Implementation of industry sustainability metrics in undergraduate design projects

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Abstract*: RMIT University Chemical Engineering has a stream of project based learning courses from first to final year. These courses are excellent vehicles for developing graduate attributes. This paper reports on implementation of sophisticated industry sustainability metrics in multiple projects from first to final year. The GEMI Metrics Navigator™ is a tool that assists organisations to develop metrics that support business strategy and contribute to business success. It facilitates analysis of complex issues in terms of environment, social and economic life cycles including stakeholder input. It uses worksheets to facilitate analysis of the most relevant business issues. The students used pair-wise comparison to rank and weight relevant issues with stakeholder input. In first year, the stakeholders were the students themselves. In the final year, students ran a community forum and questioned "stakeholders" who were role-played by a consultant engineer and social science academics. In later year projects students used additional worksheets to prioritise key areas. The students successfully used the tool to analyse process design alternatives in depth and to identify the key issues for the company and the community objectively. They learned to identify which issues can be controlled and influenced and how to incorporate stakeholder views in their design choice. The feasibility reports produced by the final year students showed a mature and considered evaluation of the design alternatives. The concept maps of year 2 students showed their understanding of sustainability increased significantly. This study found that students can use sophisticated industry metrics to develop their ideas about sustainability. Collecting and using data from a meeting with stakeholders introduced authentic community involvement into student projects. The students' learning in future years will be enhanced by returning to and building on their learning of sustainability concepts from earlier years. A longitudinal study of student learning outcomes is planned.*

Introduction

Project based learning (PjBL) is an educational approach well placed to develop all the requisite Engineers Australia competencies. RMIT's four year Chemical Engineering degree was recently "renewed" and the old structure was replaced with a core of traditional courses and a stream of project PjBL courses from first to final year, one per semester. Each PBL course is designed so that as a student progresses from project to project, new or more complex activities are undertaken, so the student gains additional technical knowledge as well as enhanced generic skills. The curriculum for technical knowledge reflects con-current theory courses. The activities to develop generic skills focus on communication, teamwork and sustainability.

However a recent study on work readiness of our PjBL graduates identified gaps in the graduates' understanding of sustainability issues. While we have attempted to address sustainability in our PjBL courses, it seems the outcomes for students are inadequate. There are few teaching resources or reports in the literature on how sustainability is addressed in engineering programs. This paper reports on implementation of a new approach to teaching sustainability implemented in 2011.

Background

The RMIT Chemical Engineering undergraduate program contains sufficient depth and breadth of core engineering courses to be accredited at a Masters level by the Institution of Chemical Engineers, UK (IChemE). It also contains a stream of PjBL courses designed to help students develop technical as well as generic skills. In the PjBL courses, students work in groups to design a process, lectures are delivered "just in time", the group is assessed through draft and final project reports and presentations, and tests are used to assess an individual student's technical knowledge. The projects are relatively small in scope in first year; they grow in complexity as students move into later years. The scaffold of lectures gradually gives way to group meetings with a supervisor or industry consultant. The PjBL courses are described in detail in elsewhere (Parthasararthy and Jollands 2009).

Prior to 2011, our students used the triple bottom line (TBL) to identify the "best process" among the alternatives. Students evaluated the economic, environmental and social impacts of each process based on their research of the literature. In the projects in year 1 to 3, they would then choose the "best" process using an *ad hoc* informal and undocumented decision process. In an IChemE seminar in 2006, hosted by RMIT and attended by all Australian University Chemical Engineering Departments, this approach was noted as best practice. Others were either not using a framework, or not using the TBL, or addressing the TBL in only one course or part of a course. However, even the RMIT students' approach lacked a systematic or objective basis. The final year RMIT students were using the detailed guidelines published by the Institution of Chemical Engineers, UK (IChemE 2006); however even these guidelines have major limitations.

In 2010 a pilot project was undertaken to assist students to assess sustainability in more depth and breadth in one design project course. A sophisticated management decision tool was trialled with one group in their final year design project. In the pilot, an engineering consultant facilitated the students' use of the tool to identify the best location for a sulphuric acid plant. The pilot was evaluated and a plan was developed to implement the approach across a number of courses the following year (Jollands, Parthasarathy and Latham, 2011). In 2011 the approach was extended to the whole student cohort in three courses in years 1, 2 and 4: Sustainable Engineering, Process Principles, and Process Systems Integration. This paper reports on the outcomes in those three courses.

