NEW PEDAGOGICAL APPROACHES IN MECHANICS YIELD INCREASED UNDERSTANDING AND LEARNING OUTCOMES

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ABSTRACT

This paper presents the use of learner-centred educational strategies to enhance the student learning experience and outcomes in a Mechanics module incorporating topics from engineering statics and dynamics. The specific pedagogical activities used include a variety of active learning methods (e.g., emphasizing learning outcomes, muddy cards, concept questions, hands-on activities and metacognition). An evaluation of the impact of the overall approach of using these active learning methods, based upon student's responses, is presented.

The method used to assess student learning outcomes was the pre- and post- self-reported attitude surveys conducted during the 2012/13 academic session. These surveys were administered using the Blackboard Learning System's Survey Manager to measure the effectiveness of the new active learning approaches and the extent to which each student achieves specified learning outcomes. The survey results would help students to reflect and develop a sense of themselves as learners and future engineers. The results would also help them to see more clearly the connections among the concepts they had learned, as well as the applications of these concepts to new situations.

On average, 82% of the 40 students agreed or strongly agreed that the module learning outcomes were perceived to have been achieved after the deliberate emphasis of them during lessons. This is an increase of 36% over the pre-survey result of 46% and supports the approach taken in terms of positively influencing student understanding and learning outcomes.

KEYWORDS

CDIO, Active Learning, Assessment, Learner centred, Engineering Mechanics, Standards: 2 and 8.

INTRODUCTION

The first goal of the CDIO initiative is to educate students who are able to master a deeper working knowledge of technical fundamentals (Crawley et al., 2007). At the same time, drawing upon a broad research base and with strong implications for teaching, the National Research Council Commission (2000) has reported that to develop competence in an area, students must have a deep foundation of factual knowledge, understand facts and ideas in the context of a conceptual framework, and organize knowledge in ways that facilitate retrieval and applications as key to successful learning.

Based upon these findings, what should the student experience in an engineering classroom look like? Clearly these findings point to a learner-centred approach to teaching—that is, the lecturer needs to help students acquire a deep knowledge of the subject matter and they also need to help them organize that knowledge in a useful way. Too often in the classroom it is left entirely to the students to put all the pieces together and see the big picture. In addition, lecturers must help students to understand, evaluate and take responsibility for their own learning. This description rarely matches what takes place in the typical engineering classroom.

This paper presents educational strategies used in Engineering Mechanics 1, MM1108, a core four-credit, semester long module that is offered to all year 1 students in the School of Mechanical and Aeronautical Engineering (MAE). The aim of this module is to provide knowledge in foundational concepts of units, dimensions, motion, forces and their effects. This subject also supports the overall course aim of developing problem solving skills in the engineering mechanics. Topics include SI Units & Dimensions, Equilibrium Conditions, Friction, Kinematics and Newton's laws of motion. This module is the foundation for the subsequent Mechanics 2 and 3 modules in years 2 and 3 respectively.

ACTIVE LEARNING APPROACHES

In the 2012/2013 academic session, the School of Mechanical and Aeronautical Engineering (MAE) initiated a pilot study to implement active learning strategies for three year 1 core modules, namely, Mechanics 1, Thermofluids 1 and Engineering Materials 1. This was implemented on students enrolled in the Diplomas in Bioengineering (DBEN) and Mechanical Engineering (DME - APEX program). Both diplomas had a small cohort size of about 20 students for each semester. The Mechanics 1 module was taught to all MAE students with a traditional approach combining 90 minutes lecture with 90 minutes tutorial per week. In addition, a 180 minutes laboratory session was conducted on a fortnightly basis. After the pilot study, active learning strategies will subsequently be phased in for years 2 and 3 modules.

