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Improving Learning in Engineering Mechanics: The Significance of Understanding

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***Abstract**: Mechanics is a key foundation topic for many engineering disciplines, the study of which usually constitutes a significant proportion of first and second year engineering undergraduate studies. Many engineering students experience substantial difficulties with introductory mechanics, and it is widely noted in the literature that pass rates in mechanics courses tend to be unacceptably low. This paper details the interim findings of, and issues arising from a literature search focusing on how engineering educators understand, describe, identify and deal with the causes of poor performance in introductory mechanics. The most striking conclusion drawn from this literature search is the lack of conclusive research into the more fundamental causes of difficulties for students studying mechanics.*

Introduction

The international engineering education literature and discourse at major engineering education conferences contain a wealth of data supporting the assertion that students experiencing substantial difficulties in fundamental engineering mechanics is a widespread and persistent problem (Dwight & Carew, 2006; Papadopoulos, Bostwick, & Dressel, 2007; Philpot, Hall, Hubing, & Campbell, 2005; Rezaei, Jawaharlal, Kim, & Shih, 2007). The focus of many publications is on attempts to improve educational outcomes for students through various teaching and assessment practices and learning resources. However, the results of these attempts often don't go beyond minor or statistically unsupported improvements in overall student grades. One may ask: Why is this?

During a literature search, undertaken as part of a larger project to identify predictors of poor performance in engineering mechanics, a number of recurring themes were identified. These themes may provide some insight as to why high failure rates are such a persistent and widespread problem in introductory mechanics. The following pages highlight some common approaches taken by engineering educators to identify and address the causes of poor student performance in mechanics, and we note the common themes present in many.

Causes of Poor Performance

One of the most common causes of failure cited is the time input from students. Balasico and others (2007) surveyed students using a compulsory; spreadsheet based self reporting form to assess the impact of time spent studying outside of class time. After analysing the results, and discarding questionable outliers, they found no statistically significant relation between independent study time and course grade. There was also no strong link between study hours and overall grade average (over the degree program). Balascio and others (2007) concluded that study hours were a poor predictor of performance, and speculated that study hours were in fact heavily influenced by the students' individual ability, rather than simply their commitment to academic achievement.

A closely related cause often suggested is student motivation. It is apparent that many attempts at improving student motivation are unable to produce improvements in learning outcomes that are consistent across several student groups (Pollock, 2005). Some note improvements in student feedback on the course but are unable to relate this to measurable improvements in learning outcomes (Crawford & Jones, 2007). Motivation for independent study and effort input could also be influenced by the marks students deem to be acceptable (Balascio et al., 2007). Anecdotally, some engineering students follow the maxim "P's get the degrees". This statement and the literature would suggest that attempts to improve student motivation may work for some students and not for others. More to the point, what motivates some people may have no, or even an adverse effect on others depending on their personal motives relating to study (Weiten, 2007). Hence, while student motivation may indeed be a limiting factor to success, it is apparent from the literature that this is unlikely to be an issue that can be effectively addressed with a single approach.

Prior learning in topics relating to mechanics, such as mathematics and physics, is frequently accused of causing troubles for students. Dwight and Carew (2006) investigated the effect of subjects taken by students in their final year of high school on first and second year mechanics subjects. They found that students who had taken high level mathematics in high school enjoyed a slight advantage in first year, but by second year that advantage had disappeared. Interestingly though, students who had taken engineering studies in high school were not advantaged in first year engineering studies.

While investigating concepts in mechanics that students found difficult, Streveler and others (2006) noticed that educators involved in the study sometimes overestimated the degree to which students understood concepts. This possible mismatch in expectation of understanding between academics and students could lead academics to overestimate the depth of students' understanding of topics that comprise the pre-requisite or assumed knowledge for a particular subject. Thus, it is conceivable that this simple misunderstanding may be a factor in the assertion by some academics that prior knowledge is a cause of students' poor performance.

Delving into cognitive psychology, a number of researchers have tested the effects of different cognitive styles on learning outcomes. Ates and Cataloglu (2007) examined the impact of students tendencies towards field dependence or field independence on their understanding of basic mechanics concepts and on problem solving ability. Field dependent thinkers tend to have difficulty separating an item from it's context, whereas field independent thinkers are able to easily separate the necessary/important information from it's surroundings (Witkin & Goodenough, 1981). They found no statistically significant difference in conceptual understanding (as measured by the Force Concept Inventory (Hestenes, Wells, & Swachhamer, 1992)) between field dependant and field independent cognitive styles. There was, however, a statistically significant advantage for field independent students in terms of problem solving skills (as measured by the Mechanics Baseline Test (Hestenes & Wells, 1992)). It must be noted, however, that there are likely to be other factors at play here. Taraban and others (2007) investigated students' responses to different types of learning resources, and found evidence to suggest that students respond differently in terms of cognition levels to different types resources (eg. text only materials vs. interactive programs). Thus, a student's performance as measured or observed in one activity may not be a true reflection of their overall or absolute ability. Their performance may be influenced by the type of assessment or learning activity.

