Teaching Qualitative Material with Interactive Feedback Learning Modules

Emma Shepherdson, Jerome J. Connor
Massachusetts Institute of Technology

Abstract

The teaching of qualitative and quantitative material simultaneously to structural engineering undergraduates has not been successful. An appropriate strategy for resolving this problem would appear to be the use of multimedia for presenting information and communicating to students. This approach allows for individual interaction for the students, interesting and informative manners for instruction, and a better opportunity for assessment.

Many educators, however, feel that the current so-called "interactive" computer learning software for teaching material with "strong qualitative content" has not achieved true interactivity and adaptability. A necessary pedagogical ingredient for an effective learning environment is informative feedback. The inherent properties of qualitative material include abstract ideas and large variability, which are difficult to cater to with multimedia, particularly when providing the desired feedback.

Endeavoring to overcome these problems, this paper proposes a different approach for educating engineers interactively with qualitative content. The approach employs a well-structured and guided environment, and encourages informative and continual feedback. These ideas are implemented through a developed module within the teaching context of Structural Behavior. This paper also presents the important design issues to consider for efficient production of this interactive a learning experience.

1. Introduction

Structural Engineering is a discipline concerned with the design of buildings, bridges, and other types of structures whose primary function is to carry loadings. Like all engineering disciplines, it requires a balance of skills; mixing art and science. Strong analytical capabilities are essential, but so is a good intuitive sense of how structures behave. These skills are becoming particularly more crucial with the increasing use of computers that is now occurring in professional practice. Major problems are created if the engineer does not interact appropriately with a structure's computer model to ensure that the structure will perform as desired. It is essential for the designer to go beyond the analytical results to understand the structural behavior and its implications.

Practicing engineers and academics all recognize that the design process is not just a matter of numerical calculations to arrive at a set of minimum dimensions. The process is much richer, requiring an ability to tease out the fundamental problem, understand its implications, prepare solution schemes, assess the most appropriate scheme, and only then carry out a full analysis or number crunching. To accomplish all of these steps acceptably, again a solid understanding of structural behavior is essential. For example, the ability to test whether a structural system is adequate without performing detailed calculations is extremely beneficial. Unfortunately, however, the undergraduate education system often overemphasizes the analytical skills at the expense of other skills. This is due in part to the institutions assuming that only the analytical skills are essential to a newly graduating junior engineer, expecting the students to pick up the extra skills once in practice.

The approach of focusing on the analytical aspects, however, does not allow the student to develop a qualitative conceptual understanding that could provide insight to the analytical aspects, or a sense of the bigger picture. Equally regrettable is the approach's damping of creativity. Without learning something of the full design process at an early level, the students miss out on seeing the exciting opportunities for creativity and challenge that are available in the Structural Engineering discipline.

An additional reason for poor emphasis on structural behavior in undergraduate education is the difficulty in teaching it and other qualitative material. It is much easier to present and test numbers and equations than it is concepts. Many of the topic's aspects are best acquired through exploratory endeavor with real life background context. The context is not too complicated to provide in class. The exploratory opportunity is, however, as it involves an interactive process of repetition, good guidance and continual feedback to the individual. For example, constantly doing rote-style math to achieve the visual representations for learning can quickly become boring for the student. Similarly, without adequate guidance and comment to ensure that they are observing the necessary issues in their work, the students' efforts are also wasted.

Therefore, based on these concerns, it would appear that the capabilities provided by multimedia and information technology lend themselves well to a solution. They allow for individual interaction for the students, more interesting and informative modes of instruction and a better opportunity for assessment. This paper presents the development of an approach that employs these technologies through a well-structured and guided web-based environment. The work is demonstrated by a module that has been realized, as discussed in Section 4. Before introducing this approach, however, the specific problems shall be examined more deeply in the next section.

2. Further Examining the Teaching Problems

The initial motivation for the research described in this paper was the desire to address an identified imbalance of teaching structural behavior within undergraduate structural engineering education. Furthermore, the authors believe that the inability to teach qualitative and quantitative material simultaneously is prevalent in engineering education, in general.

Supporting evidence for these conclusions was found through a literature review of recently published opinions on the state of our structural engineering education system. These views, as briefly summarized here are from both educators and practicing engineers.

Morreau[4], a practicing engineer wishing to provide a framework for the general observations of professional engineers, formulated a criterion for fresh graduates. It involved the following assessment measures:

1. How successfully do the graduates model the structure prior to analysis?
2. How successfully do they interpret the results of the analysis? Do they recognize the errors in these results? and
3. How successfully do they use the analysis to modify the structure?

The authors note that none of these measures are adopted in the typical academic classroom. Morreau found that, although the graduates generally cope quite effectively with the first measure, especially when posed with a straightforward problem, their inadequacies begin to show in all three measures when the problem is more complicated. For example, when the structure needs to be broken down or when boundary conditions are not obvious - essentially, when the engineer really needs to understand how a structure is functioning.

At a more rudimentary level, Brohn[2, 3], another practicing engineer and academic with an excellent teaching text, observed in students a poor ability to just sketch the approximate bending moment, shear force, reactions and deflection solution to a structure. He equates these inadequacies with a lack of understanding of structural behavior. Within the authors' own Department of Civil and Environmental Engineering, the undergraduate curriculum content has been substantially revised to address the heavy emphasis on analysis, and places more emphasis on synthesis, which requires an understanding of how physical systems respond.

In search of a solution for these problems, an examination was made of the few current attempts at teaching qualitative content. The material is typically provided in class and in a passive manner. Furthermore, any efforts to assess students' understanding of the material and provide feedback to them are poor to nil. Therefore, as alluded to in the Introduction, information technology and the use of multimedia offer a solution.

Adopting these technologies, however, reveals a third problem. The current so-called "interactive" computer learning software for teaching material with "strong qualitative content" does not live up to its potential. Its attempts at achieving true interactivity and adaptability are not very satisfactory. As will be discussed further in the next section, there are various basic pedagogical theories listing the essential ingredients for an effective learning experience. Informative feedback appears on all of them. The inherent properties of qualitative material, including abstract ideas and large variability in user responses, make it difficult to cater for, particularly when providing this desired feedback.

Hence, through exploring our initial concerns, the authors have been able to shape their final challenge into the development of teaching tools for undergraduate structural engineers that

- teach structural behavior, with the additional expansion to, more generically, cover material of strong qualitative nature
- adopt the benefits of multimedia and information technology, and finally,
- include adequate feedback and interactivity

3. A Solution to the Problems

Endeavoring to meet this challenge, our approach employs a well-structured and guided learning environment that provides effective and continual feedback. A library of modules on particular topics is envisaged. By adopting a self-study model, each module ideally could be assigned as homework to the students. The modules would then be providing conceptual explanations in a narrative form. Using this approach creates minimum disruption to the professors' existing format, yet provides complementary learning to the more analytical material covered in class. To present this material, a seamless web-based representation is used that employs text, graphics, animations and interactive exercises.

