

Physical and computer demonstrations in enhancing student understanding of structural mechanics courses

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***Abstract:** Structural Engineering, a highly technical discipline, includes foundation knowledge for a range of engineering professions and is traditionally restricted by rigorous accreditation requirements. Focused in this paper are fundamental and analytical courses in structural engineering and mechanics. These courses are generally perceived by most students as challenging at times due firstly to complicated theory and analysis concepts covered and secondly the difficulties associated with visualising how structures behave when subjected to loads. In order to help students visualise the behaviour of structures and to better understand difficult and abstract concepts, complex methodologies and computational procedures, we have endeavoured to produce a series of scaled-down physical models, hands-on demonstration and digital animation tools as visual aids, with explanations of the matching concepts and calculations being covered. This approach has been highly valued by all students. Despite the difficulty of structural mechanics content, students still find these courses challenging but also interesting and enjoyable which contributes to motivating students and maximising their learning abilities, as evident in student evaluations. This paper presents the methods used at Griffith University and the learning objectives behind them. In view of the positive feedback received from the students, this paper concludes that future research will be undertaken to quantify the efficiency of using visual demonstrations in structural mechanics courses.*

Introduction

Structural Engineering, a highly technical discipline, includes foundation knowledge for a range of engineering professions and is traditionally restricted by rigorous accreditation requirements. At Griffith University, our focus has been to teach fundamental and analytical courses in structural engineering including “Engineering Mechanics” (Year 1), “Introduction to Structures” (Year 1) and “Structural Analysis” (Year 3). Engineering Mechanics creates a foundation and a framework for most branches of engineering; Introduction to Structures aims to develop “engineering feeling” by focusing on structural behaviour and select appropriate structural systems prior to detailed analysis; Structural Analysis develops fundamental understanding of basic principles of analysis and physical behaviour of structural systems under load. The first and third courses form an integral part of the professional engineering analysis and design training provided in the Bachelor of Civil Engineering programs, while the second one contributes to the Bachelor of Environmental Design Program including Architectural Studies and Environmental Sustainability majors.

Structural mechanics courses are generally “perceived by most students as challenging not only because of the theory and analysis concepts covered, but also because it is difficult to visualise how structures behave when subjected to loads. As a result, cause and effect are not obvious and may lead to false impressions that nothing happens when the structure is loaded.” (Saleh and Gardner, 2009).

This argument goes further that if the structure's responses to loads cannot be visualised or are not "real" to students, then mechanics courses are merely exercises with mathematics and equations with no connection to any practical significance.

In the area of visual arts, Jewell (2010) commented that human beings are a very visual race and are primarily visual sensors of five-sense data. Much of what people experience can be identified and recalled much more quickly with one picture - "A picture," the old saying goes, "is worth a thousand words." Further, people have parts of their brains very well trained from infancy to absorb and process visual images. In a study on physical fitness concepts in elementary physical education, Sander and Burton (1989) also confirmed that the primary purpose of learning aids is to stimulate the formation of mental images of concepts by increasing sensory input, and that when visual and verbal learning were used simultaneously, informational recall could be increased.

In the learning process, the use of "live" visual aids in the form of either physical demonstration or digital animation has been proven effective by many researchers. According to Lin and Atkinson (2011), learning with static graphical representations requires information integration and inferential reasoning thereby imposing considerable mental load on learners. However by viewing instructional animations, learners do not exert cognitive effort to mentally construct dynamic representations. As such, more cognitive resources can be freed up and potentially be used for learning-related activities and deep processing. Luckie, Harrison and Ebert-May (2011) also confirmed that visual models are illustrations that attempt to simplify and represent a cycle, mechanism, idea, or system.

With rapid development of computer and information technology, more and more types of media are available for use in our classrooms nowadays. Through our teaching practice in the last couple of years, we have discovered that the most effective means of visual aids are various physical demonstrations and digital animations for different concepts and applications.

Physical Demonstration

Since its first offering in 2004 (Chowdhury, Guan and Doh, 2005), the final year capstone course "Integrated Design Project" has adopted a proficiency test scheme to assess the ability of students in producing correct sketches of deflected shapes and bending moment diagrams for a series of simple beam and frame structures. This exercise aimed to serve the purpose of having students well-prepared with structural fundamentals in order for them to successfully complete a design project. In the first year of offering, however, only 10% of the cohorts demonstrated a full grasp of the concepts and were able to apply the principles correctly. This fact implied that either (1) not enough coverage of the fundamentals related to deflected shape and bending moment diagram; or (2) students have not developed deep understanding of the concepts and principles. This has prompted us to develop effective and sound methodologies in achieving deep learning of these complicated topics.

