A framework for the development of a management system for Engineering education (MaSEE)

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Structured abstract

BACKGROUND

Management systems based on recognised Standards provide the framework within which engineers operate. They reduce risk by establishing consistent processes for completing projects and tasks. Traditionally, student exposure to this area of the professional environment has been addressed in the curriculum through uncontrolled work-integrated learning activities, or introduced as graduate development in industry. Similarities between core management system processes and effective teaching strategies present an opportunity to integrate industry adapted processes into the curriculum as learning and teaching tools.

PURPOSE

In this paper, a management system specifically designed for use by engineering undergraduate students is proposed as a means of increasing student exposure to contemporary engineering practice, and to foster a culture of continual improvement.

DESIGN/METHOD

In 2010 a collaboration between the University and industry identified how the similarities between management system processes and effective teaching strategies could be harnessed, to achieve improved student learning and to assist with the transition to industry. The collaboration identified six applicable industry processes and developed a modular framework to allow the processes to be scaffolded within the curriculum.

RESULTS

The concept of continual improvement is as important in the learning environment as it is in the work environment, and is aided by consistent processes. The integration of an industry adapted design verification process into a local cornerstone design assessment task, as a peer generated cyclical feedback tool, has been demonstrated to improve student engagement and learning outcomes (Willis, Foley & Wilson, 2012). This process is being used as an exemplar process for transfer to other institutions, to enable the concept to be refined and further processes strengthened.

CONCLUSIONS

This paper introduces a framework for a Management System for Engineering Education (MaSEE) that enables industry adapted processes to be integrated into the curriculum as learning and teaching tools. The framework introduces required competencies in a manner that is designed to complement, and enhance, the existing curriculum.

KEYWORDS

Peer feedback, management systems, design verification

Introduction

The establishment of greater connectivity between education and industry, in order to better prepare students for professional practice, has been identified as an important pedagogical issue for engineering educators (King, 2008). However, designing curricula to address this issue can be challenging as the work and learning environments differ.

The work environment has an innate culture of collaboration and peer review through the use of corporate management system processes. Conversely, the learning environment has discrete learning and assessment tasks that are designed to demonstrate the competence of the individual. An opportunity has been identified to blend these two environments by adapting industry processes for use in the curriculum as learning and teaching tools.

The premise that industry adapted processes integrated into the curriculum would add value to the student experience is founded on the concept of continual improvement. In industry, continual improvement is integral to an overarching management system. In higher education, students require opportunities to develop and continually improve.

In this paper, a management system specifically designed for use by engineering undergraduate students is proposed as a means of increasing student exposure to contemporary practice, and to foster a culture of continual improvement. The paper outlines the successful outcomes of a local initiative as an exemplar, presents a framework for a Management System for Engineering Education (MaSEE) and identifies processes for inclusion.

While the concepts discussed in this paper have been demonstrated to have merit at the local scale their broader development and application within the sector warrants further investigation. This paper has been prepared to disseminate and build upon the concept.

Background

In 2010 Kellogg Brown and Root Pty Ltd (KBR), a multi-national engineering firm, approached the School of Civil, Environmental and Mining Engineering at the University of Adelaide with a proposal to provide support for the development of curriculum that could address an emerging area of concern. This concern related to engineering graduates across the country, and across disciplines, having varying knowledge of quality management practices, and more specifically formal design management practices. This was then leading to variations in the implementation of the practices. The approach was timely as in 2009 the School had undertaken an internal review of its management courses and identified quality management as an area of the curriculum that could be strengthened. This area of the professional environment had previously been addressed through uncontrolled work-integrated learning activities. Adapting industry processes for use within the curriculum from day one was identified as a key strategy for the collaboration.