Screenshots from the module that display the format of the interface are given in Figs. 1 and 2. The large pale region to the left is the work area for displaying graphics, simulations, interactive problems and secondary text. The section to the upper right contains the narrative guidance, comment and written feedback. Any written questions, such as multiple choice, are also given in this area. Navigation and control through the module is provided by the arrows in the lower right corner, labeled buttons or switches when needed, and the use of the "hyperlink" concept. Hyperlinks are common to all web navigation and should be familiar to the students; anything that is underlined is clickable. Further discussion on the issues of presentation will be provided in the next section.

Based on the current opinions of practicing engineers and their needs described in Section 2, a list of the desired skills for a newly graduating structural engineer has been generated. These skills are given in Table 1. For each module, a selection of these skills is prioritized for emphasis and reinforcement.

Pedagogically, the modules are developed so as to satisfy the necessary requirements of an effective learning environment, as set out by the two primary learning theories of Perkins[5] – Theory One and Brackett[1] – the Tutorial Cycle. Table 2 lists them. The secondary pedagogical theories considered appropriate for adoption in the modules are Constructivism, Motivation Theory and to a lesser extent Situated Learning and Multiple Intelligences. Constructivism is strongly practiced through the encouragement of learning through discovery.

Having outlined the theoretical goals and approach adopted in these learning modules, the next section shall demonstrate their implementation through the presentation of a module that has been developed. The topic is "Structural Stability".

4. The Implementation

The topic of "Structural Stability" covers the stability of structural systems. Clearly described to the user at the beginning of the module, stability is concerned with how well a structure remains standing once a load is applied. There are various types of stability to be examined and learned, but one of the most elementary, with which the module was concerned, is how well a structural system works together with its supports to remain standing. A structural system can be a single element, such as a beam, or an assembly, such as a building frame or roof. The student is assumed to have already a basic understanding of elementary statics, as the module is envisaged

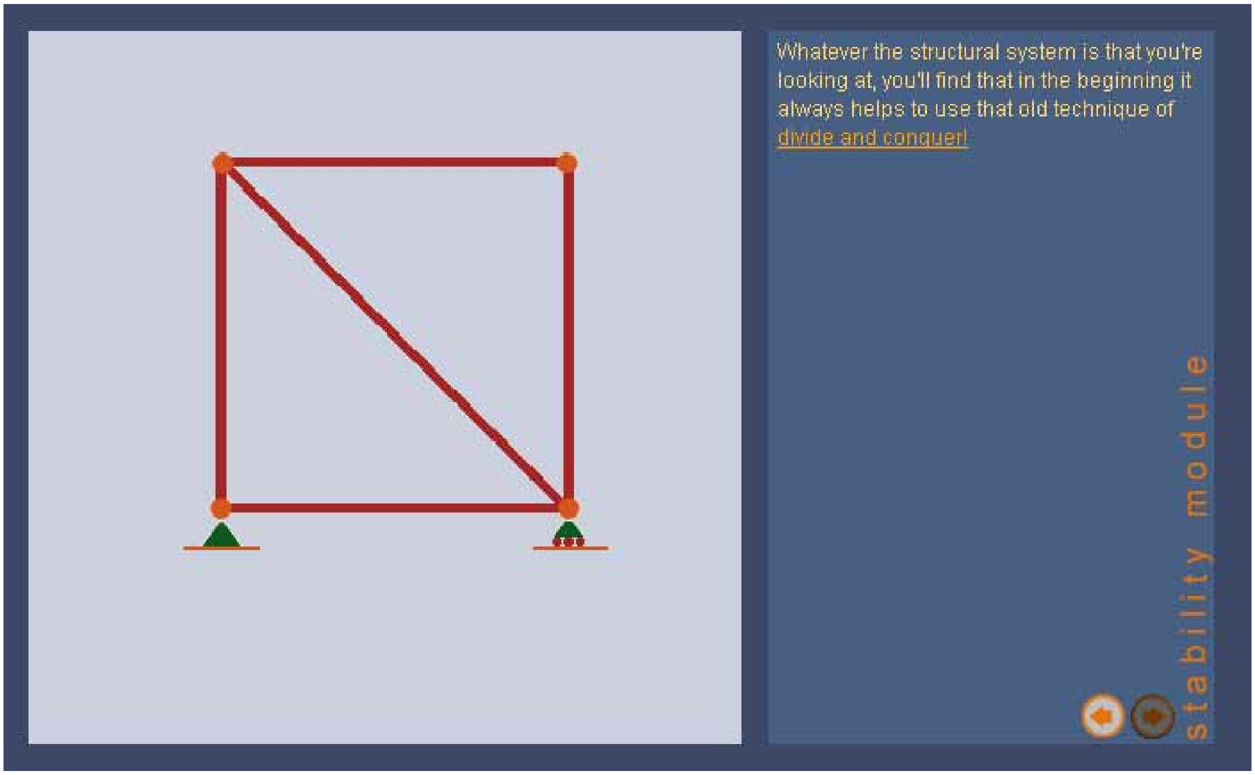

Fig.1. A screen from early on in the module, displaying the components of the screen.

