In-class and recorded physical demonstrations in enhancing student understanding of structural mechanics courses

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Structured abstract

BACKGROUND

One of the main challenges educators face when teaching structural mechanics courses is the difficulty for students to visualise the relation between the concepts taught and the actual physical meaning on the behaviour of materials or actual structures. Not visualising the structure's responses to loads may not support learning as it can lead to false interpretations of the actual structural behaviour. If the concepts taught do not appear "real" to students, then mechanics courses are merely exercises with mathematics and equations with no connection to any practical significance.

Physical models (demonstrations aids) have been developed and extensively used at Griffith University in the last several years as a tool to convey fundamental structural mechanics concepts. The approach has been highly valued by all students who unanimously claimed that the demonstrations greatly helped their overall understanding of the courses. However, when comparing students' performance before and after the use of the demonstrations, or when testing students on concepts taught with and without the use of demonstrations, no clear quantitative evidence was collected in the past on the actual effectiveness of these teaching tools.

Prior to Semester 1, 2013, the models were only demonstrated during lectures. The authors believe that students at the back of the lecture theatre may not have been able to clearly see the demonstrations performed by the lecturer in the front of the class. This may not have had assisted their understanding. Moreover, while some concepts may be obvious to the students while being demonstrated, students may need more time to assimilate and review the concepts at their own pace. From Semester 1, 2013, a video camera was introduced to project the demonstrations on the lecture theatre screen, therefore reaching the entire audience. From Semester 2, 2013, videos were also recorded and uploaded on the course sites for students to review the concepts in their own time.

PURPOSE

The purpose of this study is to collect evidence on the effectiveness of (i) using physical demonstrations in class, (iii) projecting these demonstrations on the lecture theatre screen and (iii) posting recorded videos of the same on the course website, on students' overall understanding of fundamental structural mechanics concepts.

APPROACH

A total of 216 students, from three structural and mechanics courses offered in Semester 2, 2013, were surveyed on the effectiveness of using physical demonstrations (in-class) and recorded demonstrations (outside class) on their understanding of fundamental structural mechanics concepts.

RESULTS AND CONCLUSIONS

Results showed that the use of physical models in-class is an efficient technique to convey complicated structural mechanics concepts. In large classes, the use of the video camera to project the demonstrations on the lecture theatre screen was also shown to be effective in reaching the entire audience. Additionally, the use of videos of the demonstrations placed on the course website was shown to help students in further mastering and reinforcing the important concepts taught. Results suggest that the videos are useful for about half of the students, as the in-class demonstrations would be sufficient for the other half to grasp the concepts taught.

KEYWORDS

Structural mechanics courses, physical models, in-class demonstrations, visualisation aids, recorded videos

Introduction

One of the main challenges educators face when teaching structural mechanics courses is the difficulty for students to visualise the relation between the concepts taught and the actual physical meaning on the behaviour of materials or actual structures. Not visualising the structure's responses to loads may not support learning as it can lead to false interpretation of the actual structural behaviour. According to Saleh and Gardner (2009), 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". If the concepts taught do not appear "real" to students, then mechanics courses are merely exercises with mathematics and equations, with no connection to any practical significance. Moreover, understanding conceptual knowledge (i.e. "understanding the principles governing a domain and the interrelation between units of knowledge in a domain" (Rittle-Johnson (2006)) is "critical to the development of competency in engineering students and in practicing professionals" and "present substantial challenges" (Streveler et. al., 2008).

An effective way to convey these conceptual concepts is to use visual demonstrations. According to Cadmus (1990), "demonstrations not only allow the students to see first hand how things behave, but also provide them with visual associations that they may capture, and preserve the essence of physical phenomena more effectively than do verbal descriptions." This belief is also shared by Fraser et. al. (2007) who "strongly suggest that activities that aid student visualisation of abstract concepts will foster student understanding". 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 quicker with one picture (Jewell (2010)). 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. When visual and verbal learning were used simultaneously, informational recall could be increased.