The need for inclusion of quality management practice in the engineering curriculum is limited in literature, although industry was suggesting the need two decades ago (Black, 1994). More recent literature identifies quality management as a generic management skill that *can* be incorporated into the curriculum, but ranks it as a lower priority to professional practice skills such as teamwork (Palmer, 2003). However, the need for its inclusion in the curriculum has now been recognised by Engineers Australia, as an explicit Stage 1 competency (Engineers Australia, 2011). This is a shift in expectation for engineering educators as quality management practice was implicit in the previous competency standard (Bradley, 2006).

The 2011 competency standards provide greater guidance for educators and were in-part informed by recommendations made by King (2008). These recommendations support more broadly the need to introduce students to contemporary engineering practice, suggesting that exposure to professional engineering practice should be an integral and substantive component of systematic educational design. Quality management processes are fundamental to engineering practice and requiring their use by students inherently exposes students to contemporary practice.

While quality management practice was initially targeted, it became evident that the processes for adaptation did not need to be limited to ‘quality’. Management systems more broadly provide the process orientated framework within which the engineering profession operates. Australian management systems are typically certified to, or consistent with, voluntary standards such as *ISO9001 Quality Management Systems* (ISO9001), *ISO14000 Environmental Management Systems,* and *AS/NZ 4800 Health and Safety Management Systems.* They enable an organisation to operate in a systematic and transparent manner to minimise the risk of unplanned outcomes using controlled policies, processes and tools. They also enable organisations and designers to effectively and efficiently meet statutory requirements and obligations such as those related to safe design, by consistently applying and documenting benchmark practice in design management.

The development of a teaching module related to quality management systems would directly address element 2.2(j) of Engineers Australia’s 2011 Stage 1 competency standard (i.e. understanding the role of quality management systems). However, the adaptation of industry processes for use within a specific management system enables other elements of competency to be embedded throughout a program, including elements related to: design practice (element 1.5); project management (element 1.6); engineering application ability (elements 2.1 – 2.4); and document control (element 3.4).

It is recognised that the individual processes discussed in this paper are not new and may already be included within specific institutions, programs or courses. However, the framework presented in this paper goes beyond introducing *engineering students* to specific design processes. It enables *student engineers* to use industry processes throughout their studies, in a manner similar to that expected in industry.

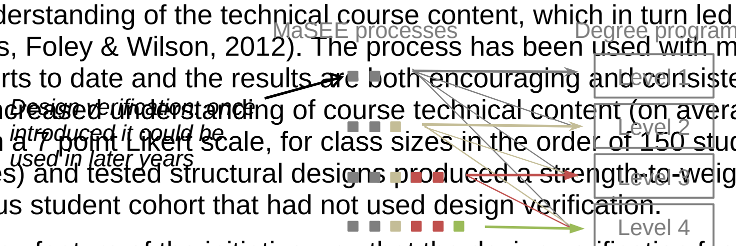
Key objectives for the project team included: retaining the authenticity of the industry process during adaptation; choosing processes based on their potential to have pedagogical merit; ensuring processes were not discipline, course or task specific; and introducing processes that complemented existing assessment tasks, to avoid increases to the teaching load and course content.

Exemplar process – design verification

In 2010, the School of Civil, Environmental and Mining Engineering introduced an industry adapted quality management process to augment an assessment task in a cornerstone design course. The initiative integrated a design verification process into the assessment task as a peer generated cyclical feedback tool. While it only required a relatively small addition to the coordination of the assessment task it had significant results on student performance and their perceptions of the educational experience. Due to its positive impact on student learning, design verification was subsequently chosen as an exemplar to demonstrate how industry adapted processes can be used as learning and teaching tools.

Design verification was the first industry adapted process introduced into the undergraduate curriculum, for two reasons. Firstly, design verification performed by peers is a fundamental practice that is of relevance to engineers throughout their entire career. It is more than simply examining the mathematical correctness of a design. It assesses whether design outputs have met their input requirements (Standards Australia, 2006). Secondly, it has similarities with proven teaching strategies and can be considered as a cyclical feedback strategy. Cyclical feedback provided by teaching staff has been demonstrated to improve student learning through increased engagement with and reflection on feedback, prior to the next step (Hounsell, McCune, Hounsell & Litjens, 2008, Quinton & Smallbone, 2010).