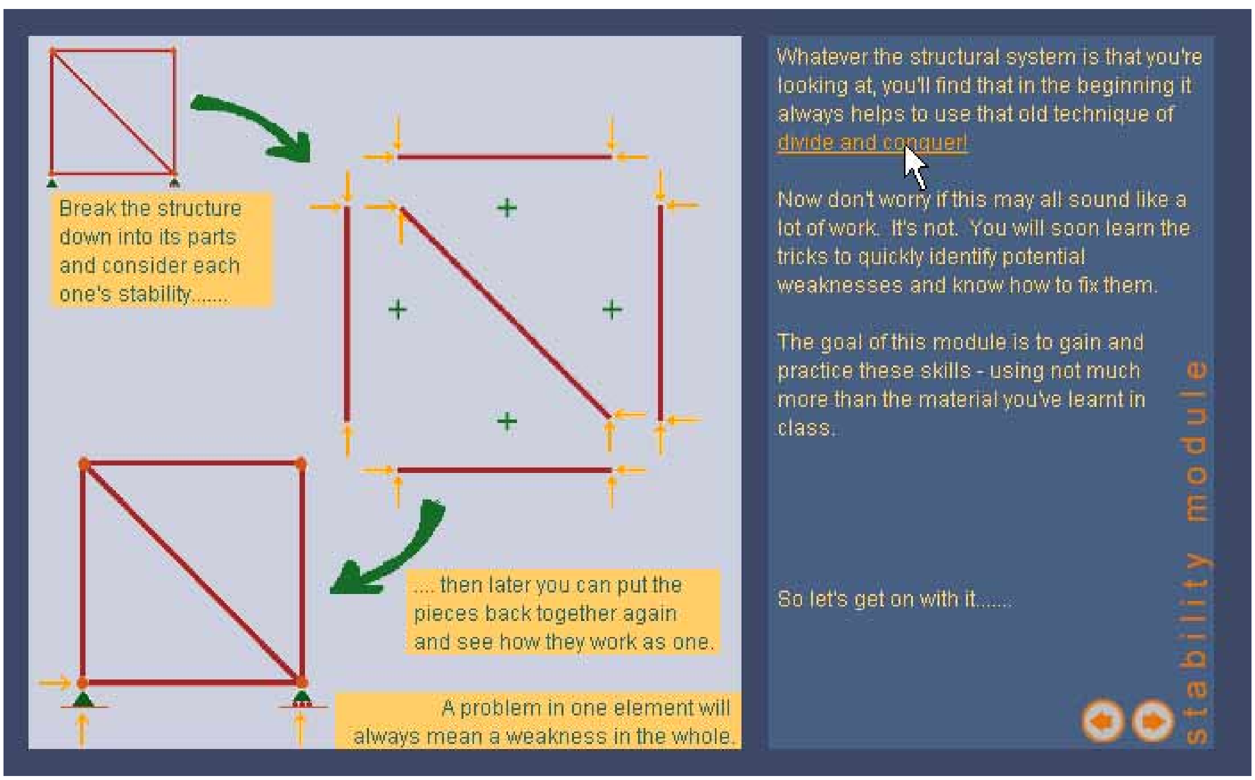

Fig 2. The screen following that shown in Fig. 1, demonstrating how context and the "bigger picture" are provided for an overall learning goal.

Table 1. The Goals for achieving a Good Understanding of Structural Behavior

Ideal Abilities:

1. Ascertain whether a computer model is correct; examining output, questioning if the results are sensible and assessing where modifications could or should be made,
2. Understand and predict the effects of changes to a model
3. Ensure that the correct models and approaches for structural analysis and design were chosen,
4. Allow back of the envelope calculations for preliminary scheme designs,
5. Conceptualize basic dynamic theory and its implications, and
6. Achieve some independence from the computer!

The skills required to achieve these abilities:

- Differentiating between a structure and a mechanism, applying the requirements of both equilibrium and stability,
- Achieving a conceptual knowledge of geometric compatibility,
- Following and identifying load paths,
- Identifying the various modes (tension, compression, bending, shear) by which the load is carried,
- Predicting not just the deflected shape, but actually thoughtfully considering how the structure - be it beam, truss or frame - deforms under load,
- Predicting the bending moment and shear force diagrams,
- Predicting reactions for any type of statically determinate structure,
- Establishing the member forces for a statically determinate truss
- Developing and using influence lines for reactions, shear force, bending moment and truss member forces, and
- Finally, communicating this information through sketches.

Table 2. Two Primary Learning Theories

Theory One (Perkins[5])	**The Tutorial Cycle** (Brackett[1])
▪ Clear information ▪ Thoughtful practice ▪ **Informative feedback** ▪ Strong motivation	▪ Presenting information related to the goals ▪ Eliciting student action toward these goals ▪ Assessing the student's action ▪ **Providing feedback to the student** ▪ Offering strategic guidance to the student ▪ Managing and motivating the process

for use during a second or third year Structural Engineering class. Discussing this topic of Structural Stability leads the student through the key ideas of single elements and rigid body motion, determinacy versus indeterminacy, support and loading types and conditions, and finally, more complex systems, or assemblies.

This topic is poorly taught by current curriculum. This is due in part to the challenge of teaching it. For the student to achieve a good handle on the concepts of stability, they rightly deserve a playful and adaptive environment with instantaneous feedback. Hence, the topic is an ideal candidate for selection as one of the learning modules. The material can be easily presented in a narrative manner with a linear progression of ideas – from the very easy to the complex. Furthermore, it fits well under the umbrella of structural behavior and qualitative concepts. Finally, as it is an important conceptual topic for the structural engineer, the authors believe that it is a good example of how if once mastered, it can provide great insight to the student. In turn both a complementary understanding to the quantitative classroom material and a motivation through demonstrating a context for their learning should be gained.

Additionally, from the list of the desired engineering skills for newly graduating engineers in Table 1, the following abilities could be reinforced by a module on "Structural Stability":

- Differentiating between a structure and a mechanism, applying the requirements of both equilibrium and stability,
- Achieving a conceptual knowledge of geometric compatibility,
- Following and identifying load paths

As the purpose is to encourage micro-level learning on a specific topic, the module is didactic with a strong overlying narrative thread. The material, however, is presented through interplay of multiple representations: text, images, interaction, etc. The continual conversational thread allows modes to segue smoothly between "time to talk and time to do". To achieve this effect best, both Shockwave movies, generated using Macromedia's Director program, and Java Applets were used. Both technologies create platform independent, interactive animations; however, each has a differing set of benefits to contribute.

Shockwave movies, through Director, allow rapid creation of "hard wired" animations and easy manipulation of media and the interface. This technology is particularly well suited to the quick generation of individual situations, slideshows, guided discussion and basic demonstrations. Its weakness, however, lies in its more primitive programming capabilities where it is unable to handle complicated mathematical manipulation. Additionally, achieving the repeatability of an exercise with different parameters, as is often desired, is laborious. Conversely, Java has great power with its programming abilities, easily presenting simulation and repetition. As with traditional programming languages, it can handle problems with underlying mathematical and quantitative queries well, even if they appear purely conceptual to the user. In turn, however, Java's weaknesses are also in its programming power. With too much control, inefficiency is created when modularity and repeatability are not adopted.

Hence, within the module, with its alternating stages of conversational interludes and repetitive exploratory studies, the capabilities of the two technologies complement each other well. The result is Java and Shockwave are merged to produce a seamless interface with each one's appropriate advantages being capitalized.

Explicitly stating the learning goals throughout provides guidance, motivation and the necessary sequential narrative thread. Various types of goals are presented, initially the long-term complex ones and then progressively the simpler short-term ones. A good example demonstrating this in the module is the understanding of assemblies. Given early on in the module, the page in Fig. 2 introduces the final goal of understanding “the stability of structural assemblies”, providing motivation and the overlying relevancy of the topic. From there, the student returns to the simpler ideas of single elements, as seen in Fig. 3. The module then progresses, accumulating stepwise learning through the short-term learning goals. By the end of the module, the student has built up complexity to arrive back at “assemblies” for further discussion and interactive problems.

Other style issues adopted in the development of the module include the presentation of the material as a conversation, using a friendly, informal tone throughout. Real images, everyday examples and accompanying explanations, are used wherever possible, to provide context and relevancy.

Up until now, the authors have presented *what* to teach, to *whom* and *why* and only just touched on the *how* through discussing the stylistic and technical approach to the module. The key issue of providing effective feedback for qualitative material, however, is still to be considered. This is more of the *how* and *when*. In achieving this, the challenge is in fashioning the material and posing the questions effectively.