Following the above observations, visual demonstrations (in the form of physical models) have been developed and extensively used at Griffith University in the last several years in five structural mechanics courses taught by the first three authors. Four courses, namely *Engineering Mechanics* (Year 1), *Mechanics of Material 1* (Year 2), *Mechanics of Materials 2* (Year 2) and *Structural Analysis* (Year 3), form an integral part of the professional engineering analysis and design training provided in the Bachelor of Civil Engineering. The fifth course, *Introduction to Structures* (Year 1), is a core course of the Bachelor of Environment (Architecture). The former three courses (*Engineering Mechanics*, *Mechanics of Material 1* and *Mechanics of Materials 2*) create a foundation and a framework for most branches of engineering; *Structural Analysis* applies these foundations to perform prerequisite analysis prior to design by solving real-world engineering problems; and the latter course (*Introduction to Structures*) aims to develop the "engineering feeling" by focusing on structural behaviour and select appropriate structural systems prior to detailed analysis.

The use of the physical models has been highly valued by students who unanimously claimed that the demonstrations greatly helped their overall understanding of the courses (Guan and Gilbert, 2011). However, when comparing students' performance before and after the use of the models, or when testing students on concepts taught with and without the use of models, no clear quantitative evidence was available in the past to support the actual effectiveness of these teaching tools.

Prior to Semester 1, 2013, the physical models were only demonstrated once during lectures and in the front of the lecture theatre. The authors believed that this delivery mode had several limitations. First, it was believed that students at the back or side of the large lecture theatre might not be able to clearly see the demonstrations, therefore limiting their understanding. Second, while some concepts may have seemed obvious to the students while being demonstrated, it was believed that students may need more time to assimilate and review the concepts at their own pace.

Consequently, from Semester 1, 2013, a video camera was introduced to project the demonstrations on the lecture theatre screen. This allowed the exact same demonstration to reach the entire audience regardless of the students' seating location in the lecture theatre. From Semester 2, 2013, videos of the demonstrations performed during the lectures were also recorded and uploaded on the course websites, allowing students to review the concepts in their own time. Concepts can be better remembered using videos as they function as a form of anecdote (i.e. something the audience remembers) (Miller and Zhou (2007)).

This paper presents the results of a survey on the effectiveness of (i) using physical demonstrations in class, (ii) projecting these demonstrations on the lecture theatre screen and (iii) posting recorded videos of the same on the course website, on students' overall understanding of fundamental structural mechanics concepts.

Physical models used

As developed in the introduction, the idea behind the physical models is based on the theory that visual learners would take more information by observing how structures actually deform under loads. This approach helps the authors to convey complicated and fundamental concepts efficiently. It aims at enhancing deep understanding (i.e. the ability of students to critically examine new facts and ideas, and "tying them into existing cognitive structures and making numerous links between ideas" (The Higher Education Academy, 2011)) of fundamental structural mechanics concepts within the Civil Engineering program at Griffith University.

(a) (b)