Literature Review

Professional bodies such as Engineers Australia and the Institution of Chemical Engineers UK (IChemE) identify sustainability as a key graduate attribute. UNESCO sponsored a meta study of courses in several European universities in terms of the pedagogical approach and effectiveness in teaching sustainability. Key sustainable development competencies were identified as "critical thinking, systemic thinking, ability to work in trans disciplinary frameworks, and capacity to live values consistent with the sustainability paradigm" (Segalas, Ferrer-Balas and Mulder, 2009). The study used concept maps to measure enhancement in student knowledge of sustainability: the more categories covered and the more interrelationships identified between categories, the better. The study found that in many cases outcomes for students were poor. In some cases students enrolled in traditional teacher-led courses scored worse on average on the evaluations at the end of the course than at the outset! Students enrolled in courses using problem based, especially community based, group projects achieved the best outcomes. However few details were given in the study on how the successful courses were run. Community based projects are not common in engineering programs.

Two management tools are available in the public domain to assess sustainability in the chemical industry. The first is the IChemE's Sustainability Metrics (IChemE 2006). These assist engineers to evaluate operating units. They include checklists of TBL indicators, including some equity issues such as employment and training. However, they have a number of limitations: they fail to focus on a set of critical issues; stakeholders have no input to the indicators; social issues are limited to health, education and income parity, and neglects equity and impact on future generations (Majumdar, Jollands and Bhasin, 2009). The IChemE guidelines have not been used in published research to the authors' knowledge.

The second management tool is The Metrics Navigator™ developed by the Global Environmental Management Initiative (GEMI). GEMI is a non-profit organization of leading companies dedicated to collaborative efforts to foster environmental, health and safety excellence and corporate citizenship. The tool helps organizations develop and implement metrics that provide insight into complex issues, support business strategy and contribute to business success. It provides an approach that assesses the materiality of issues. Input from internal and external stakeholders is used to analyse business success factors, business impacts, stakeholder concerns and the organization's perceived degree of control of each issue. Worksheets are used to help analyse business issues in terms of TBL life cycles (GEMI 2007).

The Metrics Navigator™ is a more adaptable and systematic tool than the Sustainability Metrics. It facilitates external stakeholder input, focuses on key issues, and guides prioritisation. It has a global rather than regional focus and there is no limit to the social issues considered. Hence it is the preferred tool in an Australian or Asia Pacific context .

Results and Discussion

Learning Outcomes from PjBL courses

Learning outcomes for students completing the PjBL stream are:

- To evaluate alternative design concepts competently using sustainability criteria
- To design processes accurately, feasibly and with attention to detail, including flow diagrams, and in second year, mass and energy balances, and process simulation, and cost estimates, and in final year, process control and optimisation, hazard analysis, and plant layout design
- To work in and lead a small team of chemical engineers, to collaborate on joint tasks and co-operate with shared tasks on-time and to a standard satisfactory to the team and supervisor
- To communicate (in writing and verbally) to a professional standard.

Methods

The Metrics Navigator™ includes a series of worksheets that systematically identify the business success factors, define the product and plant life cycles, and identify issues of critical relevance to the business and to external stakeholders. These were introduced in stages in different years as the projects increased in complexity. Students have on-line access to GEMI's public domain publications on The Metrics Navigator™, including blank worksheets (GEMI 2007). The worked example embedded in GEMI's materials relates to manufacture of a nutritional beverage. Latham, Jones and Tanzil (2009) published another example related to the mining industry. The two published examples demonstrate that the approach can be applied to a diverse range of business activities.

Implementation of the new sustainability approach in 2011

A summary of the courses, activities and outcomes is given in Table 1. In the first year course, Sustainable Engineering, the students worked in groups on the Engineers Without Borders Challenge (EWB 2011). Each group used a TBL framework to identify the most relevant issues from the literature and their own experience. We facilitated a workshop where the students learned to use a pair-wise comparison spreadsheet. In pair-wise comparison each pair of issues is compared, the more important identified, and a weighting is calculated based on how often each issue was judged the more important. Each group used their weighted issues to compare their alternative design solutions. The "best" design was chosen as the one that satisfied the most highly weighted criteria. This is a simple method for multi-criteria optimisation using an objective evaluation.

