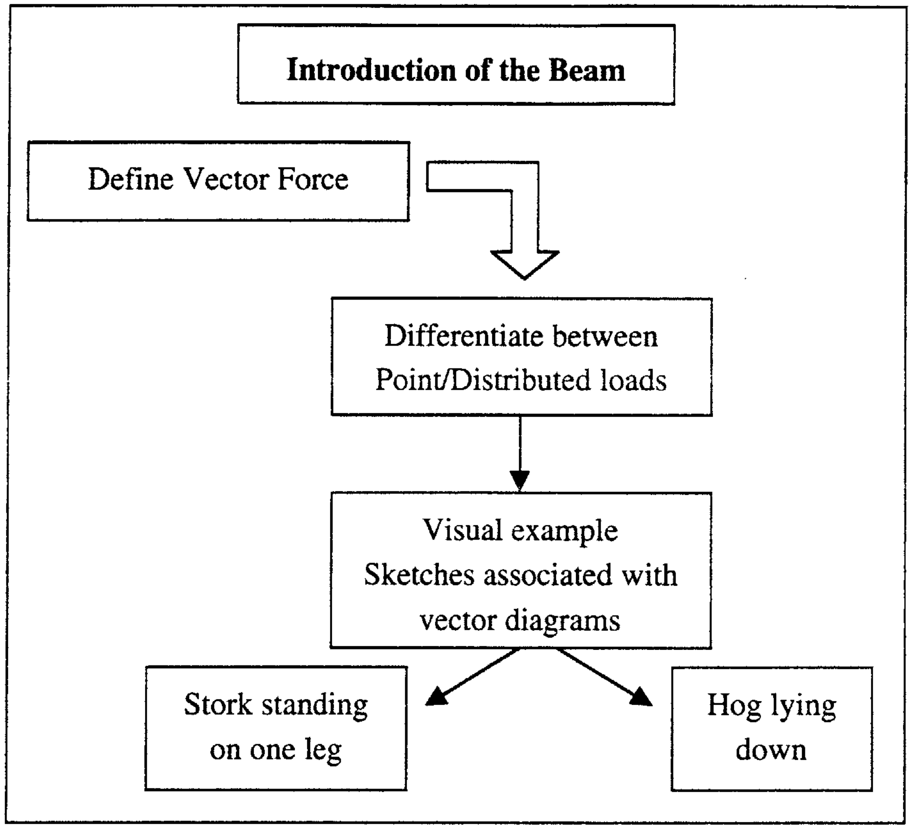

Figure A-2: Subtopic 2 – Introduction of the Loads

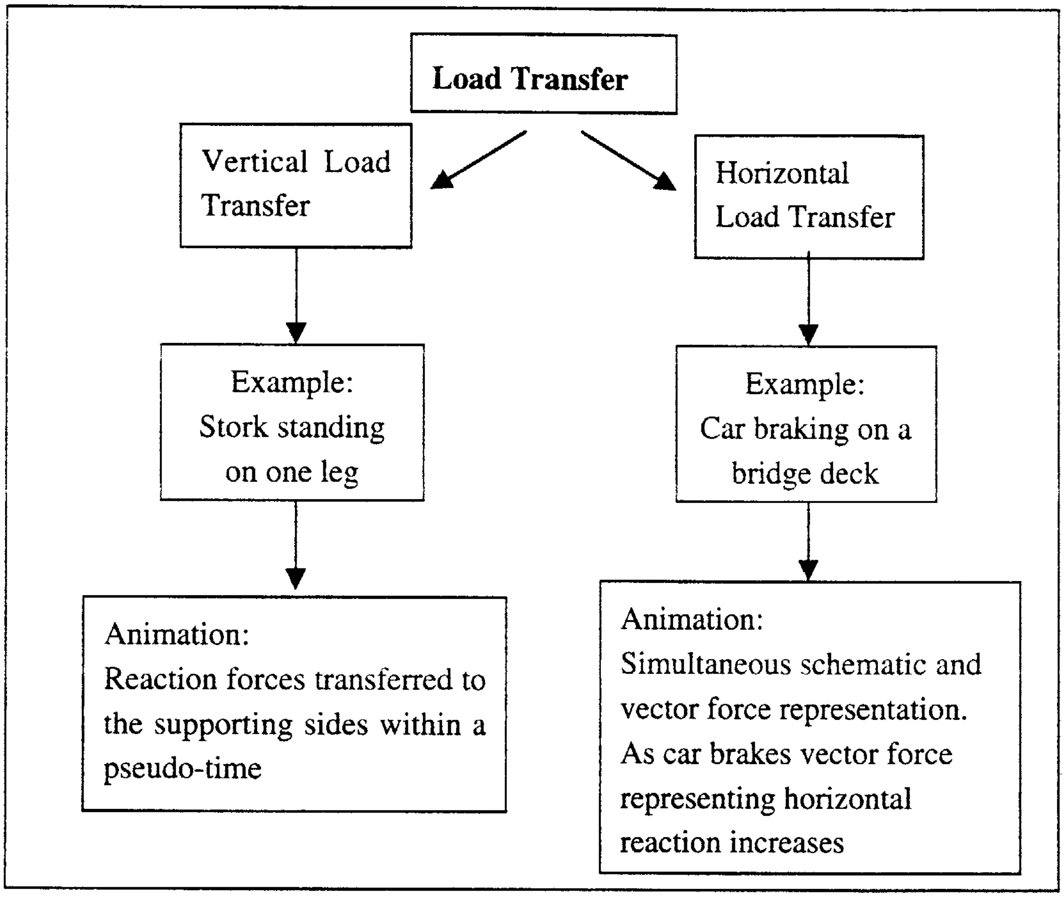