A number of physical demonstration models have therefore been developed over the years for courses like "Engineering Mechanics", "Introduction to Structures" and "Structural Analysis". The main purposes in developing these models are that they help us convey the complicated concepts based on the fact that learners take more information in visually. The simple models shown in Figures 1 and 2 demonstrate how beam and frame structures deflect under different loading and restraint conditions. These demonstrations were performed together with explanations of the matching concepts and calculations being covered. The bending moment diagrams were then discussed and constructed along with the deflected shapes. Such exercise has proven to be extremely useful because students can clearly visualise the curvature, the contraflexural points as well as tension and compression sides of the members which has largely assist them in their effort in plotting correct bending moment diagrams. These are evident in student evaluations as presented in the later section. In addition, remarkable improvement of the student proficiency level in the areas of deflected shape and bending moment diagram has been achieved in the last couple of years, as proven by the proficiency tests conducted in "Integrated Design Project" this year, where 70% of the cohorts are now able to grasp and apply the principles. The students also enjoy the exercises and become very engaged when real life applications are discussed and simplifications are pointed out.

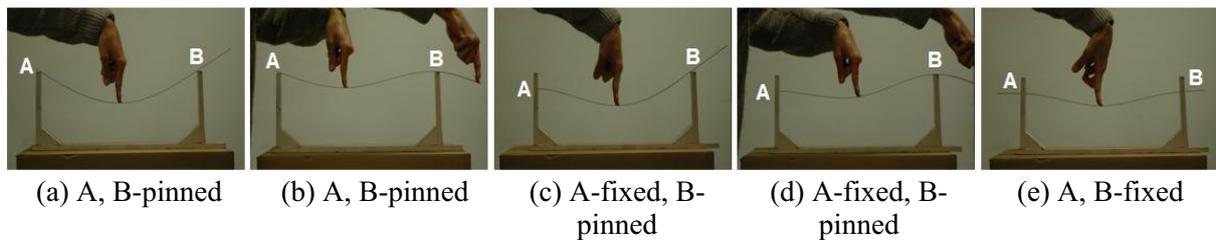


Figure 1: Physical models of a beam with various restraint conditions

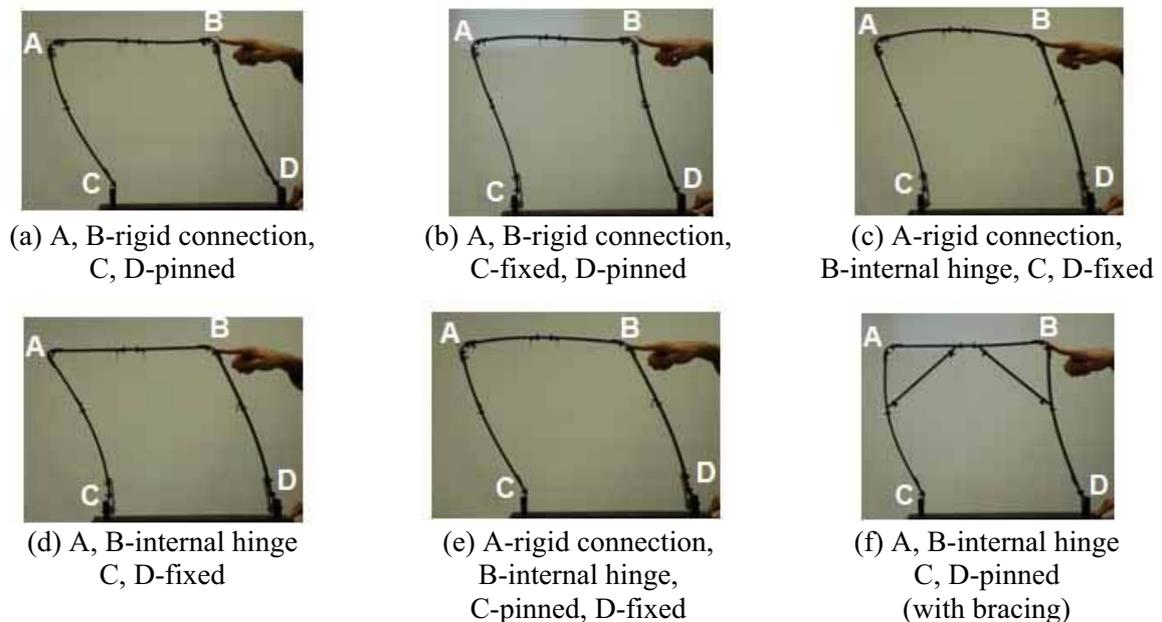


Figure 2: Physical models of a frame with various restraint conditions and connection details