In the second year course, Process Principles, the project complexity is higher than first year, and the expectations for learning outcomes greater (Table 1). The project brief concerned design of a sulphuric acid plant. The product and plant life cycles were defined for the class by our engineering consultant on sustainability. The United Nation's Committee for Sustainable Development has produced a list of issues for the 21st century, Agenda 21 (FIDIC 2004). Each group used this to shortlist the most relevant issues for this project. These shortlists were combined and the whole class voted on the most important. Each group was then assigned an issue to research and report back to the class on the life cycle stage of their issue, its risk and consequences. The results were compiled into a spreadsheet and then each group rated their alternative process against each issue, identifying the least risk process.

In the fourth year course, Process Systems Integration, the project complexity is high and the expectations for the quality and sophistication of learning outcomes are great. In 2011 the project brief concerned the best location for a sulphuric acid plant to supply a remote nickel mine. Each group made a systematic in-depth analysis of the alternative locations for the site and produced a group feasibility report. Each group developed a product and plant life cycle using The Metrics Navigator™ Worksheet 1b. The UN CSD's Agenda 21 (FIDIC 2004) was used to identify critical issues; they were prioritised using Worksheet 2b. A key innovation in this project was that the students led stakeholder meetings where they collected data on critical business and stakeholder issues. Each group was given a particular issue to research and prepare questions for the stakeholders. An engineer and social scientists were engaged to role play stakeholders at these meetings. This created a rich and stimulating, authentic experience for the students. Groups used the data from stakeholders to identify the key material issues using Worksheet 3a. Then they prepared their weighted criteria decision matrix using Worksheet 3b, and for each key issue, key performance indicators and metrics to assist the company manage the issue using Worksheet 4a. During the semester feedback from the project was positive in part, but some students requested worked examples of the spreadsheets, and others commented they were not sure of the relevance of the sustainability to their future careers (!).

Table 1 Summary of courses, activities and outcomes

Course	*Activities*	*Outcomes*
Sustainable Engineering (Year 1/ Sem 1)	4 @ 1 hr lectures on TBL. 3 @ 2 hr workshops on TBL frameworks; identifying key TBL issues; use of spreadsheet with pair-wise comparison to rank and weight issues.	Enhanced depth and breadth of analysis in reports Student satisfaction increased (survey results increased from 50% to 65%)
Process Principles (Year2/ Sem1)	3 @ 2 hr workshops on UNEP's Agenda 21; GEMI sustainability framework; risk matrices for business decisions spreadsheet; plant life cycle worksheet; project decision analysis using pair-wise comparison spreadsheet; worksheet 2a, 2b.	Enhanced depth and breadth of analysis in reports Spreadsheeting skills More complex concept maps Student satisfaction maintained (survey results constant at 50%)
Process Systems Integration (Year 4/ Sem1)	5 @ 2 hr workshops on Bridges Sustainability Framework; defining the plant life cycle; business decisions matrices; pair-wise comparison; community consultation; worksheet 3a, 3b, 4a.	Enhanced depth and breadth of analysis in reports Spreadsheeting skills Student satisfaction decreased (survey results down from 75% to 61%)

Challenges

Engaging an engineering consultant who is an expert in sustainability was the most critical success factor in implementing this project. The consultant provided rich resources on the topic and drew on his extensive industry experience to illustrate the use of The Metrics Navigator™ for students, hence countering the lack of academic resources available. A majority of the staff are involved in these courses, and so have been reading and marking the feasibility and final reports that contain the sustainability analyses. Hence staff engagement and development has started. Some staff are now developing technical research projects that include sustainability aspects. Development of more formal teaching resources and staff development is on-going.

The community forum was run successfully, thanks again to the experience of the engineering consultant in running similar forums. Suitable candidates to role play the stakeholders were identified once we established the "selection criteria". For the business manager role, a senior process engineer from a consultancy such as Uhde Shedden or Golder Associates is ideal. Suitable candidates were found among alumni or industry research partners. For the community activist role, a community activist is ideal, or social scientists or EPA field workers.

Interestingly, the Year 2 students struggled most with the concept of pair-wise comparison. Their feasibility reports often included two sections: one called "Sustainability" and one called "TBL". The first section included all the GEMI materials, and the second a purely qualitative approach using a TBL framework. It is hoped that next years' student cohort will see sustainability and TBL as the same continuum, having learnt pair-wise comparison in their first year course Sustainable Engineering.

Evaluation

Students in the year 2 class produced concept maps at the start and end of the sustainability workshops. Concept maps are graphical tools that are an easy and quick way for groups to represent their knowledge about complex topics. This was used to measure progress in the students' understanding of sustainability issues. The more progress, the greater number of topics, and the more complex the interlinks between the topics. The results for the "before and after" complexity indicators are shown in Figure 1. This shows a vast increase in the interrelationship among categories for the results before and after the workshops. The complexity factor increased by a factor of 10. This shows a clear shift on the conceptualisation of sustainability by the students.