Figure A-3: Subtopic 3 – Load Transfer

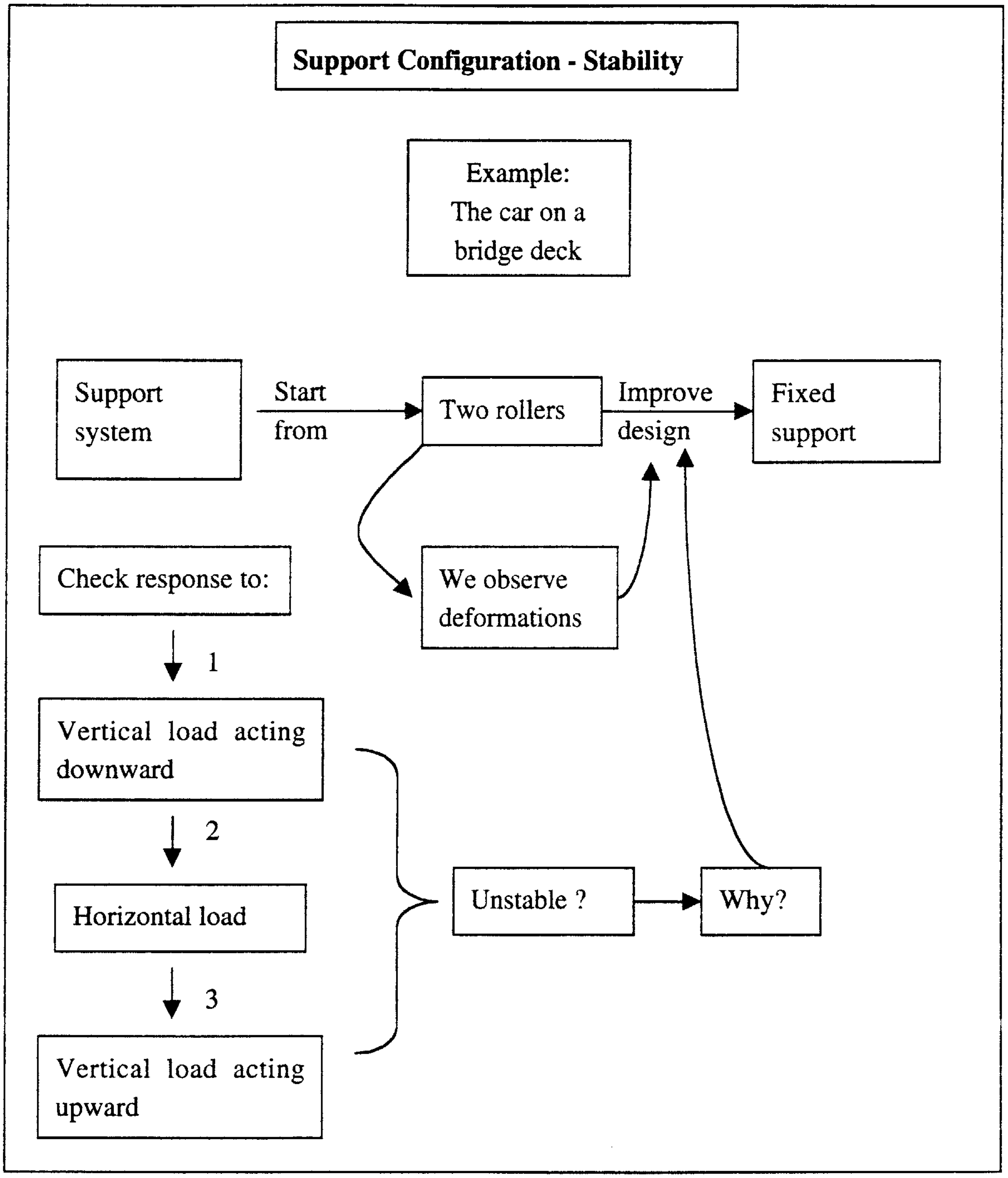

Figure A-4: Subtopic 4 – Support Configurations and Stability

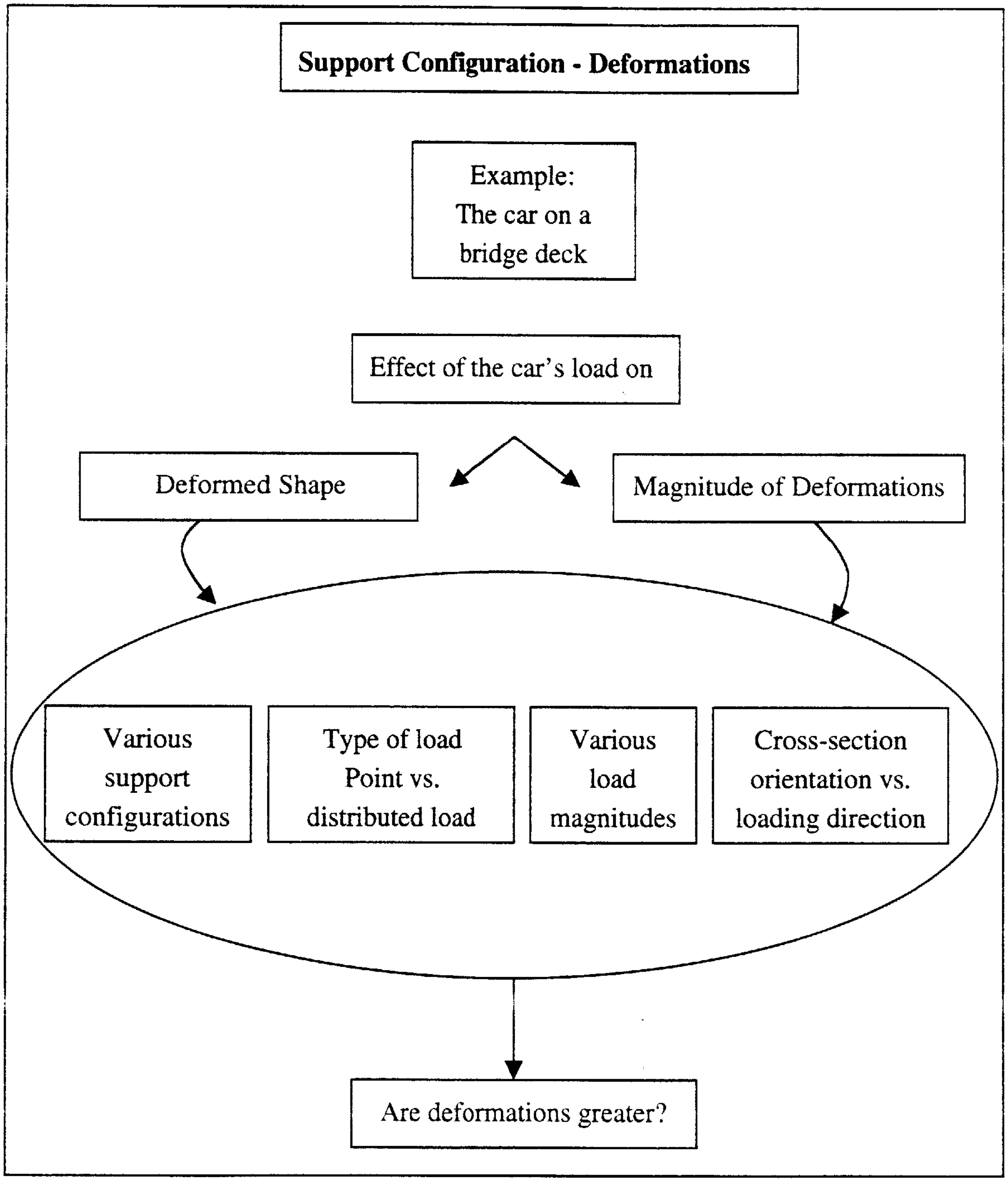

Figure A-5: Subtopic 5 – Support