Quantitative evaluation of the design verification initiative indicated that, not only did the students report that they understood the importance of design verification, they reported an increased understanding of the technical course content, which in turn led to improved designs (Willis, Foley & Wilson, 2012). The process has been used with more than five different cohorts to date and the results are both encouraging and consistent. Students reported an increased understanding of course technical content (on average >80% broad agreement on a 7 point Likert scale, for class sizes in the order of 150 students and >90% response rates) and tested structural designs produced a strength-to-weight ratio 44% higher than a previous student cohort that had not used design verification.



A distinguishing feature of the initiative was that the design verification feedback was peer generated. This added another layer of engagement for the students, and an additional similarity to industry. Peer generated feedback has been demonstrated to improve student learning through increased reflection and engagement (O'Moore & Baldock, 2007, Li, Liu & Steckelberg, 2010). Li et al*.* (2010) surmised that the process of reviewing and giving feedback was more beneficial to student learning than just receiving feedback. This supports findings by O'Moore and Baldock (2007) indicating that students used the process to see other possible approaches and sources of error. In industry, it is essential that engineers are comfortable receiving, and giving, critical feedback as it can improve design outcomes and aid professional development.

There were three primary considerations in relation to the choice of assessment task and how the process was to be integrated. Firstly, the assessment task was a 'design' task and therefore students were providing feedback on the technical accuracy of the *chosen* solution, rather than *the* correct solution. This is in contrast to analysis tasks that only have a single solution. Design tasks are typically *open-ended* and have theoretically infinite solutions, while targeting optimal solutions based on a variable such as the strength-to-weight ratio of a structure. Secondly, the process was not undertaken until students had submitted their chosen design for assessment and therefore concerns relating to plagiarism were minimised. Lastly, the process was used as formative feedback and hence the students were not 'assessing' others without sufficient knowledge of the content. This also had the added advantage of minimising any increase to the teaching load, as the process was managed by the students. The need for such considerations has also been identified by others and forms valuable lessons for implementing future processes (Ballantyne, Hughes & Mylonas 2002, Søndergaard & Mulder 2012, van Hattum-Janssen & Lourenço 2006).

Based on the success of integrating design verification the project team has started to develop a number of other processes for adaptation. A Management System for Engineering Education (MaSEE) is proposed to support the introduction and use of industry adapted processes.

A management system for Engineering education (MaSEE)

The Management System for Engineering Education (MaSEE) proposed in this paper consists of a series of industry adapted standardised processes, for student use throughout their studies. Figure 1 outlines how MaSEE processes can be progressively introduced each year into selected courses, to suit the specific program. The selection of suitable courses is flexible and does not need to follow a specific pattern. The selection would be dependent on the nature of the course and the suitability of its assessment tasks. Each process would need to be introduced with a degree of teaching support. However, once introduced the process could become an assessment requirement for similar tasks in later years, reinforcing the process as standard practice. For example, the design verification exemplar was first introduced in Level 1 and required two groups to exchange their work for peer verification. The same verification process is now an assessment requirement for students in selected Level 2 and Level 3 courses within their own project groups, and is managed by the students.

Figure 1: Relationship between MaSEE and a degree program

Figure 2 outlines the teaching package framework and again demonstrates the modular nature of the framework. Consistent with an industry management system each process will outline the requirements and responsibilities for the process and be accompanied by an appropriate template(s). To assist in their implementation by academics, the processes will also be supported by short online interactive learning modules and implementation guides. The learning modules will provide industry context, case studies, examples and guidance for students on the application of each process. The implementation guides will be prepared for use by teaching staff and act as stand-alone teaching aids. They will outline the pedagogical merit of the process and provide guidance on how to identify and modify existing assessment tasks that are deemed suitable for augmentation. This enables the processes to be integrated and used by teaching staff with varying levels of knowledge pertaining to formal management systems and processes.