Crawley et al. (2007) argued that active and experiential learning is fundamental to reaching the educational goals of ensuring students are able to master a deeper working knowledge of technical fundamentals. Educational research confirms that active learning techniques significantly increase student learning (Crawley et al., 2007). Active learning is known to support a deep approach to learning (Biggs, 2003 and Gibbs, 1992). A deep approach to learning means that students attempt to understand the concepts, as opposed to simply reproducing the information in an exam. Active and experiential learning methods influence the approach that students are likely to adopt. When students are given an active role in their learning process, they learn better because they are more likely to take a deep approach to learning. Biggs (2003) argued that students who are actively involved in their own learning make better connections, both with past learning and between new concepts. Active learning in lecture-based courses can include pauses for reflection, small group discussion, and real-time feedback from students about what they are learning. The key attributes of active learning, which engages students in manipulating, applying, and evaluating ideas, can be applied not only in experiential situations, but also in traditional disciplinary courses and larger class settings. The purpose of active learning is to enhance, engage, motivate, and excite students for deeper understanding and independent learning. Crawley et al. (2007) stated that there are several methods suitable for active learning in lectures which include muddy cards, concept questions, electronic response systems, ticking, discussions with partners or small groups and variations of these methods. Crawley et al. (2007) further maintained that studies indicate that students are more likely to achieve intended outcomes and are more satisfied with their education when they are engaged in this kind of learning method.

The following methods or approaches are some of the active learning strategies to be implemented for Mechanics 1.

Greater Emphasis on the Intended Learning Outcomes

Specifying detailed learning outcomes for disciplinary knowledge is part of the essential requirement of the second CDIO standard. According to Singapore Polytechnic (SP) Teaching and Learning handbook (2011), learning outcome has been defined as *"an explicit description of what a learner should know, understand and be able to do as a result of learning". "They may also include attitudes, behaviours, values and ethics"*. The Handbook further emphasises that learners can make a more informed choice about which learning programme/unit is most appropriate. The clearer the learning outcomes, the better informed the learners of what they are expected to learn (which could reduce problems of mismatch, demotivation and retention, as well as avoid loss of opportunity for the learner).

From the students' perspective, the students from the Chalmers University of Technology, the Royal Institute of Technology, and Linköping University made the following recommendations on learning outcomes for more effective teaching and learning. They are (Crawley et al., 2007):

1. Set clear intended learning outcomes relevant to engineering practice. Clear intended learning outcomes increase motivation and guide studies. Seeing how the course contributes to professional competence is motivating.
2. Develop teaching activities and assessment tasks that help students reach the intended learning outcomes. Motivation is increased when students know why they are asked to engage in learning and assessment activities.

The learning outcomes of all modules taught in the School of MAE are well documented in their respective module syllabi and deposited electronically in a repository. These learning outcomes are written based on the well-established Bloom's Taxonomy of Educational Objectives (Bloom et al., 1956). For Mechanics 1, there are all together 38 specific learning outcomes formulated that the students ought to know, understand and able to do as a result of learning. These 38 learning outcomes are shown in Appendix A. The intended learning outcomes (LOs) of Mechanics 1 were clarified and emphasised to ensure that the students were focussed on achieving these learning outcomes during the semester. The effectiveness of students achieving these learning outcomes was evaluated through the Pre and Post surveys before and after the coverage of Mechanics 1 topics.

Muddy Cards

Muddy cards, also known as *Muddiest-Point-of-the-Lecture* cards, gather in-class feedback to determine gaps in student comprehension (Mosteller, 1989). Near the end of a lecture or other learning experience, students are asked to reflect on what they have learned. They write down the concepts or ideas—the *point*—they found most unclear—the *muddies*t.

During the semester, the selected Mechanics 1 students were given cards to write down their 'muddiest' understanding of concepts. The lecturers collected these cards for later review. The muddy points were addressed at the start of next lesson, through printed answers, and sent email to class.

Concept Questions

The understanding of concept in Mechanics 1 was assessed through six (6) online course works throughout the semester. For each course work, students were allowed to attempt five times to ensure that they grasped a deeper understanding of the key concepts. In addition, the students Mid Semester Test results for poorer students were gathered and feedback was provided through rubrics in order to correct students' misconceptions and enhance their understanding.

Hands-On Activities

Two activities for each term were conducted by students themselves in the SP or outside campus to help them developed a deeper understanding on the underlying concepts. The activities were:

1. Construction of free body diagrams (FBD) of real life engineering structures.
2. Weighing scale experiment in moving lift.

After conducting these activities, the students presented and shared their findings during lessons. During these lessons, the lecturer would facilitate students with a better appreciation and deeper understanding on the underlying concepts of these activities.