In "Introduction to Structures" where students are not trained to become engineers, they are however required to grasp fundamental concepts of structural engineering. The beam and frame models presented in Figures 1 and 2 have not only helped students understand the deformed shape of structures but also structural efficiency. For the beam model, in particular, by using masses instead of a finger, as shown in Figure 1, students can visualise maximum deflection of the beam and draw conclusions on the role of boundary conditions on the structural behaviour. Moreover, other models showing load transfers, structural vibrations or buckling modes are usually very well received by students as proven by student evaluations.

Digital Animation

Animation, by its nature, is able to vividly present events which change over time, such as motion, processes and procedures. It provides more external support for learners to construct their dynamic internal representations than static graphics (Lin and Atkinson, 2011). In "Structural Analysis", "Influence Lines" concept has been considered to be one of the hardest topics in the entire course, together with "Moment Distribution Method" and "Stiffness Method of Matrix Analysis". Students often listed one or more of these topics in their response to "Which topic you have not learned well?" The explanations provided are often something like "did not really understand the concepts because they were too abstract".

Influence lines have important application for the design of structures that resist large live loads. Such structures include bridges (vehicular loads), industrial crane rails, conveyors, and other structures where loads move across their span. The influence line for a given force component at a specified section/member of a structure depicts the variation of said force component under a moving unit load (at the roadway level). The definition is indeed very conceptual and it is difficult to visualise the "variation of the force component under a moving unit load" using scaled-down physical models. An

interesting public domain software - West Point Bridge Designer 2002 (Ressler, 2002) has been found to be very helpful in explaining the influence line concept, where the colour of a particular truss member varies during the period of a vehicle passing the bridge (Figure 3). Members in tension are in blue whereas those in compression are marked in red. The variation of intensity of colour represents the variation of the axial force of a member, be it in tension or compression.

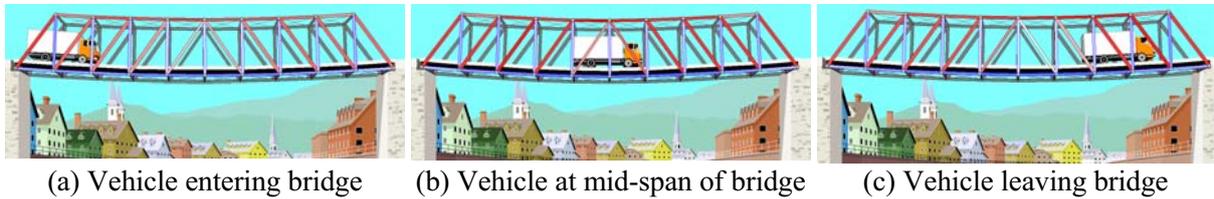


Figure 3: Digital animation of a truss bridge under traffic load – Influence Lines concept