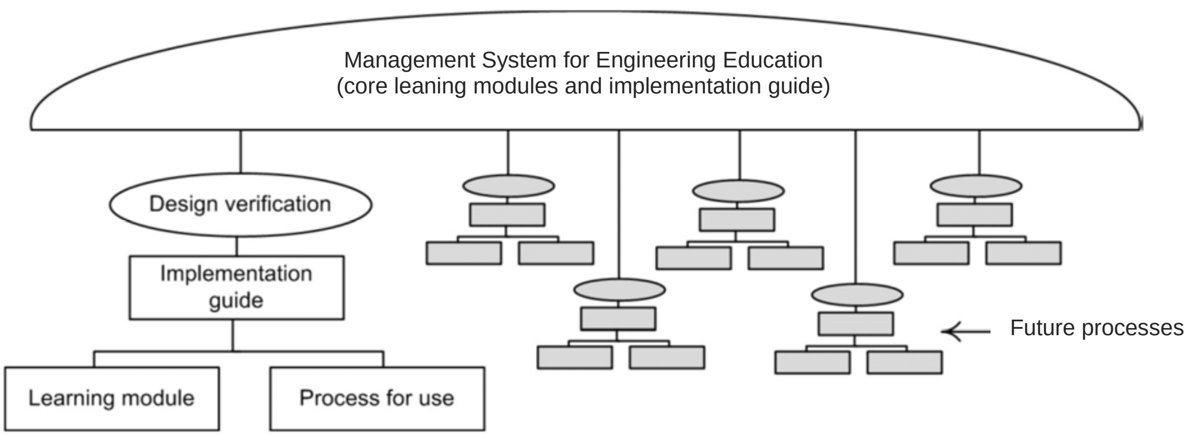


Figure 2: Teaching packages for MaSEE Processes

MaSEE processes

The MaSEE framework proposes the use of a subset of processes used in industry with an emphasis on those relevant to graduates. As shown in Figure 1 the MaSEE framework allows for the introduced processes to be scaffolded throughout the degree program. Scaffolding needs to be commensurate with the student's level of study, commencing in a cornerstone design course and continuing through to their final year. The processes identified to date, and their proposed introduction level, are outlined in Table 1.

Table 1 – Scaffold of the application of MaSEE Processes

MaSEE Process	Degree Program Level			
	Level 1	Level 2	Level 3	Level 4
Design Verification	✓	✓	✓	✓
Project Minutes	✓	✓	✓	✓
Design Review		✓	✓	✓
Project Management			✓	✓
Document Management			✓	✓
Risk Management (JSA)				✓

The processes identified in Table 1 have been deemed to be fundamental management system processes that are able to provide strategic opportunities for student engagement and learning. The appropriate scaffolding of these processes throughout the curriculum is critical. One example of this is the increased complexity of the design review process compared to that of design verification. While design verification can readily be applied to a single deliverable towards the end of the design process (such as engineering drawings or similar), design review is implemented throughout the design process and can incorporate feedback from several interview processes including multiple design tasks. Therefore, having students introduced to verification prior to design review gives them context and experience in a fundamental process before building upon it. This approach also allows the processes to be introduced gradually, without detracting from the existing course content.

A key feature of each process is an emphasis on documentation and traceability. In the learning environment students do not have the same need as industry to keep their work or demonstrate how/why design decisions are made. In industry all project material (correspondence, minutes, designs, reviews etc.) is documented, collated and filed for future reference, transparency and compliance to manage risk.

The following sections discuss each process and the reason why they have been chosen. There is flexibility within the framework to add further to these processes.

Project minutes

The documentation of meetings is routine in professional environments, but is a skill that requires development. The MaSEE framework would enable students to be introduced to the art of formally documenting meetings from the first time they were given group work to complete. It is expected that many educators would already require students to document their meetings, but the provision of a template(s) within the MaSEE framework could increase consistency and would emphasise their importance. Limited literature is available on the use of formal minutes within engineering education but what is available is consistent with our experience. Effective action-orientated minutes can increase the accountability and responsibility of team members, whilst documenting consensus on decisions and direction (Wolfe, 2006).