Metacognition

The process of metacognition helps to increase students' motivation to achieve learning outcomes and form habits of lifelong learning (Crawley et al., 2007). The metacognition process engages students in thinking about concepts, particularly new ideas, and requires student to provide some kind of overt response. In this process, students not only learn more but also recognize for themselves what and how they learn.

Throughout the Mechanics 1 module, an effort was made to educate students to become intentional learners, i.e. to use cognitive processes that have learning as a goal, instead of an incidental outcome (Bereiter & Scardamalia, 1989). Thus, rubrics were developed for the MST results to focus on how weaker students can achieve a deeper grasp of key Mechanics 1 concepts.

STUDENT LEARNING OUTCOMES ASSESSMENT

The method used to assess student learning outcomes was the pre- and post- self-reported attitude surveys introduced into MM1108 Mechanics 1 class during the 2012/13 academic session. These surveys were administered using the Blackboard Learning System's Survey Manager to measure the effectiveness of the new active learning approaches and the extent to which each student achieves specified learning outcomes. The survey results would help students to reflect and develop a sense of themselves as learners and future engineers. The results would also help them to see more clearly the connections among the concepts they had learned, as well as the applications of these concepts to new situations.

Before the start of each topic (equilibrium conditions, friction, kinematics and Newton's Law of Motion) pre-surveys was conducted amongst the 40 students. The pre-survey questionnaires (Refer to Appendix A) consisted of the learning outcomes of each topic. The students were asked about their perception in achieving the learning outcomes and rate the extent of their understanding based on a likert scale ranges from 1 (Strongly Disagree*)* to 5 (Strongly Agree), where the midpoint 3 is labelled as (Neither Agree Nor Disagree). After the responses were collected, the data was processed and the pre-survey results were shared with students during the next lesson at the start of each topic. Some sample results are shown in Table 1. The pre-survey results revealed the extent of students understanding in these learning outcomes collectively. These served as a tool to help students to identify weak areas in their understanding of these learning outcomes. As the topic progressed, the pre-survey results were periodically shown to students to enable them focused on the learning outcomes and in the process, deepen their understanding and internalising of these outcomes. At the same time, questions and feedback were solicited concerning their understanding of these learning outcomes. In addition, muddy cards were given to solicit from the students those concepts which they were still ‘muddied’.

At the end of each topic, post-survey was conducted to gauge the students’ perception in achieving the learning outcomes. Same questionnaires as the pre-survey were used and the survey was conduct through the Blackboard Learning System. All the 40 students again were requested to participate in the post-survey. Some sample results of the post-survey are shown in Table 2.

Table 1. Pre-Survey Questionnaires on Equilibrium Conditions

Strongly Disagree **1**	Disagree **2**	Neither Agree nor Disagree **3**	Agree **4**	Strongly Agree **5**

		AVE
1	I am able to resolve a force into two mutually perpendicular components.	**3.31**
2	I am able to calculate the resultant force of several forces and it's direction.	**3.29**
3	Therefore, I have developed a conceptual understanding of force and resultant force.	**3.12**
4	Therefore, I have developed an ability to determine the resultant of several forces analytically using rectangular components.	**3.29**
5	I have developed an ability to experimentally verify the resolution of force vectors.	**3.06**
6	I am able to calculate the moment of a given force about a point.	**3.00**
7	I am able to sum up the moments due to several forces acting on a body about a point.	**3.00**
8	Therefore, I have developed a conceptual understanding of moment of a force about a point, and an ability to calculate the moment and sum up several moments.	**3.06**

Table 2. Post-Survey Questionnaires on Equilibrium Conditions

Strongly Disagree **1**	Disagree **2**	Neither Agree nor Disagree **3**	Agree **4**	Strongly Agree **5**

		AVE
1	I am able to resolve a force into two mutually perpendicular components.	**3.76**
2	I am able to calculate the resultant force of several forces and it's direction.	**3.88**
3	Therefore, I have developed a conceptual understanding of force and resultant force.	**3.93**
4	Therefore, I have developed an ability to determine the resultant of several forces analytically using rectangular components.	**3.47**
5	I have developed an ability to experimentally verify the resolution of force vectors.	**3.18**
6	I am able to calculate the moment of a given force about a point.	**4.18**
7	I am able to sum up the moments due to several forces acting on a body about a point.	**4.24**
8	Therefore, I have developed a conceptual understanding of moment of a force about a point, and an ability to calculate the moment and sum up several moments.	**3.94**

Next, the results of both the pre- and post- surveys were compared to identify the extent of improvements in achieving a deeper understanding of the learning outcomes in which a sample comparison is shown in Table 3. If less significant improvements were achieved in some of the learning outcomes, they were re-emphasised in the subsequent lessons.