configurations and Deformations

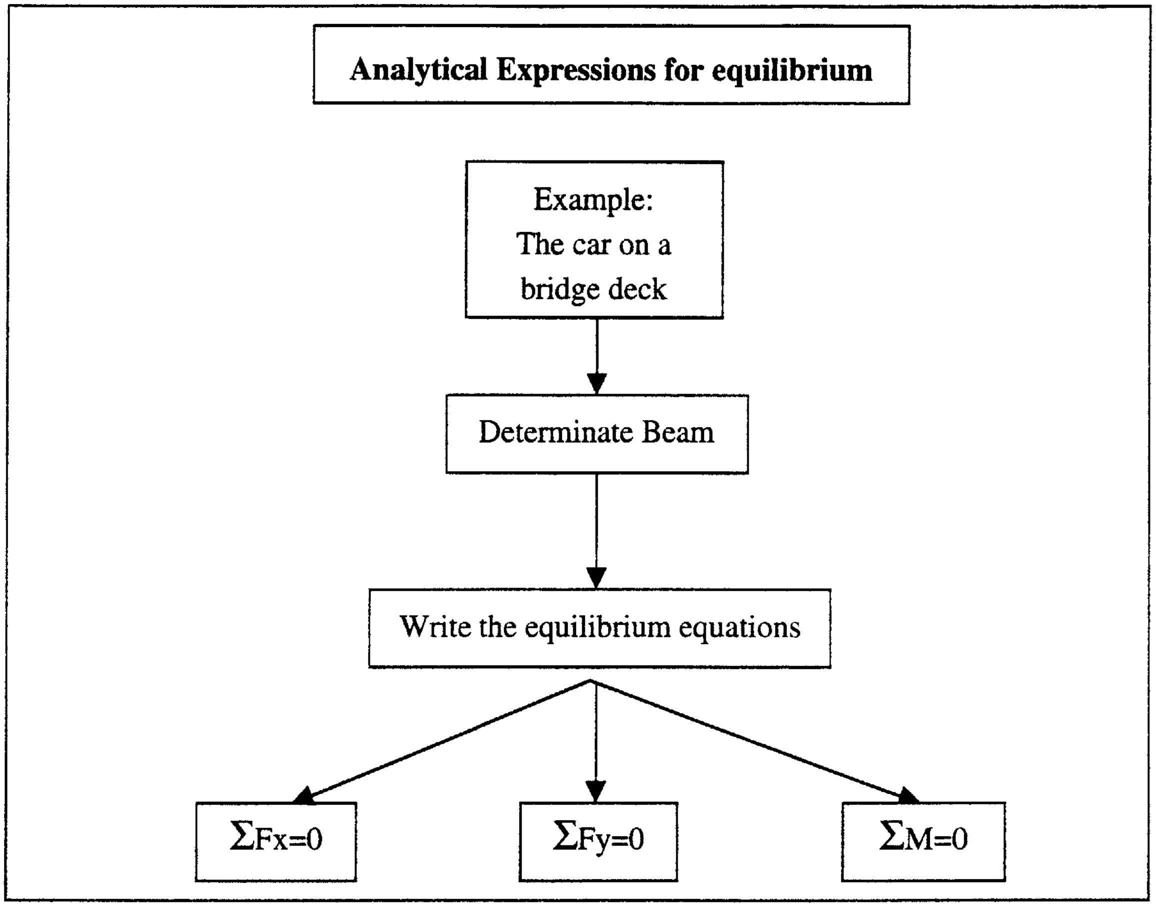

Figure A-6: Subtopic 6 – Analytical expressions for equilibrium