Design review

The design review process builds on the design verification process and is another essential design management process. Design reviews when properly conducted, increase confidence that design and development activities will be carried out with due regard to all pertinent requirements for a product throughout its life cycle (Standards Australia, 2008). From an engineering perspective introducing design reviews early within the degree program allows students to develop a mindset for the gamut of requirements that must be considered by a designer. These include factors relating to legislative requirements, safety in design, human factors, reliability, maintainability, operability and environmental impacts. From a teaching perspective the design review process has similar benefits to the design verification process as it is also a peer generated cyclical formative feedback tool. In industry design reviews are often conducted as a meeting and/or workshop that allow designers and reviewers to discuss each aspect of the design. A design review process has been introduced in a Level 2 Design course in the School of Civil, Environmental and Mining Engineering utilising a meeting checklist with three groups exchanging reviews (i.e. group 1 reviews group 2, group 2 reviews group 3 and group 3 reviews group 1). While a formal evaluation of this process has not been undertaken, a preliminary assessment indicates merit in its introduction.

Project management

The inclusion of project management tools and techniques can be found within engineering curriculum as technical content. However, requiring students to apply these principles in practice to their own projects is not as common. King (2008) describes not requiring or formally assessing students on the project management of their final year project as a lost opportunity. Incorporating a project management module within the MaSEE would provide students with the necessary project planning and control templates for use, with an expectation that they are used. From a learning perspective requiring students to plan and manage their projects creates an opportunity to increase the efficiency of projects, and minimise the risk of unplanned outcomes. This is consistent with why project management practices are used in industry.

Document management

The management of project documents and deliverables through appropriate numbering, control, distribution and filing can make a difference to project outcomes and traceability. The distribution of an outdated construction drawing can have contractual, safety and legal consequences.

Within the MaSEE framework a documentation management process would be a core learning module and also a specific process. The core learning module would have an emphasis on version control and document approval processes, including typical calculation and report cover sheets. The document management process would focus on document control requirements for larger design and research projects in the later years of the degree program. These learnings would readily translate into practice within industry.

Risk management

Risk management has broad application at all stages of the project life cycle, from the initial planning through to the project’s decommissioning. It is as applicable to project management risks as it is to technical or safety risks. A management system itself is a risk management strategy and the individual processes target different aspects of risk. For example, both design verification and design reviews are opportunities to ensure that issues related to safe design have been considered. With regard to the MaSEE framework a final module is proposed for the last year of study that will provide students with the necessary tools to manage the risk on their final year project. A Job Safety Analysis (JSA) process is proposed and this would likely need to be tailored for the institution in which it was to be applied, so that it was consistent with the institution’s own health and safety management system.

There would also be the opportunity to include learning modules related to risk management earlier in the framework or as core learning modules, to support other processes. Such a learning module would be consistent with *ISO 31000 Risk Management.*

Further research

The processes described above have been introduced within courses in the School of Civil, Environmental and Mining Engineering to varying extents, with differing degrees of formality, and with supporting material presented within lectures rather than online modules. However, design verification is the only process that has had its pedagogical merit formally evaluated. This process is being packaged, with the assistance of an Australian Government Office for Learning and Teaching (OLT) grant, to determine whether the successful outcomes achieved at the local scale can be transferred to other institutions for use by teaching staff. A key aspect of this transfer is development of the online learning modules and implementation guide. The online learning modules will be developed to include content that is currently presented by an industry guest lecturer. The implementation guide will be developed based on lessons learned to date.

The transfer of the exemplar process to other institutions will allow the process to be further refined. It will provide additional feedback in relation to suitable assessment tasks and the level of information required by teaching staff to integrate the process. An evaluation of the exemplar in other institutions will determine whether there is merit in formalising and developing the framework, and the other identified processes.