Control of the student’s location in the knowledge process is an essential issue to handle. The content material to be taught was outlined, setting the main issues as the “primary concepts”. All supporting material that provides background or clarification to these concepts is then regarded as “secondary material”. The narration is then designed so the student will make all the discoveries and conclusions on the primary concepts themselves. Clear statements or explanations are only provided in response once the student has directly interacted. The secondary material is mainly given passively to support the primary, and assist the student in coming to the correct conclusions.

The success of this approach lies in shaping the problems and exercises to achieve the desired responses. This requires controlling the problems’ scope to preserve manageability, allowing only the desired errors, and then enabling them to be addressed informatively. In most cases, a selection of feedback responses for each question is prewritten, with the appropriate reply being selected by a rule-based technique. An example is shown in Fig. 4, while other examples are given in Figs. 7, 8, and 9 in response to the problem posed in Fig. 5. Use of repetition with many of the problems in the module allows some efficiency with this technique. However, the programming still ensures variability in the response styles to avoid repetition and boredom for the student.

On the larger scale of the whole module, likely knowledge trends of a student must also be identified. This ensures tat a student is steered appropriately to make intelligent choices, yet a sense of exploratory playfulness is not lost. A good demonstration of this is through the

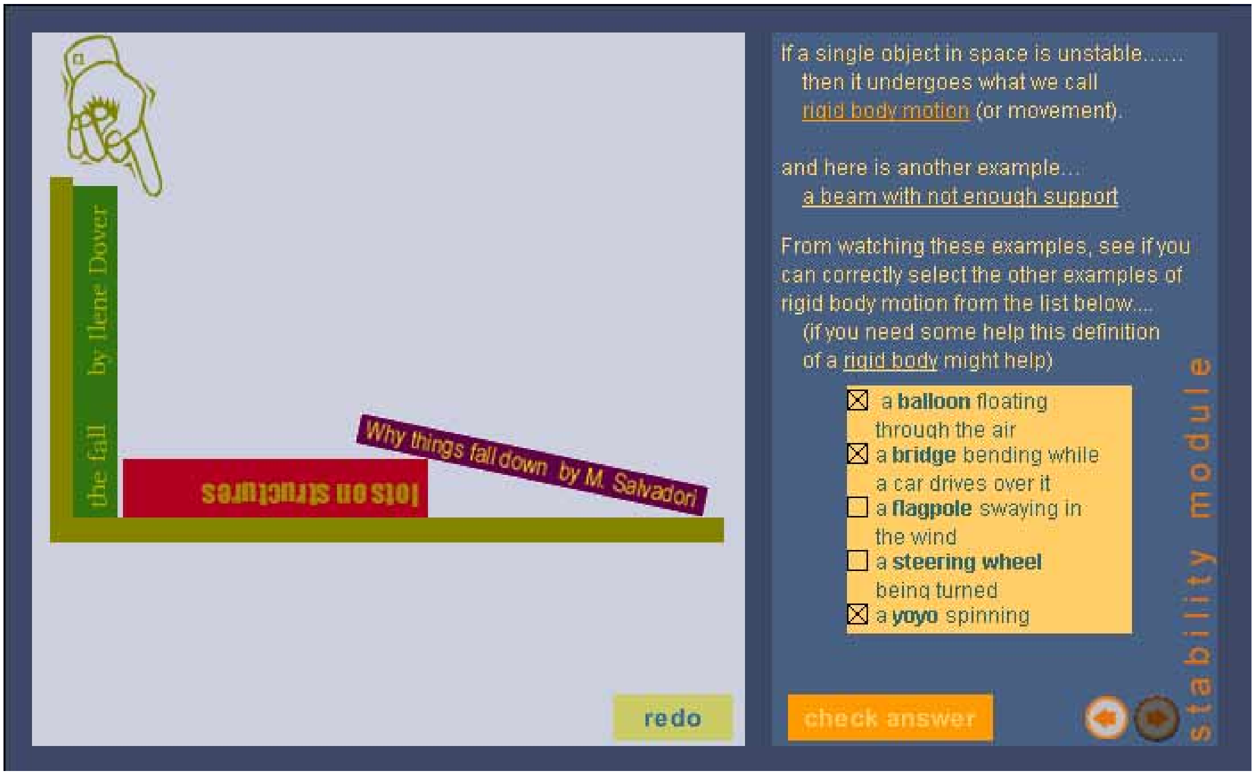

Fig. 3. The screen following that in Fig. 2, showing an example of a commonly seen single element instability – books falling over.

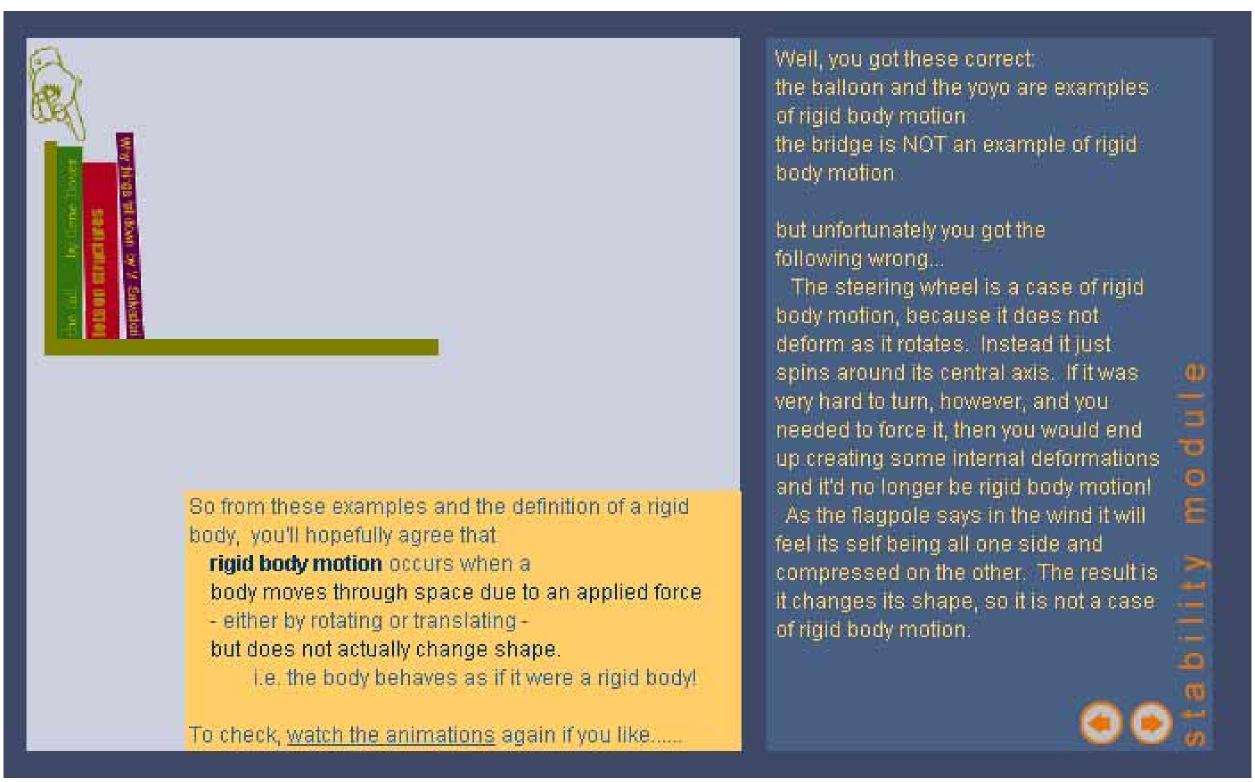

Fig. 4. The response screen to the problem in Fig. 3. The problems specific, descriptive feedback can be seen

