Topic: Teaching Practice – Chair: Anne Gardner

Want to Change Learning Culture: Provide the Opportunity.

Keith Willey
Keith.Willey@uts.edu.au
University of Technology, Sydney,
Australia

Anne Gardner
Anne.Gardner@uts.edu.au
University of Technology, Sydney,
Australia

Abstract: *Many students resist having to take responsibility for their own learning rather expecting this to be the responsibility of their teaching academics. This resistance is often associated with Asian cultures where there is a perception of a reliance on rote learning and passively being taught. Furthermore, undertaking collaborative activities may be more difficult when students are not being taught in their primary language.*

While teaching an undergraduate engineering science program in Hong Kong the authors had initially found it difficult to motivate students to actively participate in their learning. In response, learning activities were redesigned to promote a culture of learning rather than a focus on passing a series of assessments.

We found that despite some initial apprehension students enthusiastically engaged in collaborative learning when given the opportunity. Furthermore, formative activities freed students from the burden of strategically collecting marks, allowing them to focus on learning, enjoy the activities and take responsibility for their own progress.

Introduction

Engineers are often required to make critical judgements involving decisions that extend beyond traditional discipline boundaries. This requires professional engineers to undertake ongoing learning. Much of this learning is informal, learnt on the job from peers from different disciplines (Trevelyan 2007). Hence, to prepare students for professional practice they require opportunities to experience, practise, reflect and improve their ability to work in collaborative learning environments.

Many students resist having to take responsibility for their own learning rather expecting this to be the responsibility of their teaching academics. This resistance has often been associated with Asian cultures where there is a perception of reliance on rote learning and an expectation of being passively taught. These tendencies may be a result of students previous educational experience that often combined didactic teaching and passive learning. Furthermore, these tendencies may be compounded by academics' believing that students have a preference for passive rote learning, structuring their teaching and assessment accordingly (Kember 2000).

Kember (2000) uses evidence from over 90 action research projects to disprove the common assertion that Asian students prefer passive learning and resist teaching innovation. While undertaking collaborative activities may be more difficult when students are not being taught in their primary language, Kember reports that students will adjust and engage in collaborative learning activities if given the opportunity.

The University of Technology, Sydney teaches an undergraduate engineering science program in Hong Kong, where subjects are delivered in block mode. Students have typically undertaken previous engineering studies often at a local polytechnic. The authors had found it initially difficult to motivate students to participate in collaborative learning activities and in particular those that involved them using their own judgement or critical analysis. In this paper, we discuss the results from an evolutionary research investigation examining the effectiveness of integrated collaborative peer learning activities to address this issue.

Background

A number of researchers and government-sponsored reports (Hargreaves (1997), Jones (2003) Markes (2006), & Chung et al (2008)) discuss a gap between skills typically developed in engineering education and a range of skills required for professional practice such as communication, critical thinking, leadership, teamwork skills and life long learning capabilities. This requires not only considering what is taught but how it is taught (Hargreaves, 1997). Workplace learning and certainly practice is often collaborative (Littlejohn, Margaryan & Milligan (2009). It follows that students' preparation for entering this environment should include opportunities to practise collaborative learning with their peers.

Collaborative learning is also attractive from the perspective of the constructivist model of learning (Jawitz and Case, 2009). Hagstrom (2006) argues that "…contexts for new knowledge construction include a blending of people … that gives rise to differences in interpretation and provides the occasion for the construction of new knowledge….If educators simply tell students what they need to know, they encourage reliance on memorization of facts. For students to make cognitive changes, the learning experience must begin with each student becoming aware of his or her own present understanding" (Hagstrom, 2006, p28). Dana (2007) reports that compared to traditional competitive or individualistic learning environments, benefits of collaborative tasks such as small group or team based learning include higher student achievement, greater use of higher level reasoning and critical thinking skills, more positive attitudes toward the subject matter and satisfaction with the class, and better interpersonal relationships among students and between students and instructor.

While few would argue the benefits of collaborative learning these benefits are not automatic. Thoughtful design including scaffolding to motivate desired approaches and behaviour is required. Many students have suffered through poorly designed and managed collaborative activities as articulated by the following student comment *"I've attended tutorials with tutors … telling students to form groups and discuss the readings. … Hearing other students' views on topics they don't .understand results in zero learning."* (Stevens 2011).

The subject Design Fundamentals taught in Hong Kong was chosen as the vehicle to conduct the reported trials as students had previously had difficulty with the subject material that required them to apply critical thinking and judgement. In 2008 we redesigned the subject using collaborative learning to enhance critical thinking in line with the previously mentioned studies. A secondary aim was to promote a culture of learning in students as opposed to focusing on passing a series of assessment activities. Care was taken to design collaborative activities that encourage students to be 'engagers' (focused on achieving a better understanding of the subject material) rather than avoiders (focused on minimising the amount of work individual students had to do) (Yan 1996). The subject has two summative assessment components: a collaborative multistage design project and summative exam/quizzes each worth 50%. The lectures are delivered in a block mode over four consecutive days. While changes were made to both the project, method of summative assessment and the in-class activities in this paper we mainly restrict our discussion to the latter.

To investigate the effects of including collaborative learning activities in 1st semester 2010 we conducted the first cycle of the research reported in this paper (Willey & Gardner 2010). In this semester students were encouraged to test their understanding through interactive collaborative tutorial problem solving on large sheets of paper. Groups then reported to each other, discussing each other's solutions and approach. The teaching academic then discussed the topic, addressed any outstanding issues and introduce the students to further activities requiring higher level engagement and understanding. Subsequently students tested their knowledge on each topic through a series of summative quizzes that were initially taken individually and then collaboratively using the Immediate Feedback Assessment Technique (IF-AT) cards (http://www.epsteineducation.com/home). The end of session summative assessment was achieved through the combination of an individual followed by a collaborative examination.

While most students reported higher engagement, understanding and increased ability to demonstrate the subject learning outcomes we found that some students could only demonstrate this understanding in a collaborative environment. That is, these students appeared to have what we termed "*collective ability*". As part of the collaborative team they were strong contributors who appeared to understand the subject learning outcomes. However, without the support of their peers, gaps in their understanding became evident. Often groups containing these students were characterised by the group exam mark being considerably higher than the best individual mark achieved by the group members. On closer investigation, we theorised that this phenomenon had two main components. Firstly, the complex tutorial problems were mostly solved collaboratively hence not necessarily providing students with the opportunity to recognise the gaps in their own individual learning. Secondly, the quizzes generally did not contain problems as complex as those in the final exam and hence did not afford the students the opportunity to test their higher level knowledge.

In response to these findings in the second cycle in 2nd semester 2010 the summative quizzes were replaced them with a number of in-class formative assessments. We chose to make these assessments formative as we wanted students to focus on using these activities to push their learning boundaries, make mistakes, identify gaps in their learning and have these addressed by their peers and if necessary the teaching academic. Often with summative tasks students approach them, with some justification, strategically to achieve the best mark at the expense of learning (eg they may choose to divide up work, or move on without having their knowledge gaps addressed to save time).

The formative assessment was conducted after the previously described collaborative tutorials. The assessment consisted of a series of complex problems (one covering each of the six major topics) that were typically harder than they would encounter in their final examination. After an initial attempt to solve these problems independently, students were encouraged to use their course notes and other material to solve them. They were instructed to use the exercises to identify gaps in their understanding/learning. At the end of each day students' were encouraged to go home and study to address these learning gaps. On the following day students formed into groups and repeated the exercises collaboratively. The aim of the group was to not only answer the questions but to particularly focus on helping team members address their learning gaps. Finally, the course instructor led a discussion to resolve any outstanding issues.

While student learning improved as suggested by their grades (figure 1), a close inspection of their final examination work booklets revealed that the change had not fully addressed the issue of *"collective ability".* Again we are able to identify areas where students appeared in the collaborative activities to have in-depth understanding but were unable to demonstrate this individually. Students did however report that introducing them to harder more complex problems earlier in the subject provided a strong foundation for learning enabling them to recognise learning gaps that may not have been identified if simple less complex problems had been undertaken.

After discussing this problem with students we identified two issues. Firstly, being a design subject problems are often open-ended, context dependant with multiple solutions. It is not easy for students to find problems to help them learn without some sort of discourse and feedback to discover the strengths and weaknesses of their answers. Secondly, while we had given students an opportunity to identify and address gaps in their learning, we had not provided them with a subsequent opportunity to test their learning before the final exam. One could argue that this is the students' responsibility butgiven both the compressed nature of the block mode delivery and the required feedback discourse previously described we believe we needed to do more to assist students with this process (Willey and Gardner 2011).

In this paper we report on the effectiveness of changes to the collaborative peer learning process to address the issue of *"collective ability"*, and determine the willingness of students (in this case Asian students) to engage in collaborative learning.