In Semester 1 of the 2012/2013 session, extension pre- and post- self-reported surveys were conducted and there were around 40 students from DBEN and DME (APEX) who participated in the surveys. A summary result of the surveys is shown in Table 4. Refer to Appendix A for detailed results.

The above results clearly showed that with a focused and deliberate emphasis on the learning outcomes during lessons, there was a significant improvement on the students' perceived achievement of the learning outcomes. On average, 82% of the 40 students agreed or strongly agreed that the module learning outcomes had been perceived to be achieved after the deliberate emphasis of them during lessons. This is an increase of 36% over the pre-survey result of 46%.

Table 3. Comparison Between Post- and Pre- Survey Results

		POST Ave	PRE Ave	Improvement %
1	I am able to resolve a force into two mutually perpendicular components.	**3.76**	**3.31**	**13.7%**
2	I am able to calculate the resultant force of several forces and it's direction.	**3.88**	**3.29**	**17.9%**
3	Therefore, I have developed a conceptual understanding of force and resultant force.	**3.93**	**3.12**	**26.2%**
4	Therefore, I have developed an ability to determine the resultant of several forces analytically using rectangular components.	**3.47**	**3.29**	**5.4%**
5	I have developed an ability to experimentally verify the resolution of force vectors.	**3.18**	**3.06**	**3.8%**
6	I am able to calculate the moment of a given force about a point.	**4.18**	**3.00**	**39.2%**
7	I am able to sum up the moments due to several forces acting on a body about a point.	**4.24**	**3.00**	**41.2%**
8	Therefore, I have developed a conceptual understanding of moment of a force about a point, and an ability to calculate the moment and sum up several moments.	**3.94**	**3.06**	**28.8%**

Table 4. Summary on Students Perceptions on Learning Outcomes in MM1108 Mechanics 1

Unit	Learning Outcomes	% of Students who Agree or Strongly Agree		
		POST	PRE	Improvement %
2	I have developed a conceptual understanding of Equilibrium conditions which include addition of forces, moment, free body diagram, the equilibrium of coplanar, concurrent and non-concurrent force systems and the ability to verify the concepts in an experiment.	**83%**	**42%**	**41%**
3	I have developed a conceptual understanding of Friction, the ability to apply the concept of equilibrium to force systems involving friction and and verify the concepts in an experiment.	**73%**	**30%**	**43%**
4	I have developed a conceptual understanding of Kinematics which includes linear and angular motions (displacement, velocity and acceleration) and their relationships, using the velocity versus time graph and ability to compute acceleration in an experiment.	**82%**	**45%**	**37%**
5	I have developed a conceptual understanding of Newton's Law of Motion in particularly Newton's 2^{nd} Law, the ability to understand the effect of forces on the motion of bodies, apply Newton's 2^{nd} Law to solve linear motion problems and verify Newton's 2^{nd} Law in an experiment.	**91%**	**66%**	**25%**
	Average	**82%**	**46%**	**36%**

DISCUSSION

The rationale for our work in MM1108 Mechanics 1 was to employ a learner-centred approach to teaching with the goal of positively influencing students' understanding and learning outcomes. The pedagogical elements used were a number of active learning approaches. As highlighted earlier, the intended learning outcomes (LOs) of Mechanics 1 were deliberately emphasised to ensure that the students were focussed on achieving these learning outcomes during the semester. The effectiveness of students achieving the learning outcomes was evaluated through the pre- and post- surveys. The evaluation results revealed that there is a strong correlation between the adoption of the active learning approaches during lesson time and the students' achievement of the learning outcomes. The assessment data strongly supports that the deliberate act of emphasising the intended learning outcomes improves students' understanding and learning outcomes of Mechanics 1.