The causes and themes outlined above deal with the broader, non-specific causes of poor performance in introductory mechanics which are commonly suggested by engineering academics. In addition to these there are countless discrete causes speculated or noted in the literature. These generally fall into the categories of conceptual misunderstandings, procedural errors and knowledge gaps. Over 7500 literature sources containing references to these discrete causes in various science disciplines have been collected and compiled into bibliographical form by Duit (2007). Flores Camacho et al (2004) have undertaken an extensive project to convert an early version of the Duit bibliography and additional information into a searchable database. A brief search on mechanics related topics in the database returned over 70 documented misconceptions. In their analysis of the literature, Flores Camacho (2004) suggested that in efforts to rectify misconceptions and improve educational outcomes, many educators address only a handful of misconceptions. This limited approach could explain some of the poor results observed from targeted interventions in the teaching and learning of introductory mechanics. Flores Camacho (2004) also noted that addressing misconceptions in isolation may be ineffective because misconceptions are often interlinked.

Some authors cite approach to instruction, or instructors as a potential contributor to the difficulties experienced by students. Steif (2004) proposed that the apparent simplicity of statics can cause instructors to underemphasise the less obvious aspects of the equilibrium principle. Others suggest that traditional teaching methods in engineering are not conducive to effective learning of mechanics principles (Ates & Cataloglu, 2007; Crawford & Jones, 2007; Flores Camacho et al., 2004; Linsey et al., 2007). Some also suggest that successful education requires a variety of approaches (Steif & Naples, 2003).

Without even looking to the literature, the authors' experience is that a brief conversation with any mechanics educator tends to uncover a wealth of ideas relating to why students just don't seem to understand concepts, procedures and skills fundamental to mechanics. More importantly though, a brief conversation with two different mechanics lecturers will uncover differing explanations as to why students fail, and how these issues should be addressed. The message here is that these ideas, impressions and teaching approaches are of great value as they are frequently based on years of experience. Equally, these years of experience will have resulted in often greatly differing interpretations of this experience (Weiten 2007).

One thing that has become clear during the literature review is that of all the causes of poor performance that are cited, few of them are backed up by statistical analysis to provide confidence that these are in fact genuine and significant causes of poor performance. This is most notable for the broader causes such as prior learning, motivation, and other cognitive factors. This finding from the literature review, and the impacts of it, become particularly clear during the next section of the paper when we review and report on approaches being taken by engineering educators to improve learning in engineering mechanics.

Attempts at Improving Educational Outcomes

There are many documented attempts to improve educational outcomes and student grades in introductory mechanics, some successful, others less so. Computer-based learning modules are a popular approach to improving learning. Steif and Naples (2003) designed and developed courseware to improve learning outcomes for mechanics of materials students. In their statistical analysis of the students' results they discovered that two of the three modules tested were associated with statistically significant improvements in grades. In a similar study Philpot and others (2005) tested interactive courseware designed to improve students understanding of shear force (V) and bending moment (M) diagrams. They reported a statistically significant improvement in exam marks for V/M questions. Both of these examples demonstrate the possible advantages of interactive, computer based resources for targeted improvements in learning. Both Steif and Naples (2003), and Philpot and others (2005) also noted that these resources did not work for everyone and could only be considered a supplement to face-to-face teaching.

Of both these examples, it seems that the most effective part of such computer based learning modules is the repetition of attempts to solve problem examples that they encourage. The question could be posed: Did the modules improve understanding, or simply assist students in committing the information to memory? To elaborate: Is it that the students don't understand the concepts in the first place, or do they simply forget them too quickly? Here it becomes apparent that first understanding the cause of the problem could help to target the educational developments. This would help answer the question: Does more time need to be spent by the instructor explaining the concepts, or do students need more time to practice them? If either are the case, what is the ideal amount of time?

Approaches that promote active learning and engagement of students' interest are another common approach evident in the literature. Some, such as Crawford and Jones (2007), aim to spark interest and encourage enthusiasm for the subject. Some aim to encourage student interaction with their peers that they may learn from each other (Pollock, 2005). Others try to make the learning experience more tangible, introducing concepts with the aid of simple hands on tools (Linsey et al., 2007) or unaided model building (Dwight, McCarthy, Carew, & Ferry, 2006). These types of initiatives often receive positive feedback from students (Dwight et al., 2006) but do not always result in significant improvements in grades. For initiatives to improve students' engagement with their learning to succeed, it would seem reasonable that we should first determine exactly why they are disengaged and understand what will engage their interest. While efforts to move away from traditional teaching methods in mechanics are to be encouraged, without the foundational research, these attempts can be something of a hit-or-miss affair.