Method

In 1st semester 2011 we decided to expand the collaborative learning activities by redesigning the interactive collaborative tutorials to include at least three complex problems in different contexts for each of the six major topics in the subject. Students again went through the learning cycle of first attempting the problems independently, then using their course notes, then collaboratively in groups, concluding with the course instructor leading a discussion to resolve any outstanding issues and introduce questions that expanded the problem and tested students' understanding. There was a deliberate focus on students using these activities to identify gaps in their understanding/learning and having them addressed by their peers. Students were constantly reminded that *"mistakes compress learning"* and that if they are not making mistakes then they are not discovering what they do not know.

Students then repeated the process with another problem that applied the learnt principles in a different context. To make class time available for this iterative learning approach we had students complete more pre-work outside of class. Mazur uses a similar approach in his Peer Instruction methods (Crouch & Mazur (2001)) however, here we use more complex problems, take more time and reapply the principles in a different context.

These activities were followed by a formative assessment on each of the six major topics. Students initially completed these assessments individually (under formal exam conditions, closed book, separate desks etc) and then collaboratively. Again, we chose to make these assessments formative as we wanted students to focus on learning. Hence, in summary the process consisted of:

1. Collaborative tutorials: at least three complex problems on each topic set in different contexts that students attempted initially individually then subsequently collaboratively.
2. Formative assessment conducted individually under exam conditions then collaboratively
3. Final summative examination

We theorised this approach would address the *"collective ability"* problem by allowing students to individual test their ability in different contexts after each collaborative activity. Then subsequently have any rediscovered or newly identified learning gaps addressed by their peers. During each stage of the formative assessments students were asked to keep a record of how many times they realised they did not understand something and how often these issues were addressed by the explanations of their peers.

Additionally these activities were evaluated using a combination of a survey instrument, focus group, observations and video analysis. The survey instruments containing a series of simple answer and free response questions. Attention was paid to writing low-inference questions. Students were handed the first survey instrument at the start of the subject which they completed throughout the activities. The second survey was completed at the end of the block mode after the final examination. The focus groups were conducted by two independent research assistants. Both had previously tutored the subject in Australia but were not involved with the subject in Hong Kong. The assistants had an opportunity to read the survey responses before the focus groups enabling them to explore in more detail the most common issues. One of these assistants was present and made observations throughout the entire block mode.

Results / Discussion

The class consisted of 14 students all of whom volunteered to participate in the study in accordance with the conditions required for ethics approval (to remain anonymous etc).

The collaborative tutorials provided students with the opportunity to work through at least three complex problems on each of the six major topics before attempting their formative assessment. Despite this, students still reported identifying gaps in their learning (on average 58% 1 or 2 gaps, 15% 3 or more gaps) when undertaking the formative assessments individually and discovering even more gaps in their learning (on average 54% 1 or 2 gaps, 10% 3 or more gaps) when undertaking them collaboratively. These results reflect that as students understanding improved the more they realised they did not know. Perhaps more importantly, as a result of their peers explanations most students reported having nearly all of these gaps addressed.

Students commented that while this approach initially made them nervous (being different from the more passive class experience than they were used to) it changed the way they learnt and they were genuinely excited about focusing their efforts on learning rather than the final exam.

"I would prefer to learn something that I don't fully understand rather than get a good mark without learning anything" (student free response comment).

When asked to compare their previous experience in other subjects respondents reported that in their opinion the collaborative approach significantly improved their understanding, learning experience and the amount they learnt. Furthermore, on average respondents attributed the majority of this increased learning to talking to their peers in groups.

Students reported being focused on addressing gaps in their learning as opposed to their previous tendency to focus on getting the right answer. Commenting that collaborative learning *"changed how I learn"* and being *"surprised how much I learnt".* The high engagement supports Kember's (2000) finding that students including those from Asia will adjust and enthusiastically engage in collaborative learning if given the opportunity. However, in the author's opinion to get the best results one must ensure that the summative assessment activities encourage such engagement. For example, in the reported trial all respondents agreed that to do well in the subject they had to understand the concepts rather than memorising methods and that participation in the collaborative activities was good preparation for their exam.

When asked how the collaborative activities helped their learning students reported, *"the brainstorming"* in the groups *"helped reduce ... gaps", "my group members helped me to solve what I don't understand"*(sic) and I improved my learning by *"listening to the other team members ...explanation"*. Students reported that most of the time group members had different levels of understanding on different topics, enabling them to move from being a teacher to being taught. Furthermore, frequently students *"understood something in a different way"* enabling group members to reach a deeper understanding of the subject material by being able to explain something from more than one perspective.

Numerous students commented that the collaborative activities gave them an opportunity to discuss their understanding in their own language. This in turn identified areas of comprehension that needed to be clarified by the instructor. A number of students reported that they would have liked an additional opportunity to discuss these problems with their peers after the instructor had *"closed the loop"* to confirm their understanding.

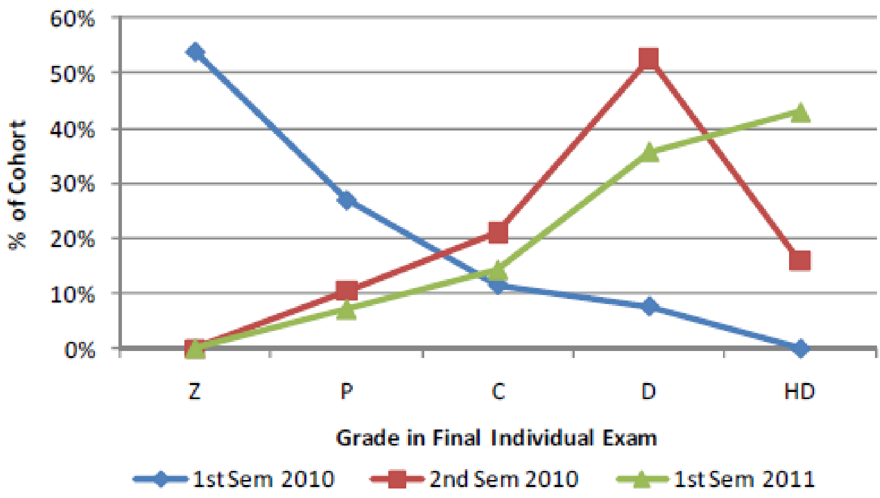

Figure 1: Final exam results for reported cycles

Our decision to make the assessment activities formative was supported by approximately two thirds of the students agreeing that if the activities had been summative it would have changed their approach from focusing on *"addressing gaps in our learning to getting the right answer*". Others said *"it would put us under pressure to agree on an answer"* rather than finding out where our opinions and understanding differed. Several students reported that being formative allowed them *"to enjoy the activities and concentrate on learning".*

While not a definitive measure a comparison of individual exam results for the three reported cycles shows an increasing trend in student achievement (see figure 1, Z unsatisfactory, P Pass, C Credit, D Distinction, HD High Distinction). This supports the evidence from our observations, student opinions and examination of student work booklets that students were more capable of demonstrating the subject learning outcomes individually. Hence, the combination of iterative collaborative learning activities and formative assessments successfully addressed the issue of *"collective ability"*.

While students were mostly positive about the reported changes, there were some complaints about the collaborative activities, the most common being:

- students would have liked *"more class time for collaborative activities"*
- on occasions no one in their group was confident they understood a particular issue so they were unsure of the correct answer until the discussion with the instructor
- and *"sometimes I learnt the wrong thing from my team members"*

Future Directions

In the next cycle of this study we will increase the pre-class activities and further integrate collaboration by sharing anonymously online student's answers and explanations to a series of introductory questions on each topic. This will enable more class time to be devoted to collaborative activities.

Conclusion

The formative assessments and associated collaborative activities were successful in addressing the issue of "collective ability", promoting higher engagement, understanding and increased student's ability to demonstrate the subject learning outcomes. Furthermore, the formative nature of the activities freed students from the burden of strategically collecting marks, allowing them to focus on learning and enjoy the activities. We found that despite some initial apprehension students enthusiastically engaged in collaborative learning activities. Our findings support Kember's that students including those from Asia will adjust and enthusiastically engage in collaborative learning if given the opportunity.

References

Chung W., Stump G., Hilpert J., Husman ., Kim W., & Lee J. (2008) Addressing Engineering Educators'Concerns:Collaborative Learning and Achievement. *38th ASEE/IEEE Frontiers in Education Conference* October 22 – 25, Saratoga Springs, NY.

Crouch, C. and E. Mazur (2001). "Peer instruction: Ten years of experience and results." American Journal of Physics Volume 69(9): 970-977.

Dana S. (2007) Implementing Team-Based Learning in an Introduction to Law Course. *Journal of Legal Studies Education*. Vol. 24, issue 1. pp.59-108

Hagstrom F. (2006) Formative Learning and Assessment *Communication Disorders Quarterly*; Fall 2006; Vol. 28, no.1, pp. 24-62.

Hargreaves D.J., (1997) Student learning and assessment are inextricably linked. *European Journal of Engineering Education*; Vol. 22, No. 4; pp. 401- 409.