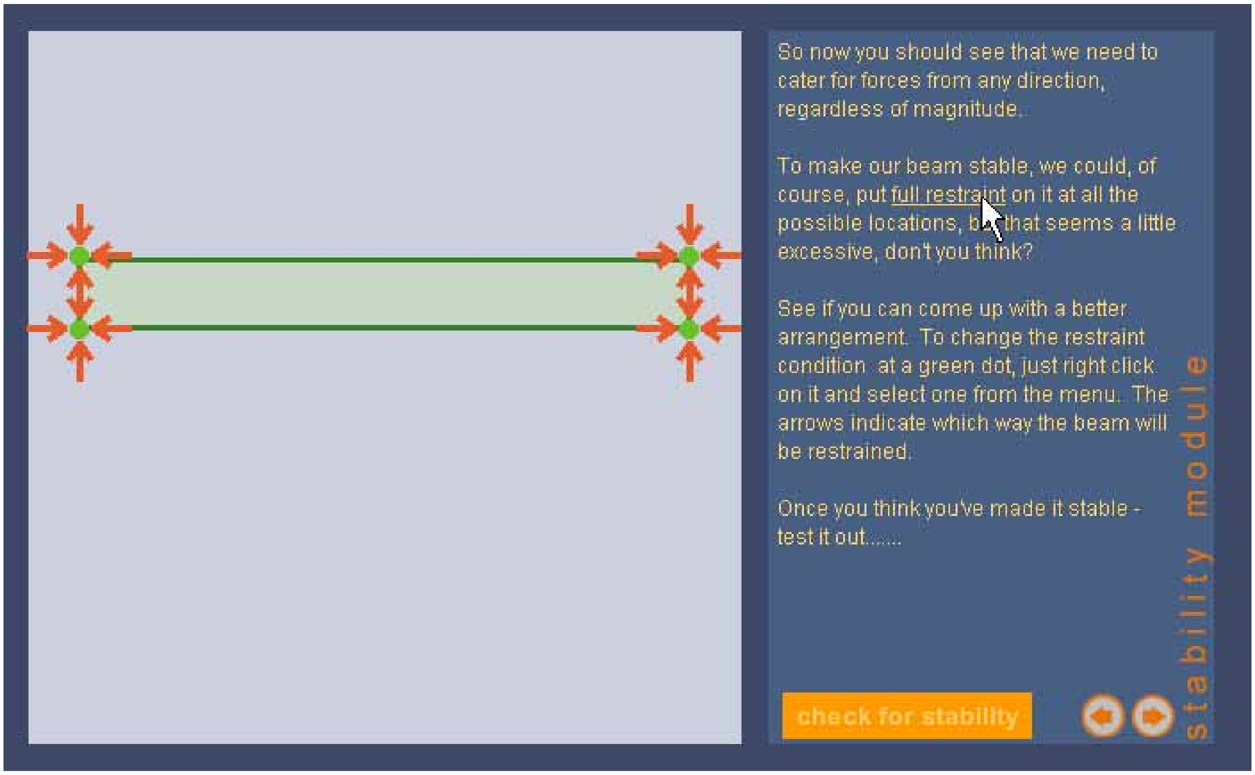

Fig. 5. One of the screens from an interactive problem in the module that requires the beam to be stabilized. This one shows how the "stupid" answers are eliminated for the students.

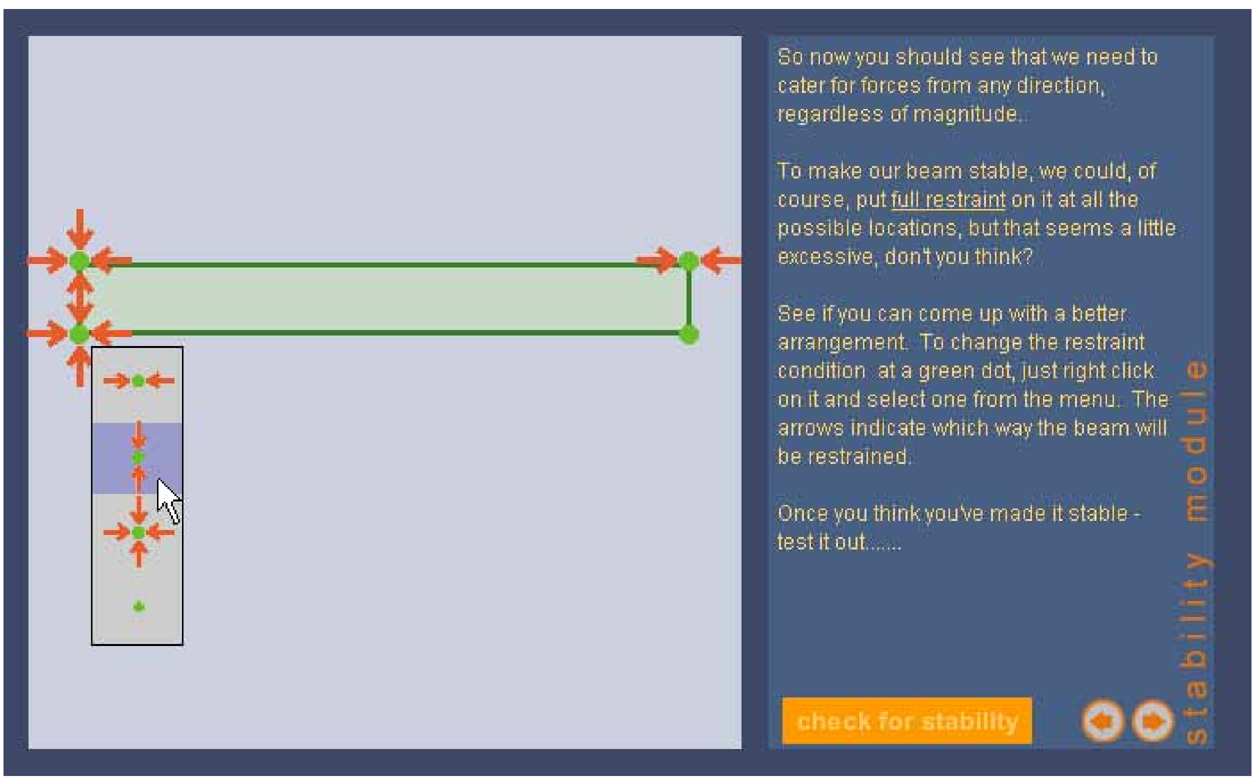

Fig. 6. Similar image to Fig. 5, demonstrating how the supports can be changed with popup menus