Summary

Management systems provide the framework within which the engineering profession operates and can influence contemporary engineering practice. The Management System for Engineering Education (MaSEE) proposed in this paper has been developed in response to industry concerns relating to graduates having varying levels of knowledge of standard industry processes. It also addresses key concerns in the latest review of engineering education in relation to strengthening the authenticity of education, and increasing exposure to industry and contemporary practice (King, 2008).

While the professional and educational environments differ, similarities have been identified that could allow industry processes to be used as learning and teaching tools to increase student engagement and learning outcomes. The similarities are founded on the concept of continual improvement and allow the industry culture of collaboration and peer review to be fostered within the learning environment, without compromising technical content or the integrity of assessments.

The first process within the MaSEE framework, design verification, has been used as a peer generated cyclical formative feedback tool since 2010. It is currently being packaged for use at other institutions through an OLT grant, to determine whether the positive outcomes achieved at the local scale can be replicated in other institutions. Lessons from the use of the design verification process at other institutions will allow further refinement of the MaSEE framework.

The MaSEE framework introduces students to contemporary practice in a manner that is designed to complement, and enhance, the existing curriculum.

References

Ballantyne, R., Hughes, K. & Mylonas, A. (2002). Developing procedures for implementing peer assessment in large classes using an action research process. *Assessment & Evaluation in Higher Education*, 27(5), 427-441.

Black, K.M. (1994). An Industry View of Engineering Education, *Journal of Engineering Education,* 83(1), 26-28.

Bradley, A. (2006). Engineers Australia National Generic Competency Standards – Stage 1 Competency Standard for Professional Engineers. Document P05. Engineers Australia.

Engineers Australia (2011). Stage 1 Competency Standard for Professional Engineer. Retrieved from http://www.engineersaustralia.org.au/about-us/program-accreditation#standards.

Hounsell, D., McCune, V., Hounsell, J., & Litjens, J. (2008). The quality of guidance and feedback to students. *Higher Education Research and Development,* 27(1), 55-67.

King, R. (2008). Engineers for the Future addressing the supply and quality of Australian engineering graduates for the 21st century. Report for the Australian Council of Engineering Deans.

Li, L., Liu, X. & Steckelberg, A.L. (2010). Assessor or assessee: How student learning improves by giving and receiving peer feedback, *British Journal of Educational Technology,* 41(3), 525-536.

O'Moore, L.M. & Baldock, T.E. (2007). Peer Assessment Learning Sessions (PALS): an innovative feedback technique for large engineering classes, *European Journal of Engineering Education,* 32(1), 43-55.

Palmer, R.P. (2003). Framework for undergraduate engineering management studies, *Journal of Professional Issues in Engineering Education and Practice*, 129(2), 92-99.

Quinton, S. & Smallbone, T. (2010). Feeding forward: using feedback to promote student reflection and learning – a teaching model, *Innovations in Education and Teaching International,* 47(1), 125-135.

Søndergaard, H. & Mulder, R. A. (2012). Collaborative learning through formative peer review: pedagogy, programs and potential. *Computer Science Education,* 22(4), 343-367.

Standards Australia (2006). AS/NZ ISO9000:2006 Quality management systems- Fundamentals and vocabulary, Standards Australia, Sydney.

Standards Australia (2008). AS IEC 61160:2008 Design Review. Standards Australia, Sydney.

van Hattum-Janssen, N. & Lourenço, J. M. (2006). Explicitness of criteria in peer assessment processes for first-year engineering students. *European Journal of Engineering Education,* 31(6), 683-691.

Willis, C., Foley, B., & Wilson, D. (2012). Improved student engagement in civil and mechanical engineering using a professional peer feedback process, *7th Australasian Congress on Applied Mechanics, ACAM 7*, December 2012, Adelaide, Australia.

Wolfe, J. (2006). Meeting Minutes as a Rhetorical Genre: Discrepancies between professional writing textbooks and workplace practice. *IEEE Transactions on Professional Communication.* 49(4), 354-364.

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