Jawitz & Case, (2009) Communicating your findings in engineering education: the value of making your theoretical perspective explicit. *European Journal of Engineering Education*, Vol. 34, No. 2, pp.149- 154

Jones M. (2003) The renaissance engineer: a reality for the 21st century? *European Journal of Engineering Education*. Vol. 28 No. 2 pp. 169-178.

Kember, D., (2000) Misconceptions about the learning approaches, motivation and study practices of Asian students. Higher Education, 40 (2000), 99-121.

Littlejohn A., Margaryan A. & Milligan C. (2009) Charting Collective Knowledge: Supporting Self-regulated Learning in the Workplace. *Proceedings of the Ninth IEEE International Conference on Advanced Learning Technologies*. 15-17 July, Riga, Latvia. pp. 208 - 212

Markes I. (2006) A review of literature on employability skill needs in engineering. *European Journal of Engineering Education* Vol 31. No. 6 pp. 637-650

Stevens M (2011) *Nothing Learnt*, Letter to the editor Sydney Morning Herald May 26, 2011

Trevelyan J. (2007) Technical Coordination in Engineering Practice. *Journal of Engineering Education.* Vol. 93, No. 3, pp. 191-204.

Willey K & Gardner A. P. (2010) "Collaborative peer learning to change learning culture and develop the skills for lifelong professional practice" Proceedings of the 2010 Australasian Association of Engineering Education (AaeE) Conference, Sydney, Dec 2010.

Willey and Gardner (2011), "Change Learning Culture with Collaboration", submitted to SEFI European Society for Engineering Education Annual Conference Lisbon 2011

Yan L (1996) "Learning outside the classroom: students involvement in peer group work transition to active learning" proceedings of the Second Pacific Rim Conference on the first year in higher education, Centre for the study of higher education, University of Melbourne.

Copyright statement

Are we accidentally misleading students about engineering practice?

James Trevelyan
James.Trevelyan@uwa.edu.au
The University of Western Australia, Perth
Australia

Abstract: *Educators who identify themselves as engineers see engineering practice in terms of the engineering they 'perform'. Depending on their background and interests, they may see themselves in the engineering science, design, or management systems movements as observed by Rosalind Williams. Texts written by and for engineering educators help to reveal their ideas of practice. Content analysis of five major texts from a perspective shaped by extensive ethnographic investigations of engineering practice leads to a detailed description of the difference between an academic setting and a commercial setting in which most graduates seek their careers. Many important aspects of commercial practice are either missing from the texts, or are portrayed in a way that could mislead students. This paper discusses two aspects of difference: uncertain information in engineering and the connection between engineering and economic value. This analysis, with further work, could help with the design of authentic learning experiences to help engineering students to bridge the gap between theory and practice more easily.*

Educators' notions of engineering

Engineering practice is a generalized concept embracing the daily work of engineers: the term praxis captures the essence. For the purpose of this paper, engineers are people for whom their primary occupational identity concerns an aspect of engineering.

Engineering educators, who help young people construct their identity as engineers through university or college education, practice engineering just as much as engineers who work in different settings: consultancies, manufacturers, construction firms, transport enterprises, defence forces etc. Difficulties arise, however, for the majority of their graduates who emerge from university or college and practice in a different setting. When graduates experience engineering as practiced in most industries other than research and education, they can feel disoriented. "When I started, I felt completely unable to do anything useful," one graduate reported to the author recently. Martin and her colleagues (2005) described how graduates found they were not well prepared to work with other people and lacked practical skills, factors widely reported in many other similar studies (e.g. Spinks, Silburn, & Birchall, 2007). In Australia, most companies assert that it takes up to 3 years for a novice engineer to become reasonably productive in a commercial context. This paper addresses the transition into industrial practice: an experience that can be discomforting for many novices and employers alike.

While many would argue that a university education should not be constrained by the training requirements of a particular profession, such as engineering, most educators would like their students to experience a successful start in their chosen careers. Medical educators have embraced extensive clinical practice and situate themselves in, or close to teaching hospitals to promote the successful transfer of academic learning to practice. On the other hand engineering educators have to prepare their students for a much greater diversity of career settings, and real engineering settings are often too large, expensive or hazardous to accommodate within a teaching institution. Therefore, the authenticity of learning experiences will strongly influence the transition into practice for most graduates. This authenticity will depend, to a large extent, on the ability of educators to design authentic learning tasks.

In the ethnographies by Stevens and his colleagues looking at engineering educators (2008), and by Tonso looking at student teams (2006), we can see how engineering education shapes the 'accountable disciplinary knowledge', skills, values attitudes and identities as students grow into "engineering". Educators assume the responsibility for appropriately shaping this developmental process, and their notions of engineering practice can have a profound effect on their students' beliefs.

Educators subscribe to divergent notions of engineering practice, shaped by their own pathways and experiences. Reporting an ethnographic study in an American mechanical engineering department, Quinlan described how 'design division' faculty saw engineering as a creative discipline through which new products are developed, whereas other faculty saw engineering in terms of developing scientifically validated theories and knowledge. She described how these different views shaped their teaching, disputes on education priorities, and hence the experiences of students in their classes. Sheppard and her colleagues (2006) provided further insights in a study that explored perceptions of about 300 faculty and students based on semi-structured interviews and focus groups in seven major American universities. These perceptions centred on problem solving based on expert theoretical and contextual knowledge, supported by a combination of formal processes and creativity.

Pawley (2009) reviewed a series of reflections on the nature of engineering and engineering beliefs among the engineering education research community between 2005 and 2007. In an ethnographic study based on extensive interviews in an American engineering school, she found that engineering faculty valued different ideas and conclusions and that calls to reshape the discipline were unlikely to influence their teaching (p309). She perceived three 'universalized disciplinary narratives': engineering as applied science and mathematics, engineering as solving problems, and engineering as making things. She questioned whether calls to "Change the Conversation" about engineering (National Academy of Engineering, 2008) would have any impact unless faculty share the messages with students and model new behaviours. Williams (2003) distinguished three diverging movements within academies: engineering science, design, and management systems, the latter two nourished from pragmatic commercial interests.

In leading contemporary engineering schools there is often an overwhelming representation of engineering technology and science researchers among the faculty. Quinlan's observation that many faculty see engineering in terms of "scientific process of developing new theories from which the viability of new designs can be tested" reflects the research identity that characterises these schools. In other words, engineering faculty subscribe to a generalised view of engineering expressed in terms of the engineering that they practice themselves.

Many students graduating from engineering schools soon encounter a very different world when they start working in a commercial or defence-related engineering environment. The difference would probably be just as great had they been educated in a commercial context and arrived for work in a research institute. Recent studies have clarified some of the differences (e.g. Anderson, Courter, McGlamery, Nathans-Kelly, & Nicometo, 2010; Domal, 2010; Faulkner, 2007; Korte, Sheppard, & Jordan, 2008; Trevelyan, 2007, 2010; Vinck, 2003). Differences between engineering practice and students' educational experiences have provided a recurring theme in recent engineering education debates.

The relative scarcity of systematic research on engineering practice (Barley, 2005; Trevelyan & Tilli, 2007) makes it difficult for educators who would like to design learning experiences to enable their graduates to manage the transition into commercial engineering contexts more easily. However, it has not been easy to sustain engineering practice research in institutions where the dominant research discourse is engineering science, as engineering education researchers are all too well aware. Employing faculty with substantial industry experience is one way to promote authentic learning experiences. This is not easy to sustain, however, in a research-led university where research output and grants are the main measure of career success. More recently, pedagogies such as inquiry-based learning, problem-based learning and project-based learning have been advocated for research-led universities to help students develop attributes and thinking styles more appropriate for industrial practice (Kolmos & Trevelyan, 2010; Savin-Baden, 2007).

Texts

Texts can play a significant part in shaping faculty perceptions about engineering practice, particularly for faculty who work in predominantly teaching institutions educating a larger proportion of the world's engineers. Texts also encapsulate notions of engineering practice held by the authors, so texts written by engineering faculty provide a further means to discern the ideas that shape students' notions of practice.

This paper presents an analysis of five major texts using a framework derived from ethnographic research studies of engineering practice (Trevelyan, 2010).

This study grew out of two fortuitous coincidences. The first arose because the author is contributing to a major curriculum redesign (Trevelyan, Baillie, MacNish, & Fernando, 2010). The new curriculum requires the use of one or more cross-disciplinary introductory texts in an integrated foundation course for all engineering disciplines.