In addition, the survey results showed that students enjoyed and benefited from the two hands-on activities. For example, a number of students remarked positively regarding the activities in the following comments. *"It did help me to understand better on drawing of FBD diagram", "Yes, they do. I learned how the concepts can be applied into our daily lives to show how forces act on the things around us or on us", "yes the weighing-scale experiment enhance my ability to draw a correct FBD of a weight attached to the scale in a moving lift very much and very fun", "Yes, the weighing-scale experiment enhance your ability to apply Newton's 2nd law to find acceleration of attached weight in a moving lift", "On the whole, the activities do help me in understanding the concepts in mechanics", "Yes, they are beneficial towards my learning of the underlying and fundamental principles of Mechanics", "yes as it help us to discover mechanics principles ourselves and learn beyond what is in the theory"*.

There were some difficulties experienced during the semester in implementing the active learning approaches. Firstly, it was difficult in soliciting written muddy cards from the students. It was observed students were not keen in submitting them as a form of feedback on their 'muddiest' understanding of concepts. This approach was modified by using a less formal way in which just post-it notes were issued to students rather than cards. Instructions were given to students to write down any feedbacks on these post-it notes and the lecturers would just collect them randomly to ensure the student identities were remained anonymous. This proved to be more effective as more students were willing to submit feedbacks.

Secondly, it was onerous and time consuming to prepare rubrics for students who did not do well during their Mid Semester Test (MST) for Mechanics 1. It was suggested that the rubrics would only be developed for weaker students who had failed the MST and the number of items in the rubric to be simplified for faster assessment.

The success of MM1108 Mechanics suggests the potential effectiveness for using learner-centred active learning approaches throughout engineering programs. Using such an approach will improve individual modules, and its consistent application throughout the curriculum likely will yield additional benefits. Huba and Freed (2000) discuss the importance of seeing our classes as part of the entire educational system. "The knowledge, skills, and abilities that students achieve at the end of their programs are affected by how well modules and other experiences in the curriculum fit together and build on each other throughout the polytechnic years.

CONCLUSIONS

A learner-centred approach to teaching Engineering Mechanics 1 using the active learning approaches as an underlying new pedagogy has been shown to be effective for engineering students. A detailed assessment on the perception of students achieving the learning outcomes supports the effectiveness of the approach for increased understanding and student learning outcomes of the Mechanics 1 module.

In particular, the assessment data revealed that a deliberate attempt on the part of lecturers to put greater emphasis on student learning outcomes would increase their understanding and learning outcomes. The above results had clearly demonstrated that with a focused and deliberate emphasis on the learning outcomes during lessons, there was a significant improvement on the students' perceived achievement of the learning outcomes. On average, 82% of the 40 students agreed or strongly agreed that the module learning outcomes had been perceived to be achieved after the deliberate emphasis of them during lessons. This is an increase of 36% over the pre-survey result of 46%.

It is also recommended that the learner-centred active learning approaches are to be widely adopted in the Engineering programs to enhance student learning.

ACKNOWLEDGEMENT

We are grateful to both Dr. Lim Chee Kian and students of DBEN and DME (APEX) who have participated in the pilot run of the active learning approaches and students participated in all the online surveys.

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APPENDIX A

			% of Agree and Strongly Agree		Improvement %
			POST	PRE	
Unit 2 Equilibrium Conditions	1	I am able to resolve a force into two mutually perpendicular components.	**95%**	53%	**42%**
	2	I am able to calculate the resultant force of several forces and it's direction.	**92%**	76%	**17%**
	3	Therefore, I have developed a conceptual understanding of force and resultant force.	**87%**	82%	**5%**
	4	Therefore, I have developed an ability to determine the resultant of several forces analytically using rectangular components.	**86%**	64%	**21%**
	5	I have developed an ability to experimentally verify the resolution of force vectors.	**73%**	27%	**46%**
	6	I am able to calculate the moment of a given force about a point.	**90%**	82%	**8%**
	7	I am able to sum up the moments due to several forces acting on a body about a point.	**88%**	67%	**22%**
	8	Therefore, I have developed a conceptual understanding of moment of a force about a point, and an ability to calculate the moment and sum up several moments.	**86%**	62%	**24%**
	9	I have developed a conceptual understanding on the nature of different types of forces namely, push, pull (e.g. tension), weight and reactions.	**90%**	60%	**30%**
	10	I know the reactions present at various supports like rollers, pin-joints, fixed ends.	**86%**	20%	**66%**
	11	I know how to sketch Free Body Diagrams of two-dimensional mechanical systems in equilibrium.	**83%**	36%	**48%**