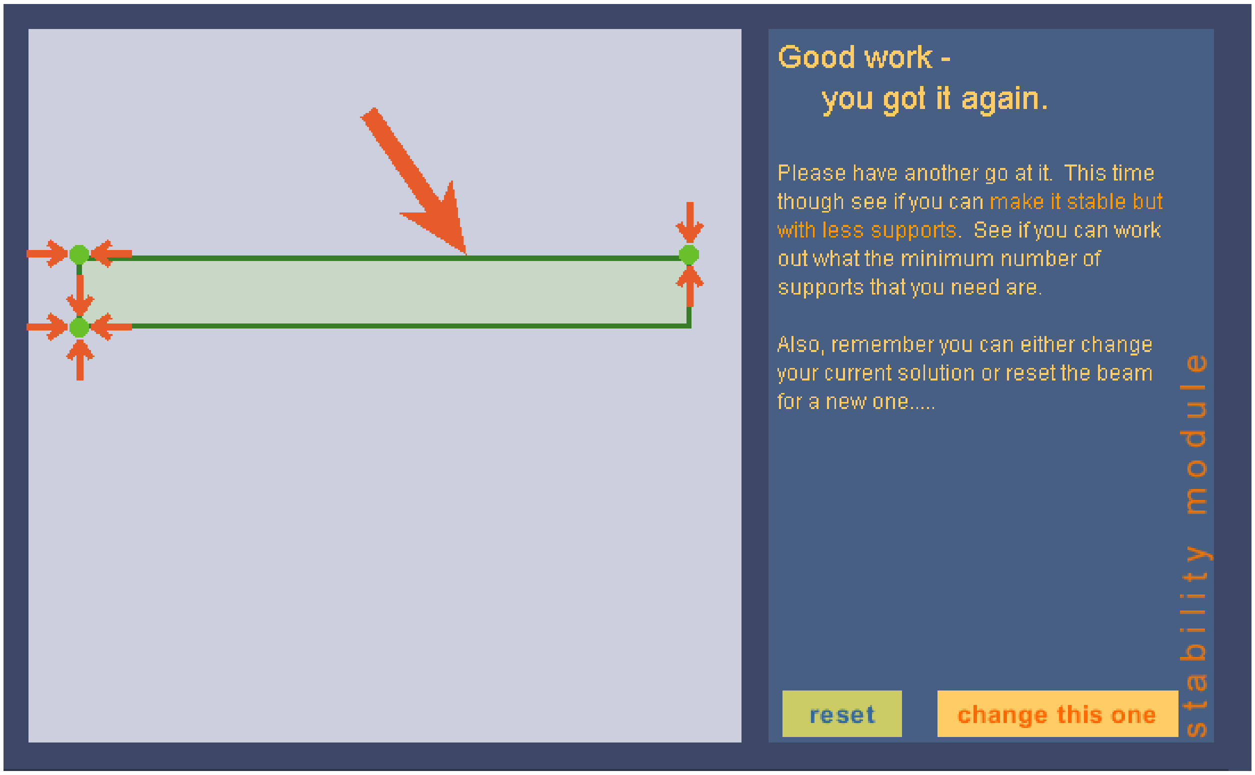

Fig. 7. An example of the response screen asking the student to try to find the minimum number of required restraints in their next attempt.

presentation of the interactive problem in Fig. 5. The purpose of this exercise is for the student to ensure the beam shown is stable. There is the obvious and somewhat “stupid” choice of putting supports at every given location. To eliminate this and the other “stupid” choice of no supports at all, the module presents them straightaway, as seen in Fig. 5. Then it is up to the student to come up with an alternative support arrangements, that will make it stable. Fig. 6 shows how they can change the supports using popup menus. The student is asked to repeat this problem, hence demonstrating there is no one right answer. After a couple of repetitions, the student will then be encouraged to reduce the number of supports until the minimum number required has been reached. See Fig. 7. By this point in the module, the student has unwittingly reached a determinate structure, which is not actually identified until a little later.

Often possible solutions, in this case support arrangements, whether correct or not, can provide valuable learning experiences. Figs. 8 and 9 show an example. (Note from these figures, the cause of the student’s error is not displayed immediately. Instead, it is provided as a hint, if desired. Hence, the student is given the chance to work it out on their own.) The chance that a student will stumble upon such valuable cases is obviously not guaranteed. Therefore, to ensure the students will do so, an additional set of tasks is assigned that provides such artful examples and asks the student to judge if they are stable. Upon replying, any useful learning insights can then be revealed to the student.

Finally, a comment should be made on the adaptability within the module for the variation in student skills. The authors originally favored the idea of providing additional segments of

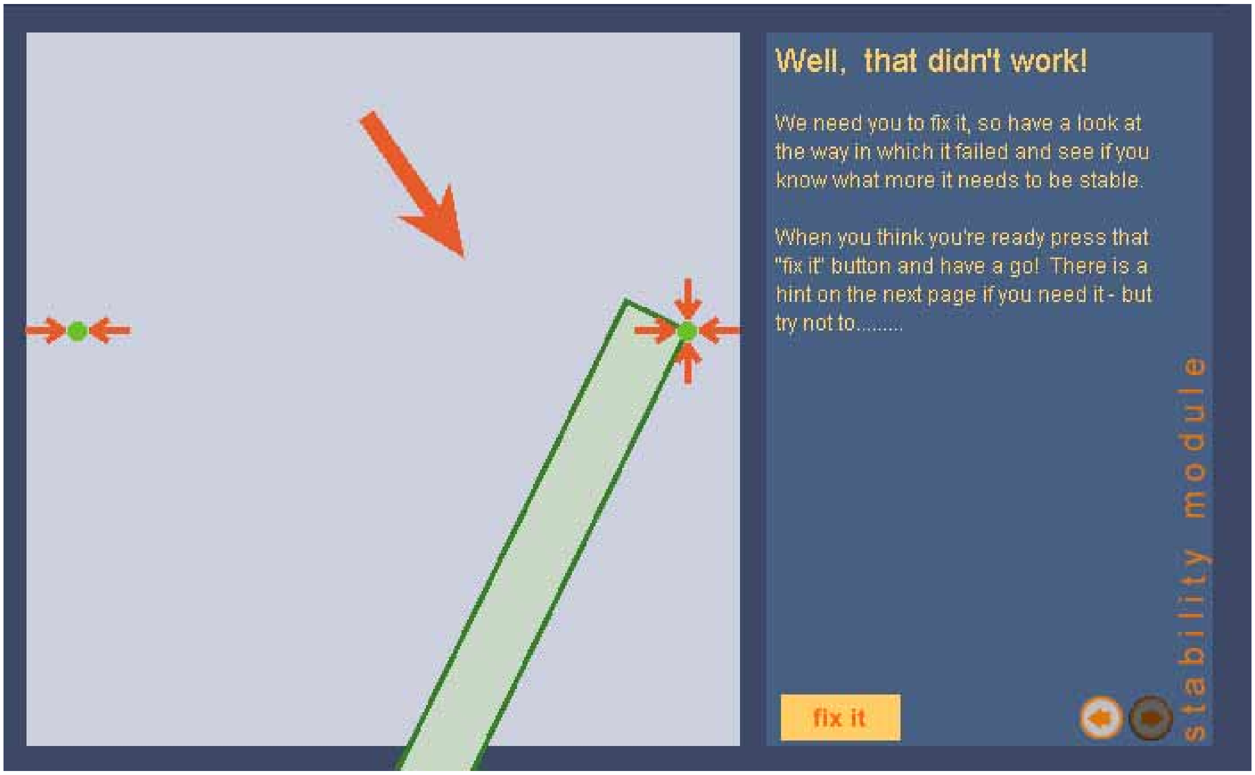

Fig. 8. An example of an unusual and incorrect support arrangement that can provide a valuable learning experience.