The second coincidence was an on-going research investigation of novice engineers (1-5 years experience) in a consultancy firm. The company management were interested to understand some of the reasons for dissatisfaction expressed by some of their clients. One of the questions included in the semi-structured research interviews was framed around participants' recent work for the firm. All the participants were contributing to reports detailing technical analysis on aspects of clients' plant and equipment. "Please tell us how your work for this report has provided value for your client." Surprisingly, none of the participants could provide a coherent explanation, beyond the notion that clients wanted to pay for the least number of billable hours needed to complete the work. One participant, after a long pause, responded *"Hmm, that's a good question. Solve problems? Make things more efficient, I suppose."* Another replied *"I guess the value of my work is getting results from the field."*

This observation led to more exploratory questions with engineers in different firms, all confirming that it was difficult for them to articulate the value of their work for clients, even for more experienced engineers. While several other interesting "gaps" or misconceptions about aspects of engineering practice emerged from this investigation, the absence of any clear understanding about the value contributed by their work stood out from the rest. Young doctors have few doubts about the value of their work: saving lives and restoring people to health has obvious value. It was puzzling that young engineers had such difficulty explaining why their work could be valuable.

This observation, with others, provided a set of issues to frame the analysis of the texts. Passages from each of the selected texts addressing aspects of engineering practice were compared with evidence on engineering practice collected in the contributing ethnographic studies. In several instances, there was no relevant material in the texts. In other instances, the texts contributed only part of the picture, leaving other parts unstated, suggesting fundamental "hidden" and explicit assumptions in the texts that conflict with research evidence on engineering practice.

The five texts comprise two multi-disciplinary comprehensive introductory texts for foundation studies in engineering, two texts on professional engineering practice intended to complement conventional technical disciplinary courses, and a recent detailed prescriptive text on engineering education design.

1. Holzapple and Reece's comprehensive text (2003) is framed in terms of engineering accounting, a teaching approach that casts the conservation laws (e.g., energy, mass) as simple "accounting" procedures, a unifying concept that facilitates problem-solving in all engineering disciplines. The book was intended to provide first year students with a "solid foundation" for the future coursework. It provides an overview of the engineering profession, introduces engineering skills, and describes fundamental engineering topics, such as thermodynamics, rate processes and Newton's laws.
2. Brockman's text (2009) was inspired by the National Academy of Engineering (2005) report "Educating the Engineer of 2020" to improve the quality of engineering education with three main objectives: understanding what engineering is and how it is practised, developing and applying fundamental engineering skills, and gaining practical design experience as part of a multidisciplinary team. The book advocates the notion that engineering can be fun, is inherently multidisciplinary, that modelling is the key for making good

engineering decisions, and that engineering is more than applied maths and science.

3. Wright's introduction to professional engineering (2002) aims to help students understand the context within which their disciplinary-centred technical skills will be used. The book provides a valuable treatment on the historical development of engineering from a European and American perspective, followed by engineering challenges for 21st century engineers in the industrialized world such as energy, maintenance of public infrastructure, reducing hazardous (nuclear) waste issues and space exploration. Later chapters provide instructive sections on engineering practice, communication, teamwork and ethics.
4. Dowling, Carew and Hadgraft (2009), like Wright, recognised the need for a text to help students develop professional engineering skills. This text provides more detailed instructional source material than Wright's text and includes major sections on problem solving approaches, sustainable development, written and interpersonal communication skills, ethics and project planning.
5. ASCE issued the "Civil Engineering Body of Knowledge for the 21st Century" (2008) to establish a "gold standard" for civil engineering education: a prescription that was intended to set a standard for educators to aspire to reach. Written by a large panel of authors of whom the majority were engineering faculty, the report provides a detailed guidance on desirable outcomes for engineering education.

In this paper, it is only feasible to discuss two issues from this study of the texts in this paper. The first aspect is the notion that the parameters of real engineering problems are seldom fully defined, and are often imprecisely known. As explained below, this is an example of how texts can create implicit assumptions through the ways that they present learning tasks for students. The second stems from the observations reported above, the connection between engineering and value. This is an example of an issue that seems to be completely missing from the texts.

Uncertain information in engineering

Many people characterise engineering in terms of precision and certainty. Recently a banker explained some of the difficulties of economic forecasting to my students: *"All that you know about the answer that you get is that it is wrong. You just don't know how wrong it is. It is very unlike a mathematical equation or an engineering solution when you know that the answer is right. You have to take account of that in your thinking."*

This statement embodies a common misperception about engineering, that engineering problems have known solutions for which one can *"know that the answer is right."* In engineering practice, however, it is rare (and often considered a trivial case) when one can know that the answer is right.

None of the several texts examined discussed the inevitable uncertainties and gaps in the information that engineers use in their work. For example, an engineer can seldom define a precise loading (external forces acting) on a structure in advance. The in-service loading will depend, for example, on how the structure is used and environmental factors that cannot easily be predicted in advance. In many instances, it can be difficult to predict installation and construction loads accurately. While this is well known among practitioners, there was no reference to this reality any of the texts. As a consequence, there is no guidance for students on ways to choose an appropriate loading for design and analysis.

Instead, every sample problem presented in the texts has precisely defined parameters, reinforcing the notion that engineering is based on precisely known information, on objective certainty. Figure 1 illustrates a typical student problem that one could find in an engineering text. In this instance, students might be asked to predict the reaction forces at the two support points in response to the forces shown acting on the beam.

In order to construct a more authentic learning exercise for students, an engineering educator could replace the numbers above the force arrows with question marks. Even some of the length dimensions could be replaced with question marks. The students could be asked to estimate appropriate loads in order to design the beam instead of having the loads defined precisely, given a qualitative description explaining the intended use of the beam.

Initially students might find this kind of problem insoluble. However, the educator can suggest that students examine beams in similar applications to understand how one might estimate the loads they were designed for.

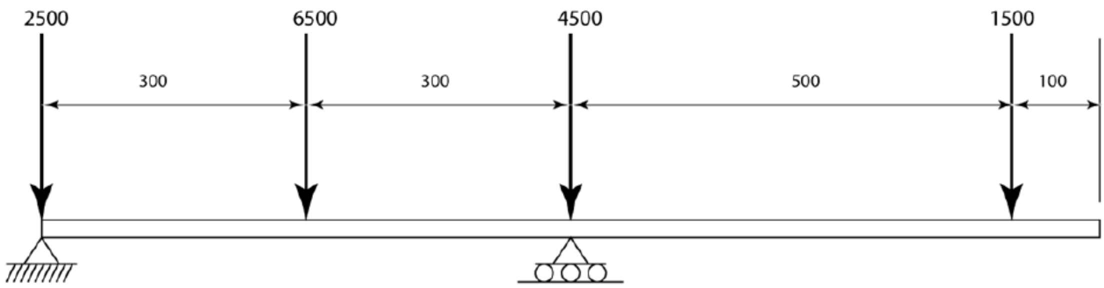

Figure 1: A typical student problem in a foundation course on statics

For example, students could reverse-engineer the building in which they are situated. *"See that beam above you? How much weight do you think it could support without permanent deformation?"* By asking the students to calculate the maximum load that an actual beam in their building can withstand, students can learn useful analysis methods and, at the same time, learn about the typical design loading needed for a specific building application. Students can then learn that existing structures can provide safe models and precedents from which they can deduce appropriate design requirements for new structures.

Connecting engineering with value

Recent work by economists has demonstrated the importance of seeking alignment in the identity and values of the organization, its employees, shareholders and even clients (Akerlof & Kranton, 2005). Major companies operating in contemporary post-industrial societies are obviously seeking economic value, but also value safety for both the community and employees, and also value respect for social, governance and environmental values.

The fact that organisations employ engineers suggests that engineers can contribute value for clients as well as wider social benefits. Yet, all five texts seem to present this as an implied assumption. None explain how the technical work performed by engineers creates value for their clients. Two of the texts (Holzapple & Reece, Wright) briefly refer back to a single quotation “Engineers can do with one dollar what any bungler can do with two dollars” quoted from Wellington (1887) without further explanation. A recent UNESCO report advocating the positive role of engineering in human development also demonstrates similar assumptions, and does not include detailed explanations on how engineering can make valuable contributions (Marjoram, Lamb, Lee, Hauke, & Garcia, 2010).

How does value arise from engineering practice, in the form of real social or economic benefits? In several studies of engineering practice, little evidence has emerged of engineers with significant hands-on participation in making the products that arise from their work or delivering utility services (Trevelyan, 2007, 2010; Trevelyan & Tilli, 2008). The value of their work, therefore, arises indirectly, through the work of other people.

For example, in deciding how to design a bridge beam, an engineer has to predict the most severe loading (external forces acting) on the beam. Standards and codes often provide guidance on how to do this, and often require a factor of safety. A factor of safety of 2, for example, means that the beam must be designed to withstand twice the most severe anticipated loading. Taking the time to predict loads more accurately, to design the beam with more ingenuity to carry a higher load, more care with material selection, procurement, manufacture, assembly, and erection may allow lower safety factors to be used. The resulting beam is lighter, consumes less material, requires less supporting structure, is easier to transport and erect on site. This is how better prediction and more care in organizing, planning and monitoring production can facilitate large cost reductions. This an example of a direct cost saving and many (but not all) engineers can explain the value of such savings.

In the research studies in different countries, few engineers seemed to be aware of indirect costs such as opportunity costs or lost production resulting from equipment failures (Hägerby & Johansson, 2002). Even fewer engineers, only two in the entire series of studies, explained a link between reducing uncertainty and added value, as explained by Browning (2000). Several interviews provided evidence that engineers were making costly decisions for their employers because they were unaware of this link.