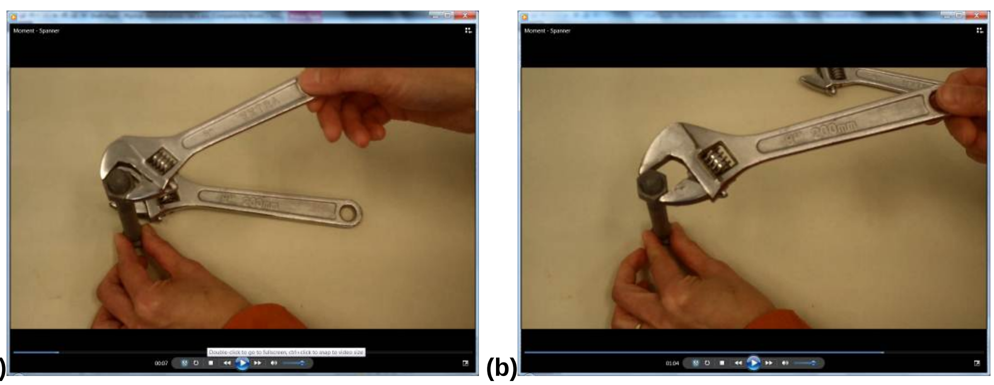
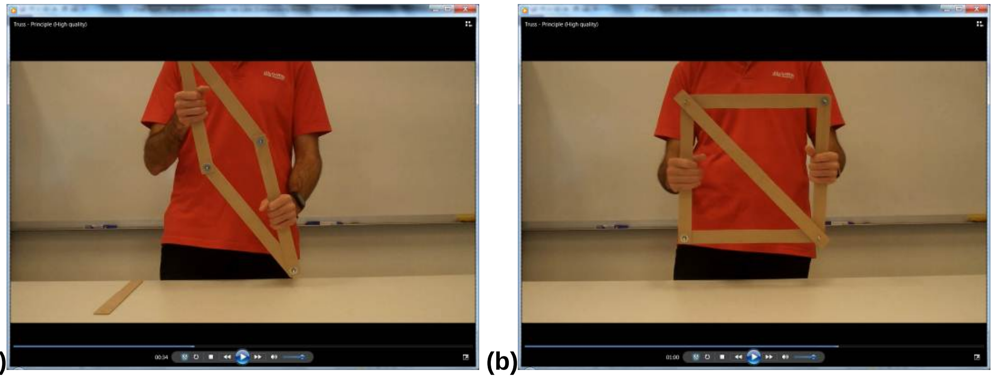


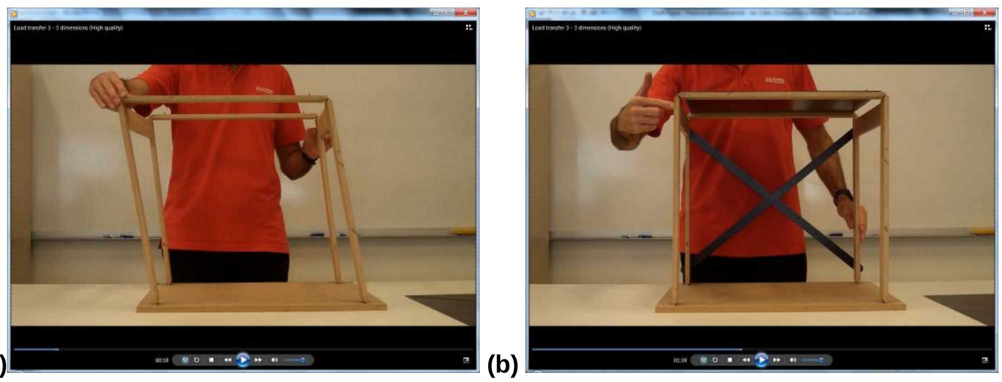
Figure 1: Video demonstration of the concept of a moment using (a) a "short" and (b) a "long" lever arm

In class, the demonstrations are usually performed together with explanations of the matching concepts and calculations being covered. The videos placed on the course website are not performed with calculations, only explanations. The aim of the videos is more to assimilate and review the concepts covered in class than to learn these concepts from the beginning. Covered concepts range from "simple" ones, such as the concept of a moment (Figure 1) or the principle of a truss (Figure 2), to "more complicated" ones, such as three dimensional load transfer (Figure 3) to framing systems (Figure 4). For the various frame configurations in Figure 4, the bending moment diagrams are also discussed in class 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. This greatly assists them in their effort in plotting correct bending moment diagrams (Guan and Gilbert, 2011). Moreover, by improving the deep understanding of key civil engineering concepts, it is anticipated that graduates will be better trained and more employable.