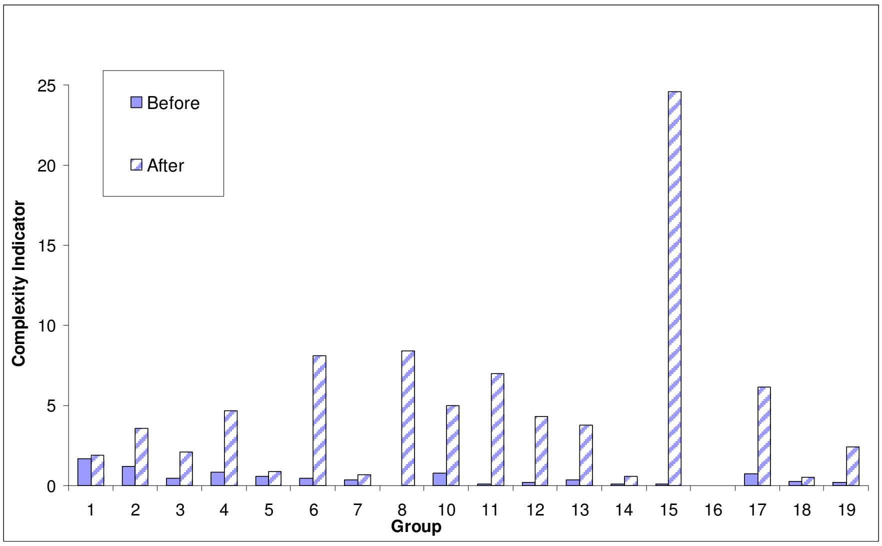

Figure 1 Complexity Indicator of Year 2 Process Principles students' concept maps

In year 4, the feasibility reports demonstrated a high level of understanding of The Metric Navigator™ methodology and, on the whole, the worksheets were used effectively to present group findings. The issues identified by the project stakeholders had an influence on the students' approach to their project. The assessors were impressed by the quality of the reports.

Some limitations in the implementation of the approach were also observed. At RMIT surveys of courses are carried out every semester and student feedback is compiled to give a "good teaching scale" (GTS). The GTS increased for the year 1 course, reflecting student feedback was generally positive, but didn't change for the year 2 course, and decreased for the year 4 course. The students struggled to learn and use to full effect parts of the tool in the limited time available. For this project we implemented the tool in 3 courses in 3 different years, so none of the students had used the tool previously. The year 4 students gave us feedback that they felt they should have been introduced to the tool in earlier years. We concluded learning outcomes will be achieved better when the students have progressed through each of the 3 courses over the next 3 years. In addition, some aspects of the tool will be introduced into one PjBL course in year 3 as well. The knowledge of students will be built incrementally with application of key skills to more and more complex projects. In this way it is hoped that students will develop a deeper and more comprehensive knowledge of sustainability issues. The staff involved in supervising groups in these courses will also gain new knowledge from working with their students and reading their reports in multiple projects. They will then become more confident facilitators of student learning in sustainability.

It will be several years before the full impact of this approach will be demonstrated in graduate outcomes. An effective way to evaluate the effectiveness of such a project is to undertake a longitudinal study of students as they progress through the different projects. Clarificative evaluation using program logic would be a suitable approach. This is planned for 2012 to 2014.

Conclusions

Educating chemical engineering undergraduates in sustainability is a key goal at RMIT. However, our efforts are hampered by lack of resources, and lack of relevant skills among academic staff. The literature shows that the outcomes of existing courses on sustainability are highly variable and none give details of types of tools used to assist decision making. The Chemical Engineering stream of project based learning courses offered scope for a systematic and detailed analysis of the sustainability of alternative designs. A sophisticated and complex framework tool – GEMI's The Metrics Navigator™ - was introduced in three courses spanning first to final year. We found that The Metrics Navigator™ can be used by undergraduates to make better qualified design decisions. Learning to use such a sophisticated tool is best approached by incremental development of student skills and knowledge. Different aspects of The Metrics Navigator™ can be introduced in different year levels. The full benefit will be achieved once the students progress through the whole stream of courses and staff develop more confidence in facilitating sustainability learning. A longitudinal study will be undertaken to evaluate development of understanding of sustainability among the student cohort.

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