Reducing uncertainties also can reduce financing costs. An investment with less uncertainty in financial returns can attract more conservative investors who will provide more finance at a lower interest rate and a longer payback time. This can make a big difference in the financial viability (and therefore value) of an engineering project. However, this simple connection between uncertainty and financial value seems to be elusive for practising engineers (Crossley, 2011). As a senior mining executive stated in response to some of our recent research results, *"Our engineers don't understand the business imperative of this organisation. They simply don't get it and it frustrates me immensely."* Others refer to this issue as 'lack of commercial awareness'.

All this analysis can demonstrate is that there is a possible connection between the absence of explanations on the economic and social *raisons d'être* of engineering in major texts and a significant limitation that restricts the ability of engineers to understand and explain the value of their work. Labour market economics provides a causal link between "marginal product", the financial value that an employee creates for an organization from their labour, and remuneration. Engineering work is highly autonomous: most engineers have a large influence in deciding what they do each day. It is possible that, if engineers could understand and explain the value they create, that they could improve the value created from their work as suggested by expectancy-value theory and therefore provide greater rewards for their employers and consequently gain significantly higher remuneration. Understanding non-financial values could bring similar benefits. Further work is needed to confirm this possibility.

Concluding Remarks

Analysis of the five texts has revealed, so far, about 25 significant aspects of engineering practice relevant to all engineering disciplines that are either not mentioned or presented in ways that can lead students to form inappropriate assumptions. These include aspects of teamwork and communication in engineering practice, engineering knowledge, significance of hands-on practical work, uncertainties inherent in human behaviour, engineering problem descriptions, analysis and design approaches, standards, and computational tools. All these assumptions are reinforced in one way or another, unintentionally, in ways that lead to misunderstandings about engineering practice among novices. Most of these misunderstandings are evident from recent on-going studies of novice engineers in their work environments, and some can also be seen in published literature. They also help to explain some of the observations on student conceptions of engineering found by (Dunsmore, Turns, & Yellin, 2011).

This analysis contributes a more detailed insight on gaps between engineering education and practice. The value of this analysis is that it suggests ideas for engineering educators to create more authentic practice tasks that reinforce learning of engineering concepts. This work also highlights the need for many more detailed engineering workplace observation studies to inform engineering educators: such studies are valuable capstone research projects for engineering students (e.g. Crossley, 2011). The results would almost certainly help students cross today's divide between education and practice more easily, with the possibility that they would be significantly more productive as engineers.

Educators need to heed this advice to avoid future accusations that they deliberate mislead their students.

Acknowledgements

The author would like to thank his colleagues and students for contributions to this research and many valuable suggestions. In particular, conversations with Alan Kerr, Chief Mechanical Engineer in the WorleyParsons Group, led to some of the ideas presented in this paper. The author would also like to acknowledge the contributions of about 150 engineers (and their employers) in Australia, Pakistan and India who contributed to studies leading to this research as interview participants and by letting the author and his students observe them at work.

References

Akerlof, G. A., & Kranton, R. E. (2005). Identity and the Economics of Organizations. *The Journal of Economic Perspectives*, 19(1), 9-32. doi: DOI: 10.1257/0895330053147930

American Society of Civil Engineers. (2008). Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future (2nd ed., Vol. 2008). Reston, Virginia, USA: ASCE Committee on Academic Prerequisites for Professional Practice.

Anderson, K. J. B., Courter, S. S., McGlamery, T., Nathans-Kelly, T. M., & Nicometo, C. G. (2010). Understanding engineering work and identity: a cross-case analysis of engineers within six firms. *Engineering Studies,* 2(3), 153-174. doi: DOI: 10.1080/19378629.2010.519772

Barley, S. R. (2005). What we know (and mostly don't know) about technical work. In S. Ackroyd, R. Batt, P. Thompson & P. S. Tolbert (Eds.), *The Oxford Handbook of Work and Organization* (pp. 376-403). Oxford: Oxford University Press.

Brockman, J. B. (2009). *Introduction to Engineering: Modelling and Problem Solving.* Hoboken, New Jersey, USA: John Wiley.

Browning, T. R., Deyst, J. J. J., Eppinger, S. D., & Whitney, D. (2000). *Complex System Product Development: Adding Value by Creating Information and Reducing Risk*. Paper presented at the INCOSE, Minneapolis, Minnesota USA.

Crossley, M. (2011). *Business Skills in Engineering Practice*. Bachelor of Engineering, The University of Western Australia, Perth.

Domal, V. (2010). *Comparing Engineering Practice in South Asia and Australia*. PhD PhD, The University of Western Australia, Perth.

Dowling, D. G., Carew, A., & Hadgraft, R. G. (2009). *Engineering Your Future: Wiley*.

Dunsmore, K., Turns, J., & Yellin, J. M. (2011). Looking Toward the Real World: Student Conceptions of Engineering. *Journal of Engineering Education*, 100(2), 329-348.

Faulkner, W. (2007). Nuts and Bolts and People. *Social Studies of Science*, 37(3), 331-356. doi: DOI:10.1177/0306312706072175

Hägerby, M., & Johansson, M. (2002). *Maintenance Performance Assessment: Strategies andIndicators*. MSc, Linköping Institute of Technology, Linköping.

Holzapple, M. T., & Reece, W. D. (2003). *Foundations of Engineering* (2nd (International Edition) ed.). New York, USA: McGraw-Hill.

Kolmos, A., & Trevelyan, J. P. (2010). *Real Engineering – Bringing Practice into the Curriculum* Paper presented at the Educating Engineering Leaders - An Invitation Symposium, Imperial College, London.

Korte, R. F., Sheppard, S. D., & Jordan, W. (2008, June 22-26). *A Qualitative Study of the Early Work Experiences of Recent Graduates in Engineering*. Paper presented at the American Society for Engineering Education, Pittsburgh.

Marjoram, T., Lamb, A., Lee, F., Hauke, C., & Garcia, C. R. (Eds.). (2010). *Engineering: Issues, Challenges, Opportunities for Development.* Paris, France: United Nations Educational, Scientific and Cultural Organization.

Martin, R., Maytham, B., Case, J., & Fraser, D. (2005). Engineering graduates' perceptions of how well they were prepared for work in industry. *European Journal of Engineering Education,* 30(2), 167-180.

National Academy of Engineering. (2005). Educating the Engineer of 2020: Adapting Engineering Education to the New Century Retrieved April 24, 2006

National Academy of Engineering. (2008). *Changing the Conversation: Messages for Improving Public Understanding of Engineering*. Washington, DC: National Academy of Engineering.

Pawley, A. L. (2009). Universalized Narratives: Patterns in How Faculty Members Define "Engineering". *Journal of Engineering Education,* 98(4), 309-319.

Savin-Baden, M. (2007). Challenging Models and Perspectives of Problem-Based Learning. In E. De Graaff & A. Kolmos (Eds.), *Management of Change: Implementation of Problem-Based and Project-Based Learning in Engineering* (pp. 9-30). Rotterdam / Taipei: Sense Publishers.

Sheppard, S. D., Colby, A., Macatangay, K., & Sullivan, W. (2006). What is Engineering Practice? *International Journal of Engineering Education*, 22(3), 429-438.

Spinks, N., Silburn, N. L. J., & Birchall, D. W. (2007). Making it all work: the engineering graduate ofthe future, a UK perspective. *European Journal of Engineering Education,* 32(3), 325-335. doi: DOI: 10.1080/03043790701278573

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D. M. (2008). Becoming an Engineer: Toward a Three Dimensional View of Engineering Learning. *Journal of Engineering Education*, 97(3), 355-368.

Tonso, K. L. (2006). Teams that Work: Campus Culture, Engineer Identity, and Social Interactions. *Journal of Engineering Education*, 95(1), 25-37.

Trevelyan, J. P. (2007). Technical Coordination in Engineering Practice. *Journal of Engineering Education*, 96(3), 191-204.

Trevelyan, J. P. (2010). Reconstructing Engineering from Practice. *Engineering Studies,* 2(3), 21.

Trevelyan, J. P., Baillie, C., MacNish, C., & Fernando, T. (2010, December 6-8). *Designing an Integrated Engineering Foundation Course.* Paper presented at the Australasian Association for Engineering Education Annual Conference, University of Technology, Sydney.

Trevelyan, J. P., & Tilli, S. (2007). Published Research on Engineering Work. *Journal of Professional Issues in Engineering Education and Practice,* 133(4), 300-307.

Trevelyan, J. P., & Tilli, S. (2008, June 20-22). *Longitudinal Study of Australian Engineering Graduates: Preliminary Results*. Paper presented at the American Society for Engineering Education Annual Conference, Pittsburgh.

Vinck, D. (Ed.). (2003). *Everyday Engineering: An Ethnography of Design and Innovation*. Boston: MIT Press.