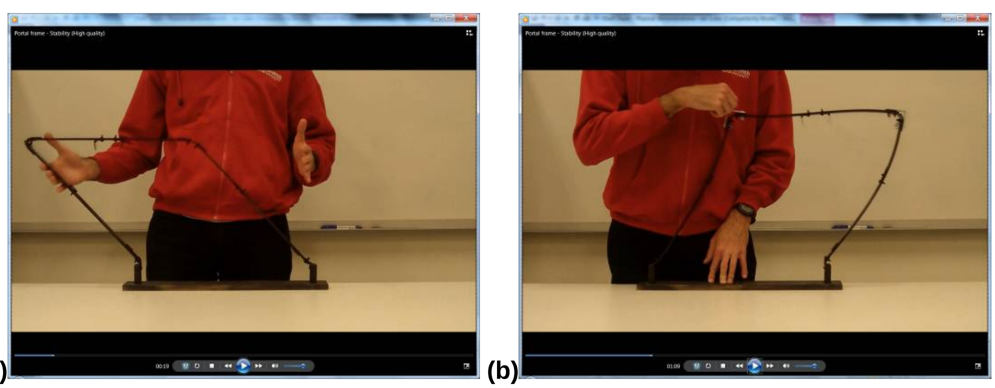
(a) (b)

Figure 2: Video demonstration of the principle of a truss (a) without (free to deform in shear) and (b) with diagonal bracing member



(a) (b)

Figure 3: Video demonstration of a 3D load transfer using a two-row structure: (a) no bracing, shear wall or slab (structure free to deform) and (b) bracing added at the back row and slab connecting the two rows together (stable structure)



(a) (b)

Figure 4: Video demonstration of a frame with various restraint conditions and connection details: (a) hinged at the base and between beam and columns and (b) hinged at the base and fixed between beam and columns

Surveys

Students were surveyed in Week 10 of Semester 2, 2013, in the three structural and mechanics courses offered in the semester, i.e. *Engineering Mechanics*, *Mechanics of Materials 2* and *Introduction to Structures*. For these three courses, respectively 116, 60 and 40 students answered the survey, totalling 216 responses. This represents a significant number of students across two different bachelors (Civil Engineering and Environment (Architecture)) and years (first and second year courses). As from different cohorts, students unlikely answered the survey twice in two different courses. Each of the three surveyed courses is taught by a different lecturer.

In total, 7 questions, divided into two parts, were asked. Part 1 aimed at collecting quantitative and qualitative data on students' thought on the effectiveness of the physical models used in-class in improving their understanding of structural mechanics concepts (Question 1) and performance in the course (Question 3), and the effectiveness of projecting the demonstrations on the lecture theatre screen (Question 2). All students were asked to answer Part 1. Part 2 aimed at collecting quantitative data on students' thought on the effectiveness of the online videos in reinforcing or mastering the structural mechanics concepts (Questions 5 and 6) and eventually improving their performance in the course (Question 7). Only students who made used of the videos were asked to answer Part 2. Specifically:

1. Part 1 comprised three "5-scale" questions and one "open" question. The three scaled questions were articulated as below:

    - Question 1: *I think that the use of physical models during the lectures, rather than relying on verbal explanations or two dimensional drawings, made it a lot easier to properly visualise what the lecturer was trying to get across. This provided clarity for difficult mechanics/structural concepts and helped me in my learning effort*.
    - Question 2: *I think that having the demonstrations projected on the screen, instead of having the lecturer purely demonstrating in front of the class without being projected on the screen, was efficient in helping me visualising the concepts*.
    - Question 3: *In general, I think that the use of physical models during the lectures helped or will help me performing in the course*.

    For these questions, the adopted 5-scale ranged from *I strongly disagree to I strongly agree.* For the "open" question (Question 4), students were able to add any comments on why the use of physical models helped them or not in the course, and how the models or videos could be improved to benefit their learning.