Bearing this in mind, some researchers opt for diagnostic tests to establish exactly what knowledge gaps or misconceptions exist. Two popular examples of these types of tests are the Force Concept Inventory (FCI) developed by Hestenes, Wells, and Swachhamer (1992), and the Mechanics Baseline Test (MBT) developed by Hestenes and Wells (1992). These authors have used these tests to identify specific misconceptions, and have changed their approach to teaching and addressed identified misconceptions with some success. These tests, and other similar tests, have been used by other researchers as a means of proving or disproving hypotheses (Ates & Cataloglu, 2007), testing the effectiveness educational developments, and to test correlation with other assessment methods (Steif, Dollár, & Dantzler, 2005). The literature shows that simple, broad tests such as these are useful tools for indicating/suggesting where educational developments should be targeted with respect to discrete misconceptions and knowledge gaps.

Discussion

The literature search reported in this paper sought to find answers to the fundamental questions: "Why do so many students fail engineering mechanics?" and "What can be done about it?". The answer has come in the form of a blurred flurry of information in such magnitude that it sometimes seems unmanageable. From speculation, to quantitative and qualitative research, to fundamental cognitive and behavioural psychology, the solution is clearly a complex one.

The conclusion we have drawn from this is that of all the causes and all the possible solutions to each of them, no single approach can cure all. Students studying introductory mechanics are individuals with individual learning styles, motives, misconceptions and attitudes. If we are to effect a substantial improvement in learning outcomes, we may need to utilize numerous approaches to educational improvement simultaneously. While this may seem impractical, unfeasible, and at odds with the ever increasing workload on engineering academics, there is hope. Given the sheer volume of literature on the topic, it is safe to say that much of the work towards understanding the problem of student failures in introductory mechanics has likely already been done. There are many existing learning resources of high quality (Hadgraft, 2007), and statistically supported studies of problem causes which can provide a head start, they just need to be decoded, organized, and summarized into a more usable form

Finally, as is so thoroughly demonstrated in the literature, efforts to improve learning outcomes in foundational mechanics would sensibly commence with a thorough, statistically supported analysis of *what* isn't being learned (problem analysis) and *why* (identification of causes). It is hoped that such an approach would allow the limited time and dollar resources available to be accurately targeted toward the problems and students at the heart of chronically high failure rates in introductory mechanics.

Future Research

In light of the findings of this literature review, and the issues raised, a project team has now obtained funding from the Australian Learning and Teaching Council to find some solutions. The authors, plus

Alan Henderson (UTas), Giles Thomas (UTas), and Anne Gardner (UTS) will explore the reasons behind the difficulties experienced by students, and collate existing knowledge and resources into a simple to use 'toolbox' for supporting learning in engineering mechanics. A website for this project is due to be set up in early 2009, and comments and suggestions are welcome.

Summary of Issues

The table below summarises the issues that have been at the focus of some of the studies found in the literature review, and what has been found. The table (and this paper) refers to a representative sample of a larger volume of literature.

Issue	Findings/Observations	References
Student time input	Time devoted to studying by students not reliably linked to final grade outcome	(Balascio et al., 2007)
Student motivation	Difficult to achieve improvements across a variety of student groups/demographics	(Pollock, 2005)
	Positive feedback not linked to improved grade outcome	(Crawford & Jones, 2007)
	Attempts to improve motivation for learning hampered by marks deemed acceptable by students (ie. Low pass)	(Balascio et al., 2007)
	Variety of motivators: Improvements for some may have opposite effect for others	(Weiten, 2007)
Prior learning	Some small impacts found but no effects beyond 1st year	(Dwight & Carew, 2006)
Estimation of students' understanding	Some mismatch found between educators impressions of student understanding, and actual understanding	(Streveler et al., 2006)
Cognitive styles	Advantage found in mechanics problem solving ability for field dependant thinkers over field independent thinkers	(Ates & Cataloglu, 2007)
Teaching methods	Educators can overestimate the simplicity of concepts for learners	(Steif, 2004)
	Traditional, teacher focused teaching not conducive to effective learning	Many…
	Variety of approaches, including interactive computer programs needed to improve learning	(Steif & Naples, 2003)
Online resources	Often helpful as additional learning resources to complement face-to-face teaching	(P. Steif & Naples, 2003)
	Useful way to improve students' ability to construct shear force and bending moment diagrams	(Philpot et al., 2005)
Diagnostic tests	Useful for identifying specific areas to focus attention on when teaching	(Hestenes & Wells, 1992; Hestenes et al., 1992)
	Useful for testing hypotheses in educational research and development	(Ates & Cataloglu, 2007)
	Useful for assessing impact of educational developments	(Steif et al., 2005)
Time/funding for development of educational resources	There is an abundance of freely available online resources to support education	(Hadgraft, 2007)

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