Wellington, A. M. (1887). *The Economic Theory of the Location of Railways*. New York: John Wiley.

Williams, R. (2003, January 24). Education for the Profession Formerly Known as Engineering, *The Chronicle of Higher Education*, p. B12.

Wright, P. H. (2002). *Introduction to Engineering* (3rd ed.). Hoboken, New Jersey, USA: Wiley & Sons.

Copyright statement

Teaching practices of engineering faculty: Perceptions and actual behavior

Cynthia J. Finelli
cfinelli@umich.edu
University of Michigan, Ann Arbor, MI,
United States of America

Shanna R. Daly
srdaly@umich.edu
University of Michigan, Ann Arbor, MI,
United States of America

Abstract: *In this paper, we present our study of engineering faculty teaching practices, focussing especially on faculty perceptions and their actual behavior. This is part of a larger, institutional-change-based effort to motivate changes in classroom practices at our College of Engineering to better support a diverse student body.*

Introduction and Context

Ample research demonstrates that faculty teaching practices can improve student learning, engagement, and interest in engineering (e.g., Prince, 2004; Seymour & Hewitt, 1997; Smith, Sheppard, Johnson, & Johnson, 2005; Tobias, 1990), and many of these practices have been shown to be especially effective for educating a diverse student body (Prince, 2000; Seymour & Hewitt, 1997). In spite of this evidence, though, translation of research to actual teaching behavior has been slow at many institutions (Friedrich, Sellers, & Burstyn, 2009), including our own College of Engineering.

We assert that institutional change initiatives are necessary to accelerate this transition from research to practice. We further believe that these initiatives will be more effective if they are (1) grounded in research about successful faculty teaching practices, (2) integrated with local evidence regarding institutional context, student perspectives, and faculty perceptions and behavior, and (3) informed by theories of learning, faculty development, and institutional change. At University of Michigan (U-M), we have initiated research – based on these premises – to motivate faculty to change their teaching practice. Here, we report the outcomes of one phase of our research focused on understanding the current teaching practices of our faculty. Specifically, we investigated engineering faculty perceptions of their own teaching, we characterized their teaching practices through both faculty self reports and through objective classroom observations, and we explored the connections between them.

Research Questions

Our study was guided by the following research questions:

- What are engineering faculty's perceptions of their teaching practices?
- What are engineering faculty's actual classroom practices?

    - What portion of class time includes faculty and student questions and answers?
    - What portion of class time includes active learning?
- How do engineering faculty's perceptions compare with their behavior?

The answers to these research questions are important to engineering education as they provide abaseline from which to measure change. They also are an essential first step in the design and implementation of data-driven institutional change at our College of Engineering. The data we collect will allow us to identify research-based effective teaching practices that are presently in use and target those practices that would be best to adopt in our context. Additionally, understanding ways that faculty perceptions of their teaching aligns or does not align with actual practice will allow us to better support the adoption of effective practices.

Theoretical Framework

There are three key components to our evidence-based approach to enabling institutional change (Figure 1). First, we will ground our work in existing research about faculty teaching practices shown to be effective in promoting student engagement and success. Second, we will situate this research in the local institutional context, building on local evidence and understanding the local reward structureand motivators for faculty change. And third, our work will be informed by theories of learning, faculty development, and institutional change. The latter component offers several useful frameworks.

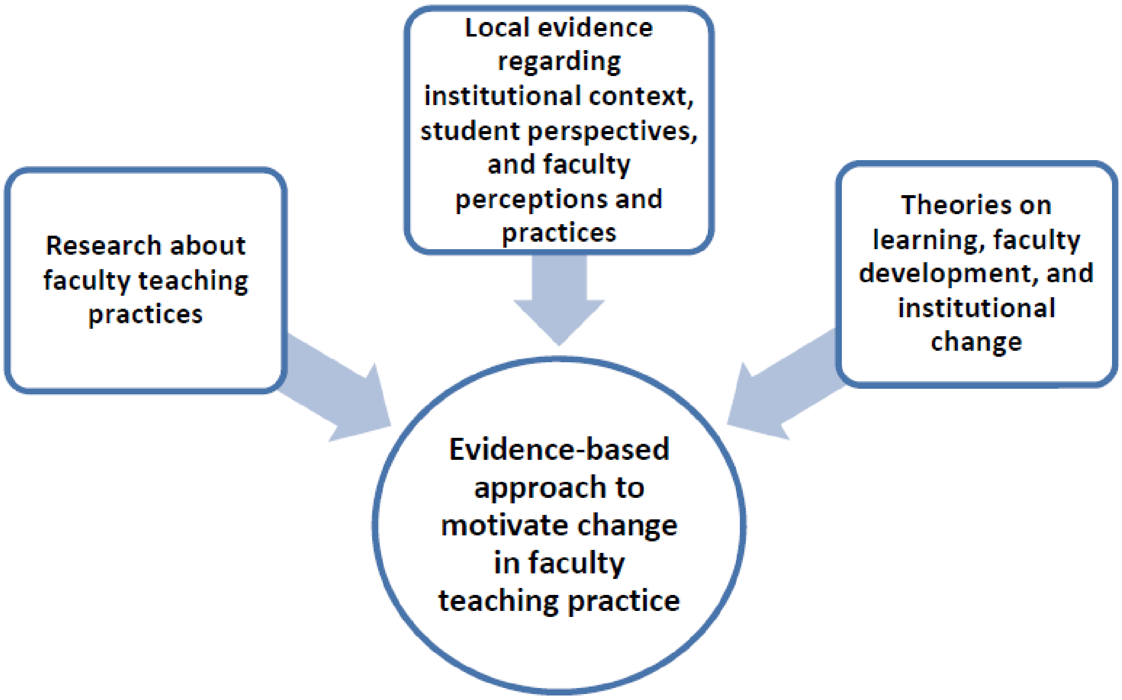

Figure 1. Our Model for Institutional Change

Learning theory research will be important in our efforts. Social constructivism (Wertsch, 1997; Von Glaserfeld, 1989), for instance, supports our framework of using both faculty perceptions and local culture to design a plan for motivating change in faculty teaching practices. We also will employ the principles of the expectancy-value theory (Wigfield & Eccles, 2000) to understand how reward structures and other incentives play a role in faculty's motivations to change their classroom practices.

Faculty development models will guide our efforts, too. The SUCCEED model, developed by eight engineering universities in the Engineering Education Coalition, supports the value of credible engineering faculty delivering workshops on teaching and learning (Brawner, Felder, Allen, & Brent, 2002). That model has been successfully utilized to promote effective teaching in engineering. Other research shows that faculty development programs are more likely to be successful (e.g., participants will learn more and will be more likely to implement the innovation goal of the program) if the programs include a clear set of opportunities and provide sustained contact among participants and leaders (Garet, Porter, Desimone, Birman, & Yoon, 2001; Hawley & Valli, 1999; Luft, 2001).

We also will use multiple models of organizational and institutional change to guide our work. One specific model is the Strategies and Tactics for Recruiting to Improve Diversity and Excellence model, developed at U-M (Stewart, Malley, & LaVaque-Manty, 2007). The model involves a group of respected faculty, led by a content expert, who work together to understand the literature in the field and then create a series of interactive workshops to present strategies to their faculty colleagues. Effective attributes of the workshops include having data and substantive research and providing specific strategies and recommendations for action. Research about the model highlights the importance of respected faculty serving as leaders, faculty synthesizing the empirical research for themselves, and providing credible data (that is valid and can be replicated). Additionally, socialcognition models – such as those described by Morgan (1986) – which relate to the way learning new information may lead to a realization of the need to change (Morgan, 1986), will play an important role in our efforts.

Methods

Selection of Sample

We used a stratified random selection process to identify 30 courses for possible observation during the Winter 2011 term. First we excluded all courses with fewer than ten students enrolled, all graduate courses, and all non-lecture style courses. We then categorized each of the remaining 216 undergraduate, lecture-style courses as small, medium, or large (enrollments of 10-40, 41-74, and 75 or more, respectively) and as introductory or upper division (100- or 200- level and 300- or 400-level, respectively). Finally, we randomly selected 14%1 of all classes in each of five categories (1: small or medium, introductory; 2: large, introductory; 3: small, upper division; 4: medium, upper division; 5: large, upper division).

We invited the primary faculty member for each of the 30 courses to participate in our project (i.e., to allow us to observe one of her/his typical class sessions and to complete an optional online survey), and 26 agreed (three were teaching half-term classes that had ended by the time our project was announced, and one was not interested). Our participants varied by gender (two women and 24 men), faculty rank (six lecturers, three assistant professors, six associate professors, and 11 full professors), and instructional department. Information about the respective courses of the 26 participants is shown in Table 1. At the conclusion of the project, 25 of the 26 faculty participants received a $5 gift card for the local coffee stand (one participant declined the incentive).