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			% of Agree and Strongly Agree		Improvement %
			POST	PRE	
	12	Therefore, I have developed a conceptual understanding of Free Body Diagram and an ability to sketch free body diagrams.	**79%**	33%	**46%**
	13	I am able to state the conditions of equilibrium for concurrent forces.	**86%**	27%	**59%**
	14	I am able to determine if a body is in equilibrium of coplanar, concurrent force systems.	**82%**	22%	**60%**
	15	I am able to solve Statics problems involving concurrent force systems.	**77%**	20%	**57%**
	16	Therefore, I have developed a conceptual understanding on equilibrium of coplanar, concurrent force systems, and the conditions for equilibrium.	**82%**	38%	**44%**
	17	I am to state the conditions of equilibrium for non-concurrent forces.	**74%**	16%	**59%**
	18	I am able to determine if a body is in equilibrium of co-planar, non-concurrent force systems.	**76%**	16%	**60%**
	19	I am able to solve Statics problems involving non-concurrent force systems.	**71%**	16%	**55%**
	20	Therefore, I have developed an understanding of equilibrium of coplanar and non-concurrent forces, and an ability to experimentally verify the conditions for equilibrium.	**72%**	27%	**45%**
	Average		**83%**	42%	**41%**
Unit 3 Friction	21	I have developed a conceptual understanding of frictional force, normal reaction, coefficient of friction, and angle of friction.	**69%**	30%	**39%**
	22	I am able to state the 5 laws of friction.	**69%**	7%	**62%**
	23	I am able to differentiate between static and kinetic frictions; and between coefficient of static and coefficient of kinetic frictions.	**77%**	23%	**54%**
	24	I have the ability to sketch the free body diagram of a block moving or tending to move on horizontal and inclined planes.	**74%**	56%	**19%**
	25	I have developed an ability to apply equilibrium conditions to solve friction problems for both horizontal and inclined planes.	**74%**	35%	**39%**
	26	I have developed an ability to determine the coefficient of friction between contact surfaces through an experiment.	**74%**	28%	**46%**
	Average		**73%**	30%	**43%**
Unit 4 Kinematics	27	I have developed a conceptual understanding of linear displacement, linear velocity and linear acceleration.	**93%**	49%	**44%**
	28	I have developed an ability to sketch the linear velocity vs time graphs for motions involving uniform accelerations and retardations.	**89%**	54%	**35%**
	29	I have developed an ability to solve problems involving uniformly accelerated motion using formulae and linear velocity vs time graphs.	**86%**	56%	**29%**
	30	I have developed an ability to experimentally compute the acceleration of a given body in linear motion.	**75%**	56%	**19%**
	31	I have developed a conceptual understanding of the radian, angular displacement, angular velocity and angular acceleration.	**82%**	41%	**41%**
	32	I have developed an ability to solve problems involving rotational motion using formulae and angular velocity vs time graphs.	**82%**	26%	**57%**
	33	I have developed an ability to derive formulae and solve problems involving linear motion linked to angular motion.	**68%**	36%	**32%**
	Average		**82%**	45%	**37%**
Unit 5 Newto	34	I have developed a conceptual understanding of the effect of forces on the motion of bodies.	**91%**	79%	**12%**
	35	I have developed a conceptual understanding of Newton's three laws of motion.	**95%**	61%	**35%**

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		% of Agree and Strongly Agree		Improvement %
		POST	PRE	
36	I have developed an ability to apply the equation "S F = ma" to problems involving linear motion.	**95%**	79%	**17%**
37	I have developed an ability to determine the kinematic quantities of a body, bodies, a mass or masses in motion.	**86%**	61%	**26%**
38	I have developed an ability to experimentally verify Newton's 2nd law of motion.	**86%**	50%	**36%**
	Average	**91%**	66%	**25%**

BIOGRAPHICAL INFORMATION

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