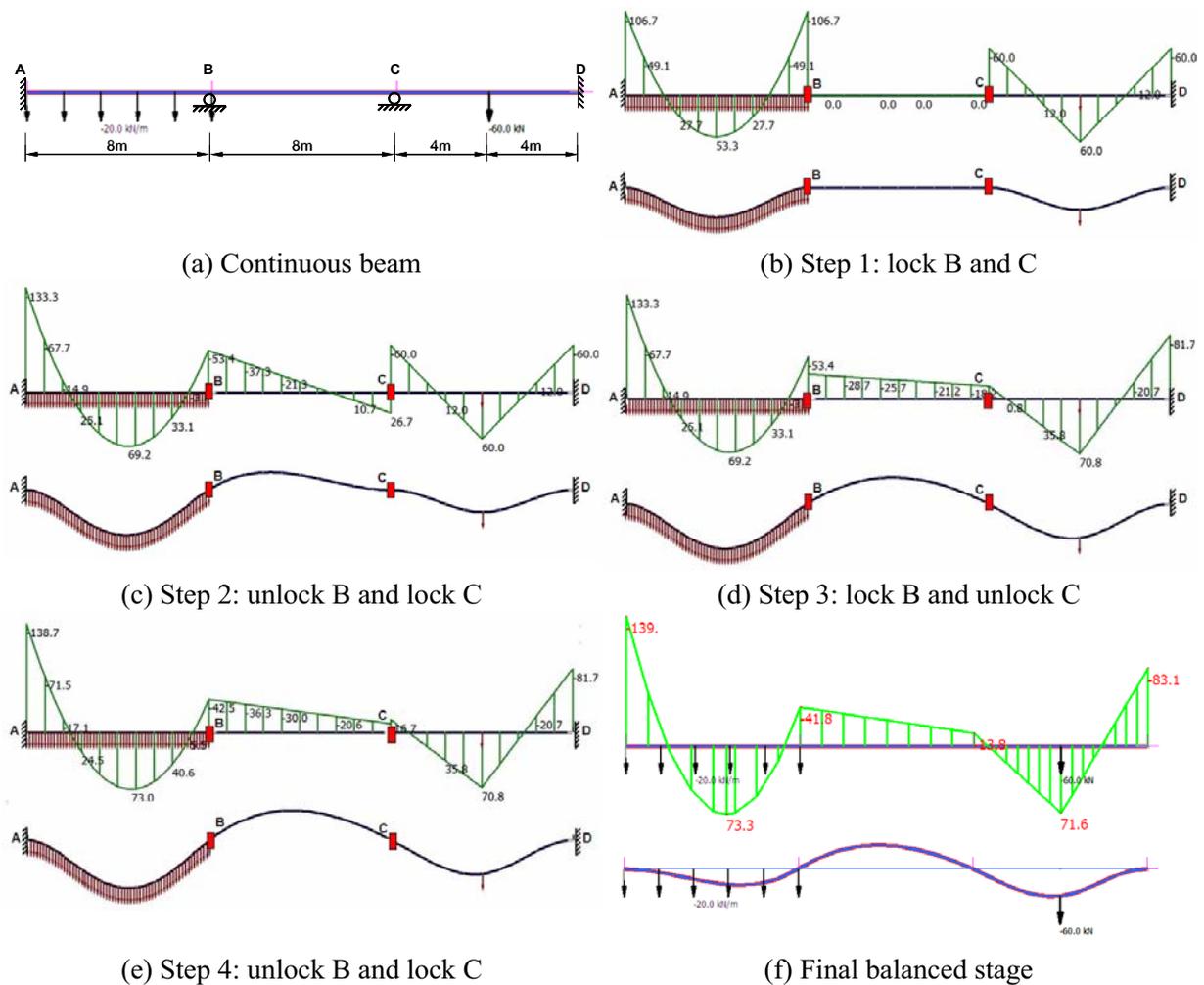


Figure 4: Digital animation of moment distribution process for a multi-span continuous beam

Figure 4 shows the screen shots of an animation movie demonstrating moment distribution method for a continuous beam. The primary difficulty associated with understanding moment distribution concept is its underlying assumption where each joint of a structure is fixed. Then by unlocking and locking each joint in succession, the internal moments at the joints are "distributed" and balanced until the joints have rotated to their final or nearly final positions. Again the ability of demonstrating "locking" and "unlocking" through a physical model is limited. Digital animation, on the other hand, is able to clearly show the iterative process of the method with successive approximation. As the method deals with both unbalanced moments at joints and corresponding deflected shape, the animation developed has helped the students to visualise that the amount of unbalanced moment quickly diminishes until the release of a

joint causes only negligible rotation. The process leads to the final equilibrium stage in terms of balanced bending moment at joints and true deflected shape. Upon understanding the fundamental concept of the method, the students found the subsequent numerical calculations much easier to follow.

Student Evaluation

The use of physical demonstrations and digital animations has shown positive outcomes in learning and teaching of structural mechanics courses. Figure 5 presents the relevant questions and corresponding scores/RIB values in the Student Evaluation of Teaching for “Structural Analysis”, taken at the end of Semester 1, 2011. The class size was 181 and the participation was 31%. Highly positive responses with regard to demonstrations, illustrations and explanations are clearly evident.