Table 1: Course information

Course category	*Participant number*	*Instructional department*	*Students enrolled*
1: Small or medium, introductory	1	Mechanical Engineering	74
	2	Materials Science and Engineering	60
	3	Aerospace Engineering	43
2: Large, introductory	4	Atmospheric, Oceanic, and Space Sciences	75
	5	Atmospheric, Oceanic, and Space Sciences	182
	6	Materials Science and Engineering	189
	7	Biomedical Engineering	91
	8	Mechanical Engineering	92
3: Small, upper division	9	Computer Science and Engineering	31
	10	Biomedical Engineering	24
	11	Atmospheric, Oceanic, and Space Sciences	10
	12	Computer Science and Engineering	31
	13	Atmospheric, Oceanic, and Space Sciences	18
	14	Mechanical Engineering	33
	15	Undergraduate Education	28
4: Medium, upper division	16	Industrial and Operations Engineering	55
	17	Electrical and Computer Engineering	63
	18	Computer Science and Engineering	63
	19	Mechanical Engineering	59
	20	Computer Science and Engineering	48
	21	Industrial and Operations Engineering	44
	22	Materials Science and Engineering	55
5: Large, upper division	23	Aerospace Engineering	80
	24	Chemical Engineering	75
	25	Industrial and Operations Engineering	75
	26	Industrial and Operations Engineering	93

Faculty Perceptions of Teaching

Each participant was invited to complete an optional, online survey. The survey included basic questions about the course s/he was teaching as well as two short research-validated inventories: Trigwell and Prosser's revised *Approaches to Teaching Inventory* (Trigwell & Prosser, 2005) and *Murray's Teaching Behaviors Inventory* (Murray, 1985). We requested that participants complete the survey using the specific class that we selected for observation as the context.

The revised Approaches to Teaching Inventory contains 22 items, eleven that represent a teaching approach that Trigwell and Prosser define as information transmission or *teacher-focused* and eleven that represent a conceptual change or *student-focused* teaching approach. A high score on either scale indicates high importance being placed on that approach to teaching; since the two scales are independent, it is possible for an instructor to score highly on both the teacher-focused and student-focused scales. Participants responded to statements about their teaching approach on the instrument's five-point scale (1=only rarely or never, 2=sometimes, 3=about half the time, 4=frequently, 5=almost always or always).

The Teaching Behaviors Inventory includes 30 separate low-inference teaching behaviors categorized into six meta-behaviors: enthusiasm, clarity, interaction, task orientation, rapport, and organization. For example, "Gives multiple examples" is a specific low-inference behavior in the clarity category. Participants rated the degree to which they implemented each of the 30 low-inference behaviors on a five-point scale (1=almost never, 2=rarely, 3=sometimes, 4=often= 5=almost always).

Classroom Observations

Unlike other research that has studied teaching practice primarily through self-reported behavior, our research also included observational data of the 26 faculty in action. To guide the observations, we used variations of two standard protocols – the *Structured Observation Protocol* from University of Wisconsin-Madison (Hora, Ferrare, & Anderson, 2009) and Murray's (1985) Teaching Behaviors Inventory. The first protocol includes items for the observer to code types of instructional method (including questions asked by faculty and by students), level of student engagement, cognitive activity of students, and material artifacts. We adapted the protocol by separating the first category into types of instructional methods and types of questions, and by adding a category for types of active learning. During the class period, the observer coded faculty behavior in five-minute segments, indicating the number and types of questions asked by faculty and students (and noting whether the former were answered) and the number and types of active learning exercises used by the faculty.

Our second observation protocol includes the same 30 teaching behaviors as the faculty survey. However, we modified the instrument for the observer to mark whether or not the faculty member exhibited each of the 30 low-inference behaviors during the class period (yes/no) and to rate the degree to which the faculty member demonstrated each of the six meta-behaviors (enthusiasm, clarity, interaction, task orientation, rapport, and organization). For the meta-behaviors, we used a simplified three-point scale because it improved consistency and inter-rater reliability in our pilot test. Two professional instructional consultants, each with backgrounds in engineering, were trained to use the observation protocols and to apply them consistently. Participants suggested a "typical" class period to observe, and one of the two consultants completed the observation.

Data Analysis and Results

For this paper, we present our results in three ways. First, we show the self-perceived degree to which each participant believes in a teacher-focused and student-focused approach to teaching (computed by summing the individual items from the Approaches to Teaching Inventory). Second, we study the five-minute segments of our classroom observations to determine whether: (1) the faculty asked no questions, (2) the faculty asked any “non-productive” questions (i.e., questions that were not answered by the students), (3) the faculty asked any substantive questions that were answered by the students and therefore contributed to student engagement, (4) the students asked any substantive questions, and (5) the faculty used any active learning. Then for each class, we compute the percent of segments during which each of these events occured. And third, we compare the faculty’s self-rated use of the six meta-behaviors (enthusiasm, clarity, interaction, task orientation, rapport, and organization; computed by averaging the score on the four to six associated specific behaviors on the 30-item Teaching Behavior Inventory) with the observer’s rating.

Faculty Perceptions of Teaching

As they are comprised of eleven separate items scored on a five-point scale, both the teacher-focused and student-focused scales of the Approaches to Teaching Inventory can range from 11 to 55. There are no normalized scores available in the literature because scores are considered context dependent and not absolute for a specific person. The scores, however, can be compared with our observational data to examine relationships between perceptions and actual behavior and can be used as a baseline against which we can measure changes in teaching approach. For the 25 participants who completed our survey (one faculty member chose not to do so), the teacher-focused scores ranged from 20 to 51 (average = 37.1), and the student-focused scores ranged from 20 to 53 (average = 36.4). The data are shown in Figure 2. The correlation between the two self-reported scales is negligible (0.12).

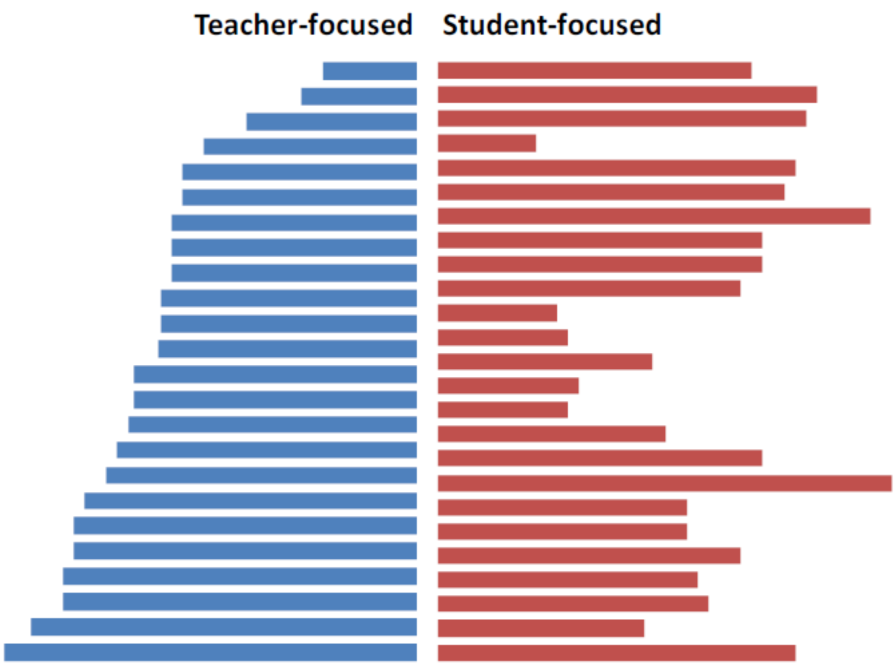

Figure 2: Faculty’s self-reported teacher-focused and student-focused approach to teaching

Classroom Observations

Our observational data included documentation of the ways faculty promote interaction with and among students by asking questions, by encouraging student to ask questions, and by using active learning. This is displayed in Table 2 which shows the percent of five-minute segments for each participant's observed class period during which there was several types of activities. For example, Participant #1 asked at least one question during 81% of the five-minute segments, asked questions with no student response in 31% of the segments, and asked questions to which students responded in 81% of the five-minute segments. Similarly, students asked questions in 31% of the segments, and the faculty member used some type of active learning in 25% of the segments. Note that since a single

five-minute segment could include multiple activites (e.g., one unanswered faculty question, two faculty questions answered by students, one student question, and a think-pair-share active learning exercise), the columns do not necessarily sum to 100%.

Table 2 illustrates that there is high variation in classroom style among participants. In one class (#22), the faculty member asked no questions, while in another class (#20), 94% of the five-minute segments included at least one faculty question. The table also shows that some faculty asked a lot of questions but did not succeed in getting students engaged. For example, in one class (#17), the faculty asked questions in 66% of the five-minute segments but got no student responses to questions in one quarter of the segments. Further, students asked questions in only 8% of the segments, and the faculty used no active learning in the observed class period. On the other hand, some faculty members with a high percentage of segments in which they asked non-productive questions also had a high percentage with questions to which students did respond (e.g., # 8). This could indicate the faculty rephrased questions or introduced new questions to facilitate student responses.