2. Part 2 also comprised three "5-scale" questions. These three scaled questions were articulated as below:

    - Question 5: *I think that the videos of demonstrations placed on the course website were helpful in further mastering and reinforcing the important mechanics/structural concepts taught.*
    - Question 6: *Without the videos of demonstrations placed on the course website, and solely relying on the in class demonstrations, I would have not been able to understand or mastering the important mechanics/structural concepts taught.*
    - Question 7: *In general, I think that the videos of demonstrations placed on the course website helped or will help me perform better in the course.*

    Similar to the "scaled" question in Part 1, five different answers were possible, ranging from *I strongly disagree to I strongly agree.*

Results and discussion

Part 1, effectiveness of the in-class demonstrations

86.1% of the students strongly agreed (43.5%) or agreed (42.6%) that the physical models used during the lectures made it a lot easier to properly visualise what the lecturer was trying to get across. Therefore, it provided clarity for difficult structural mechanics concepts and helped them in their learning effort (Question 1). Answers to the “open” question (Question 4) reinforce the need for students to visualise how structures behave or deform to grasp fundamental concepts: “*It was much easier to get an understanding of how it worked*”, “*As a visual learner, I found the models more engaging than the verbal explanations or picture in slides*” or “*A physical demonstration allows information and assumption to be seen clearly and proven*”.

On the 6.9% of the students who disagreed (5.1%) or strongly disagreed (1.8%) to Question 1, the answers to the “open” question (Question 4) tend to indicate that either these students were not visual learner: “*I am a theoretical learner*” or “*The diagrams in picture form were enough to get the point across without the videos*”, or were questioning the choice of some models used: “*The examples were not always very clear and sometimes were a bit difficult to visualise*”.

78.2% of the students strongly agreed (33.3%) or agreed (44.9%) that projecting the demonstrations on the lecture theatre screen was efficient in helping visualising the concepts (Question 2). This high percentage enforces the need to project the demonstrations and therefore similarly reach all students regardless of their seating position in the lecture theatre. 13.9% of the students neither agreed nor disagreed. No answers to the “open” question related to Question 2. Yet, an informal survey, performed after projecting the demonstrations for the first time in Semester 1, 2013, indicated that the students found the method initially disturbing but enjoyable when they understood that they have to look at the screen, not the lecturer. For *Engineering Mechanics* (taught in a lecture theatre of 600 seats), the Student Experience of Course (SEC) survey conducted at the conclusion of Semester 2, 2013, signifies that the students enjoyed the demonstrations projected on the screen, which had greatly helped their understanding of difficult topics and improved their knowledge with the complex problems. Giving a scale of 1 for *I strongly disagree* to 5 for *I strongly agree,* the correlation coefficient r between Questions 1 and 2 is weak and equal to 0.65.

81.7% of the students strongly agreed (37%) or agreed (44.7%) that the use of physical models during the lectures helped or will help them perform better in the course (Question 3). The answers to Question 3 were correlated to the answers in Question 1 (r = 0.73), indicating that if the demonstrations help better understanding difficult concepts (Question 1), they will logically help performing in the course. The correlation coefficient r between Questions 2 and 3 is weak and equal to 0.57.

Detailed answers for the three courses for Questions 1 to 3 are given in Table 1. It may be noted in Table 1 that architecture students (*Introduction to Structures*) responded more favourably to the use of the models than engineering students (*Engineering Mechanics* and *Mechanics of Materials 2*).

Table 1: Detailed answers per course (in percentage) for Questions 1 to 3

	Engineering Mechanics					*Mechanics of Materials 2*					*Introduction to Structures*				
	SD	D	N	A	SA	SD	D	N	A	SA	SD	D	N	A	SA
Q1	3.4	4.3	6.9	48.3	37.1	0	10	11.7	46.7	31.7	0	0	0	20	80
Q2	2.6	3.4	13.8	50	30.2	3.3	11.7	16.7	46.7	21.7	0	2.5	10	27.5	60
Q3	3.7	3.7	13	48.1	31.5	3.3	6.7	15	50	25	0	0	2.5	27.5	70

Part 2, effectiveness of the online video demonstrations

Videos of the demonstrations were not posted on the course website for *Mechanics of Materials 2* and this section only relates to the students' experience in *Engineering Mechanics* and *Introduction to Structures*. For the latter two courses, 108 students indicated that they made use of the online videos and answered Part 2 of the survey. This represents 75 and 33 students for *Engineering Mechanics* and *Introduction to Structures*, respectively.