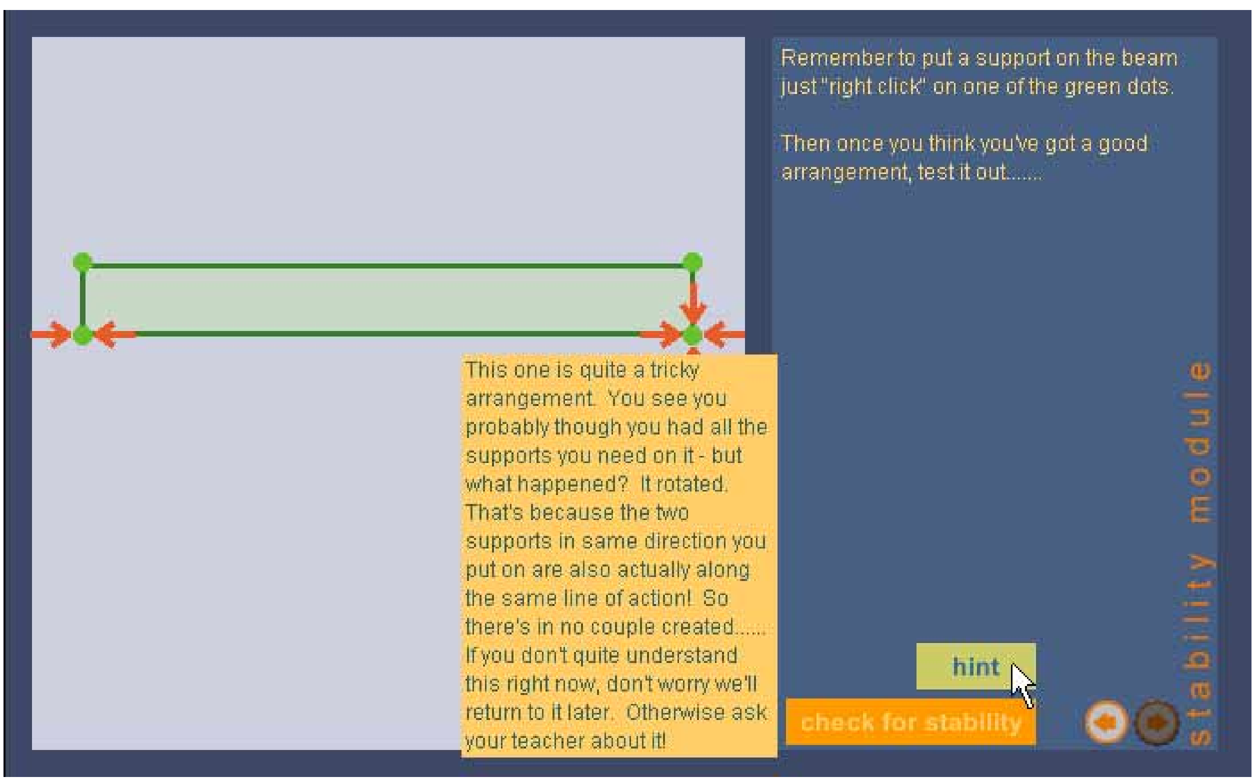

Fig. 9. The reason for the error of the arrangement used in Fig. 10 is provided indirectly through the hint.

information for students having difficulties. However, it was recognized that intelligent students often desire all these "extras" as well. Hence, everyone has access to all the material, with the choice provided for the user to explore it all. Examples of this approach implemented include the use of popup windows with additional information in them, as in Fig. 10, and in the repetitive problems, where the smart students can continue to "play" if they wish after they have completed the required task, as in Fig. 11. Slower students find the required task a little longer and are prompted to continue "playing".

5. Conclusion

An alternative mechanism for students to accumulate qualitative knowledge in the domain of Structural Engineering has been presented. This mechanism adopts web-based technologies to develop individual, self-contained learning modules that provide fluidity between discussion and practice. Some of the modules key abilities are:

- practical and relevant context to classwork material,
- qualitative explanations of structural concepts previously taught in class,
- freedom to experiment,
- graphical representation of behavior in various visual forms, and
- an opportunity to demonstrate an understanding of "complete" structural systems, with feedback.

Through the presentation of a developed module, "Structural Stability", the important issues to consider in the design process to achieve these abilities were presented. The issues include the choices of style to be adopted, the careful and appropriate control of the student's movements and knowledge, and the clear defining of the learning goals and primary concepts to be taught.