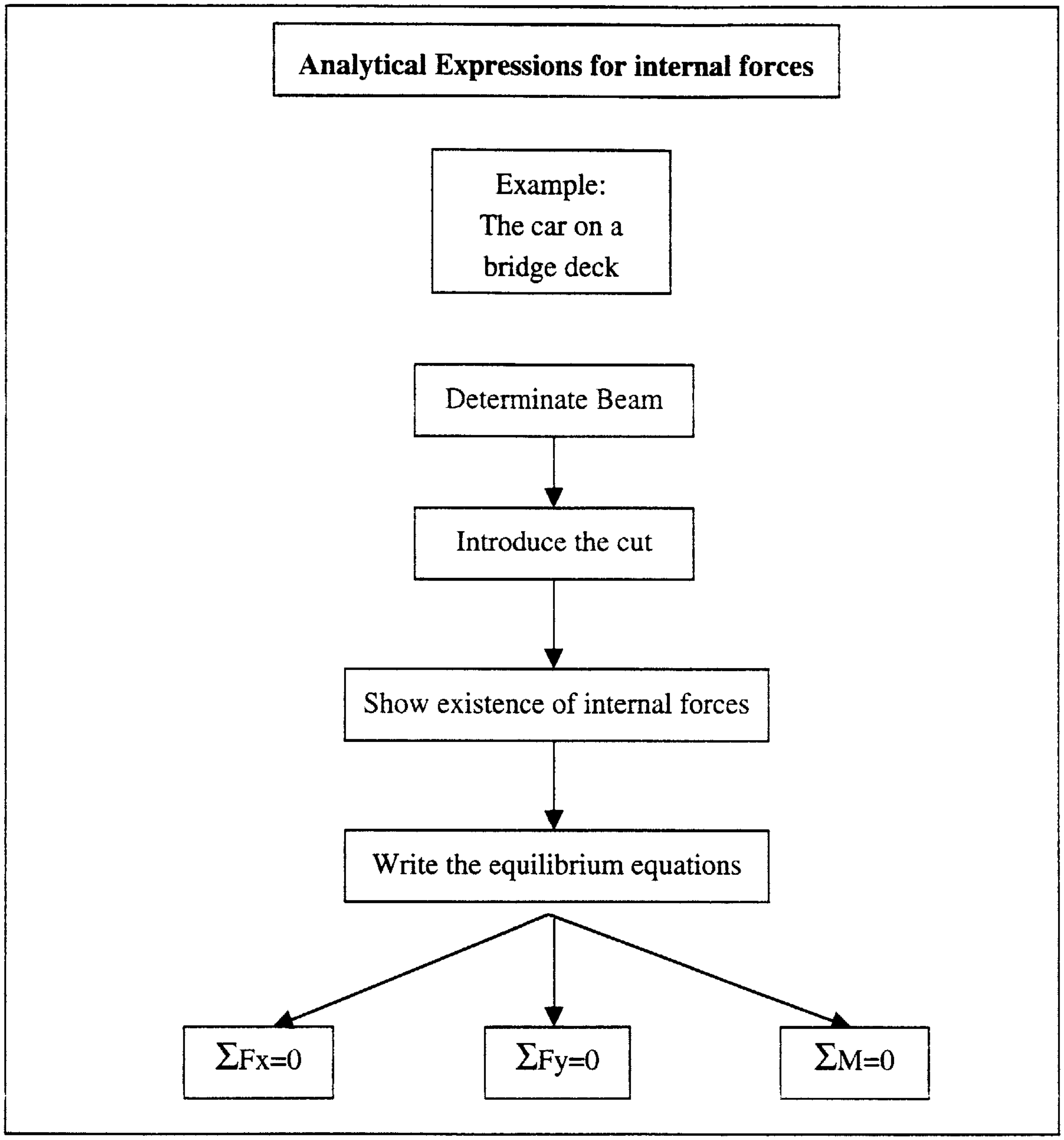

Figure A-7: Subtopic 7 – Analytical expressions for internal forces