77.3% of the students strongly agreed (29.3%) or agreed (48%) that the videos of the demonstrations placed on the course website were helpful in further mastering and reinforcing the important concepts taught (Question 5). 22.2% of the students neither agreed nor disagreed. Very few comments in the "open" question (Question 4) provided suggestions to understand why the videos were efficient in improving learning. Nevertheless, one student stated that "*it allows people to go back and repeat several times without being embarrassed*". As the videos were not professionally recorded, few students commented on the quality of the audio and images.

62% of the students strongly agreed (21.3%) or agreed (40.7%) that without the videos of the demonstrations placed on the course website, and solely relying on the in-class demonstrations, they would have not been able to understand or mastering the important concepts taught (Question 6). This score is about 25% lower than the strongly agreed or agreed answers to Question 1. Additionally, only 69.2% of the surveyed students claimed to have made use of the online videos. On the assumption that the remaining 30.8% of the students did not feel the need to rely on the videos to better understand the concepts taught, it may be extrapolated from Question 6 that demonstrating the concepts in-class may be sufficient for half of the students. The videos would therefore be an efficient tool for the remaining half to better assimilate and master the concepts taught.

For Question 6, 22.2% of the students neither agreed nor disagreed and 15.8% strongly disagree (5.6%) or disagree (10.2%).

The answers to Question 7 are very similar to Question 6, with 63.3% of the students strongly agreeing (24.8%) or agreeing (38.5%) that in general, they think that the videos of demonstrations placed on the course site helped or will help them perform better in the course. However, the correlation coefficient r between Questions 6 and 7 is weak and equal to 0.52, while the correlation coefficient between Question 5 and 7 is strong and equal to 0.80. These correlation coefficients indicate that of the students who made use of the videos, (i) some had already understood the concepts (Question 5) and therefore using the videos did not provide significant further help (Question 6); and (ii) some needed the videos to understand and master the concepts (Question 5) which in turn helped or will help them perform better in the course (Question 7).

For Question 7, 21.1% of the students neither agreed nor disagreed and 15.6% strongly disagree (3.7%) or disagree (11.9%).

Detailed answers for the three courses for Questions 5 to 7 are given in Table 2. Contrary to Part 1, it may be noted in Table 2 that the videos posted on the course websites has similar learning outcomes for both architecture (*Introduction to Structures*) and engineering (*Engineering Mechanics*) students.

Table 2: Detailed answers per course (in percentage) for Questions 5 to 7

	Engineering Mechanics					*Introduction to Structures*				
	SD	D	N	A	SA	SD	D	N	A	SA
Q5	2.7	8	12.0	48	29.3	3	3	18.2	45.5	30.3
Q6	6.7	13.3	24.0	38.7	17.3	5.9	23.5	26.5	29.4	14.7
Q7	2.7	6.7	18.7	42.7	29.3	3	3	12.1	57.6	24.2

Conclusion

The purpose of this study was to gather quantitative and qualitative data on the effectiveness of the use of physical demonstrations in enhancing students' understanding of fundamental structural mechanics concepts. A total of 216 students were surveyed in three different structural and mechanics courses offered in Semester 2, 2013.

Results showed that the use of physical models in-class is an efficient technique to convey complicated structural mechanics concepts. 86.1% of the students claimed that the physical models used during the lectures made it a lot easier to properly visualise what the lecturer was trying to get across. In large classes, the use of a video camera to project the demonstrations on the lecture theatre screen was also shown to be an efficient method to reach the entire audience regardless of the students' seating location in the theatre. Additionally, 81.7% of the students claimed that the use of physical models during the lectures helped or will help them performing in the course.

Results showed that the use of videos of the demonstrations placed on the course website helps students in further mastering and reinforcing the important concepts taught. 62% of the students who made use of the videos claimed that without the videos of demonstrations placed on the course site, and solely relying on the in-class demonstrations, they would have not been able to understand or master the important concepts taught. Yet, results suggest that the videos are useful for at least half of the students, as the in-class demonstrations would be sufficient for the other half to grasp the concepts taught.

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