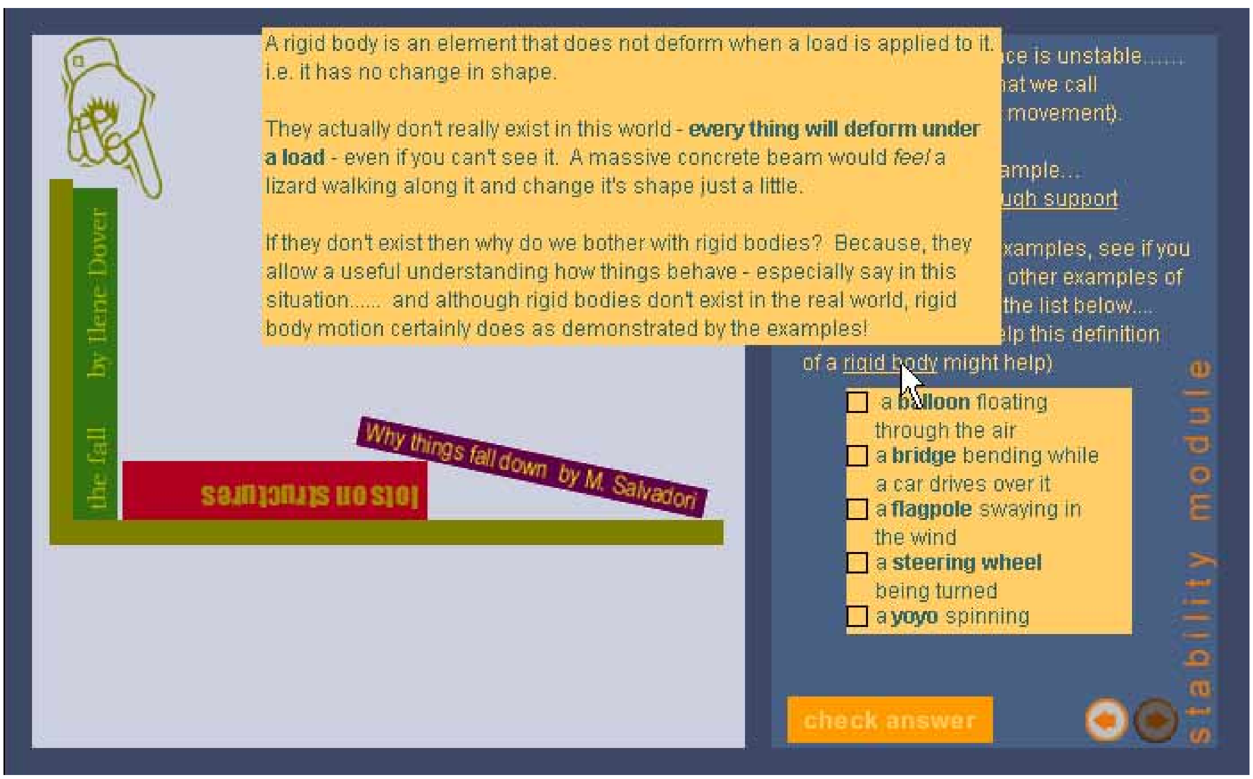

Fig. 10. An example of additional, helpful information, available only if desired.

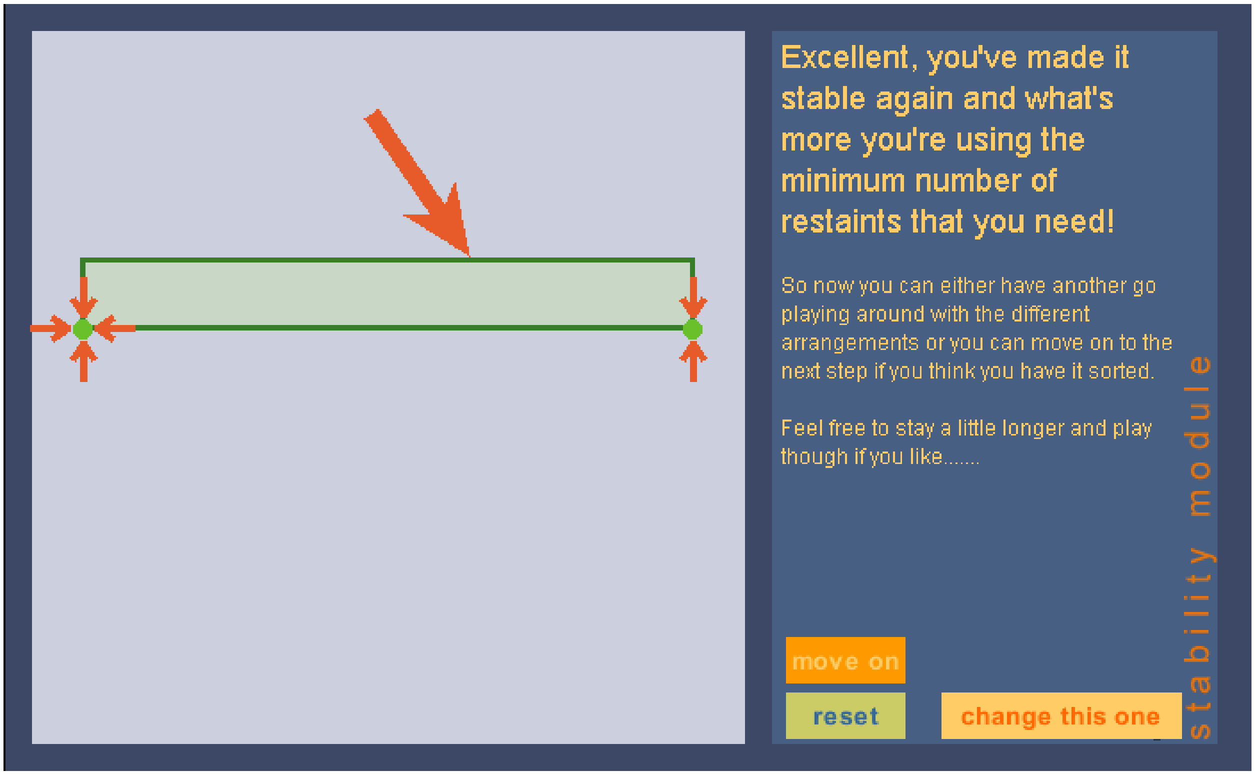

Fig. 11. Another example demonstrating how choice is provided to the student. Here the user can move on or continue playing with the task.

The pedagogical goals of this research were to provide effective and informative feedback and to adopt a constructivist approach. These were both satisfied through the practice of encouraging the student to interact intelligently with the principle being taught. The student could then make their own conclusions before being given an explicit written response, based on a diagnosis of the student's current understanding.

Finally, a comment should be made on the intensive effort that is required to develop such a module as presented here. The future steps in this research is to carry out comprehensive testing on students to examine the modules effectiveness in regards to the teaching goals outlined in Section 2 and to gauge the students interest and thoughts on the approach. From this, it is anticipated that the effort will be proven worthwhile.

Bibliography

1. Brackett, G. Course Notes - Spring 1998; T525: Designing Educational Experiences -Using Networks and Webs. Harvard Graduate School of Education, Cambridge, MA (1998).
2. Brohn, D.M. Understanding Structural Analysis. Oxford: BSP Professional Books, (1990).
3. Brohn, D.M. A new paradigm for structural engineering. The Structural Engineer, v 70, n 13, 7 July 1992 pp. 239-242.
4. Morreau, P.M. Understanding structural behaviour. The Structural Engineer, v 68, n 15, 7August 1990 pp. 299-300.
5. Perkins D. Smart Schools -from training memories to educating minds. New York, N.Y: The Free Press (1992).

EMMA SHEPHERDSON
Emma Shepherdson is a research assistant and doctoral student with the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology. Prior to commencing graduate school, she worked for a few years with Ove Arup and Partners in Brisbane, Australia, having obtained a B.E. (Civil) at the University of Queensland. In addition to her research, Emma recently taught Introductory Structures at the Boston Architectural Center. Her graduate studies have been assisted by a Freda Bage Fellowship, sponsored by the Australian Federation of University Women, Queensland, and a NSF grant through the Mid-America Earthquake Center.

JEROME J. CONNOR
Professor Connor is a senior faculty member of the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology. He has been involved with Computer Aided Structural Engineering for many years. His recent research interest is focused on the development of electronic learning environments that provide the capability for active learning.