Noticeably, we observed very little active learning in our sample. Although a few faculty used multiple active learning exercies (e.g., #1 used four think-pair-share activities during the observed class period), and some included a single active learning exercise requiring significant time, such as agroup discussion, 16 of the 26 observed class periods used no active learning.

Table 2. Amount of student engagement

Participant Number	*Percent of five-minute segments with at least one:*				
	Faculty question	*Unanswered faculty question*	*Faculty question (and response)*	*Student question*	*Active learning exercise*
1	81%	31%	81%	31%	25%
2	69%	38%	63%	31%	25%
3	92%	54%	77%	38%	0%
4	93%	27%	80%	13%	27%
5	25%	13%	19%	13%	19%
6	60%	30%	50%	20%	0%
7	63%	50%	38%	0%	0%
8	90%	80%	70%	20%	0%
9	75%	75%	6%	44%	0%
10	50%	42%	17%	17%	0%
11	50%	19%	44%	25%	19%
12	27%	13%	13%	33%	0%
13	60%	40%	50%	40%	0%
14	91%	82%	73%	36%	0%
15	80%	50%	80%	30%	30%
16	35%	15%	25%	0%	15%
17	67%	58%	25%	8%	0%
18	56%	44%	38%	13%	0%
19	63%	44%	25%	38%	0%
20	94%	56%	88%	50%	13%
21	79%	36%	64%	21%	43%
22	0%	0%	0%	0%	0%
23	44%	19%	44%	44%	0%
24	89%	56%	67%	44%	0%
25	88%	69%	75%	19%	0%
26	56%	13%	50%	44%	13%
Average	**64%**	**40%**	**48%**	**26%**	**9%**

Comparisons

The six plots of Figure 2 present a comparison of faculty perceptions of their teaching (from the Teaching Behaviors Inventory) and the actual practices we observed (from the observation protocol). The correlations were low in all six comparisons, ranging from 0.02 to 0.14, indicating that participants do not perceive their own actions in ways that are consistent with objective observations. For many of the six meta-behaviors, faculty reported implementing them at least "sometimes," but our observers' ratings ranged along the complete 3-point scale. One potential reason for this high selfperception is that faculty may be poor judges of their own practice, especially since they have little opportunity to see other teaching approaches. For example, a faculty member may believe he is fostering considerable interaction or is bringing clarity by stressing important points; but a trained observer – and possibly a student in the class – might not share this belief.

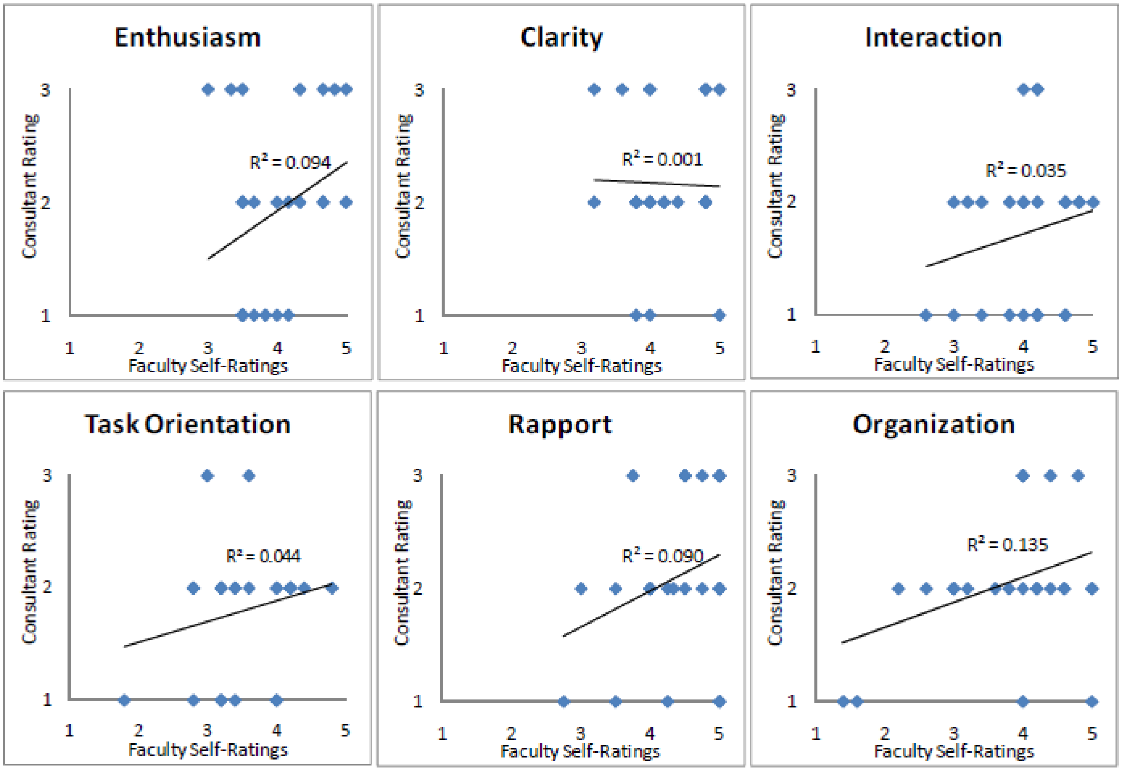

Figure 2: Comparison of faculty self-ratings and consultant ratings

Future Research

This project is part of a larger effort which will result in an improved learning environment for all engineering students at U-M and better support for a diverse student body. Besides the work presented here, our efforts include:

- synthesizing existing literature about faculty teaching practices that support a diverse student body and situating that literature in the U-M context using data from multiple sources (student demographic and academic data from the registrar and interviews with academic advisors);
- administering a student survey and conducting focus groups with students at all levels of academic achievement to identify teaching practices perceived by students to support and to hinder their success in engineering;
- surveying all engineering faculty at U-M and conducting one-on-one interviews with some to ascertain faculty beliefs about their own teaching practices and about how their practices affect student learning and to identify factors that influence faculty motivation to change their teaching practices; and
- developing an evidence-based institutional plan for motivating change in faculty teaching practices.

Although our work is local in context, the evidence-based approach to enabling institutional change will serve as a model for others and will contribute to the larger body of literature on how to support faculty in implementing best teaching practices in engineering education.

References

Brawner, C. E., Felder, R. M., Allen, R., & Brent, R. (2002). A survey of faculty teaching practices and involvement in faculty development activities. *Journal of Engineering Education*, 91(4), 393-395.

Friedrich, K., Sellers, S., & Burstyn, J. (2009). Thawing the chilly climate: Inclusive teaching resources for science, technology, engineering, and math. In D. Robertson and L. Nilson (Eds.), To Improve the Academy: *Resources for Faculty, Instructional, and Organizational Development.* Jossey-Bass.

Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K. S. (2001). What makes PD effective? *American Education Research Journal*, 38, 915-945.

Hawley, W., & Valli, L. (1999). The essentials of effective professional development: A new consensus. In G. Sykes and L. Darling Hammond (Eds.), *Handbook of teaching and policy*. New York. Teachers College.

Hora, M., Ferrare, J., & Anderson, C. (2009). *Structured observation protocol for instruction in Institutions of Higher Education.* Madison, WI: University of Wisconsin-Madison, Wisconsin Center for Education Research.

Luft, J. A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry based professional development programme on beginning and experienced secondary science teachers*. International Journal of Science Education*, 23, 517-534.

Morgan, G. (1986). *Images of organization*. Newbury Park, CA: Sage.

Murray, H.G. (1985). Classroom teaching behaviors related to college teaching effectiveness. In J.G. Donald & A.M. Sullivan (Eds.), *Using Research to Improve Teaching*. San Francisco: Jossey-Bass.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223–246.

Seymour, E. & Hewitt, N. (1997). *Talking about leaving.* Boulder, CO: Westview Press.

Smith, K., Sheppard, S., Johnson, D., & Johnson, R. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education*, January, 87-101.

Stewart, A., Malley, J., & LaVaque-Manty, D. (2007). Faculty recruitment: Mobilizing science and engineering faculty. In A. Stewart, J. Malley, and D. LaVaque-Manty (Eds.), *Transforming science and engineering: Advancing academic women* (pp. 133-151). Ann Arbor, MI: The University of Michigan Press.

Tobias, S. (1990). *They're not dumb, they're different: Stalking the second tier*. Tucson, AZ: Research Corporation

Trigwell, K., & Prosser, M. (2004). Development and use of the Approaches to Teaching Inventory. *Educational Psychology Review,* 16(44), 409-424.

Von Glaserfield, E. (1989). *Constructivism in education.* Pergamon. Oxford.

Wertsch, J. V. (1997). *Vygotsky and the formation of the mind*. Cambridge.

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of motivation. *Contemporary Educational Psychology*, 25(1), 68-81.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant #0941924. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors gratefully acknowledge the support of the 26 faculty who allowed their class to be observed.

Copyright statement