Question	#		Score	RIB* Comparison	%+ve %-ve	Med ian	Std dev	Mean	RIB* 25%	RIB* 75%	RIB* Rank
The staff member made good use of examples and illustrations to explain difficult concepts.	35	SA	62.5%	40.5%	+96.4 -1.8	5	0.63	4.6	4.0	4.4	High
	19	A	33.9%	44.3%							
	1	N	1.8%	8.4%							
	1	D	1.8%	5.3%							
	0	SD	0%	1.5%							
This staff member gave clear demonstrations and explanations of the material/techniques.	35	SA	62.5%	62.6%	+96.4 -0	5	0.56	4.6	4.5	4.6	High
	19	A	33.9%	30.8%							
	2	N	3.6%	5.6%							
	0	D	0%	0%							
	0	SD	0%	0.9%							

Figure 5: Student Evaluation of Teaching for “Structural Analysis”

(**Legend:** 5pt Likert scale: SD - Strongly Disagree, D - Disagree, N - Neutral, A - Agree, SA - Strongly Agree; *RIB - Rating Interpretation Benchmark - Comparison aggregation of courses/classes in the same Group and Course/Class size (<21, 21-50, 51-200, 200+). Only shown if more than 4 responses per question exist (from any semester) within the same category. RIB based on surveys from past to 05-06-2011.)

Further to the above quantitative summary, typical qualitative responses are also given in Table 1. These responses have provided a sound evidence of the effectiveness of using physical demonstration and digital animation in improving student perception of structural behaviour and overall comprehension of the subject matter, and therefore likely enhancing the learning process.

Table 1 Student qualitative responses.

Areas of concern	Typical comments
Understanding of structural behaviour	<p>“Physical apparatus and computer animation help in showing the way structures move under loads etc.”</p> <p>“The use of apparatus to demonstrate the deflection of beams and frames.”</p> <p>“The use of some basic practical demonstrations in class, such as bending the ruler to plot tension side of BMD etc helped me.”</p> <p>“The visual demonstrations you give in the lectures provide clarity for different bending moment and restraint concepts.”</p>
Comprehension of subject matter	<p>“Consistent use of physical apparatus during the lectures, rather than relying on verbal explanations or two dimensional drawings, made it a lot easier to properly visualise what she was trying to get across; this again re-enforced the subject matter, making it easier to comprehend.”</p> <p>“The use of props to provide a visual representation of the topics being discussed was very helpful in reinforcing the important concepts especially in terms of bending moment diagrams and deflection of beams.”</p> <p>“... helpful by bringing beams and stuff to class to help visually explain the concepts of the subject.”</p> <p>“Use of physical animations and models in lectures provided a better way of</p>

	<p>mastering the concepts.”</p> <p>“Use of apparatus was also helpful in understanding important concepts.”</p>
Enhancement of learning process	<p>“The lecturer used illustrative material to demonstrate physical behavior of structural elements. This was very helpful in the learning process.”</p> <p>“The use of illustrative material to explain the behavior of structural elements was very helpful in our learning effort.”</p> <p>“All demonstration tools contributed to my learning in this subject, especially the replica truss structure thing (the bits of plastic with the bolts for the joints). This really gave me an understanding of how structures deformed under different loading and makes it easier to visualise the deformed shapes when faced with a problem.”</p>

Conclusion and future work

Frequent use of physical demonstration and digital animation tools in structural engineering and mechanics courses has proven to be informative and effective in engaging students on complicated, abstract and nonfigurative concepts. According to the student evaluations, this led to better comprehension of the subject matter and likely improvement of learning outcomes and performance on related assessments as demonstrated in the final year capstone course “Integrated Design Project”. Highly valued by all the students, such teaching practice will continue to be improved by introducing more physical and computer demonstrations in a more comprehensive and systematic way. This will ultimately facilitate the students gaining positive and “fun” experience in learning these fundamental and traditionally being perceived as challenging and “dry” structural mechanics courses.

Based on the descriptive account of the practice and approach we have used with physical models and digital animations, further research will be conducted to quantify the effectiveness on enhancing the learning process. Cohorts of students are thought to be subjected to similar teaching procedures, with and without visual demonstrations. The influence of the physical and computer demonstrations on long-term learning will be assessed by testing students at various time frames. The following research question is also thought to be answered: what are the differences in efficacy of different demonstration approaches, and which kinds of concepts are better grasped with each approach?

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