Implementation of industry sustainability metrics across multiple undergraduate design projects

Margaret Jollands, Mark Latham[a] and Raj Parthasarathy
RMIT University, Latham Solutions[a]
Margaret.jollands@rmit.edu.au:

BACKGROUND
This paper reports on student learning outcomes from an innovative approach to teaching sustainability. Employers continue to find gaps in attributes of their engineering graduates concerning sustainability. Teaching sustainability is problematic, with highly variable outcomes, but there is a consensus that problem based learning is a suitable pedagogical approach. A sophisticated industry decision-making tool was introduced to assist students to make better design decisions in a more systematic and rigorous way incorporating sustainability metrics. The tool has been introduced in problem based learning design courses spanning three years of a chemical engineering undergraduate degree program.

PURPOSE
This study focused on the question, can the use of a sophisticated industry decision-making tool in several projects spanning several years enhance students learning in sustainability?

DESIGN/METHOD
Students work in groups to select the best process for a given chemical product. Workshops are held with an industry expert where students complete a series of worksheets to identify materiality of issues, ranking of issues by stakeholders, and key performance indicators to measure impact of key issues. Student learning outcomes in sustainability are gauged by the complexity and breadth of concepts contained in concept maps submitted before and after the workshops. Concept maps from 2nd and final year students are compared to evaluate enhancement of learning over multiple projects.

RESULTS
All 2nd year students groups showed a substantial increase in complexity and interconnectedness of sustainability concepts after the workshops. On average the number of interlinked concepts increased by an order of magnitude. The concepts also became more evenly distributed across relevant categories. The class of 2012 started at a higher level and made significantly more progress in understanding than the previous year, attributed to greater experience of the lecturers in teaching in this field. Final year students started the course with a higher level of knowledge than 2nd years, and also made some progress in their understanding. Their lower rate of learning may be attributed to different supervision arrangements, with supervisors with limited knowledge of sustainability.

CONCLUSIONS
Project based learning is a good pedagogical approach to incorporate sustainability thinking into undergraduate design courses. Use of a sophisticated industry decision-making tool can enhance learning in sustainability especially in lower year levels. Concept maps are a good tool to capture student learning, as well as to identify foci for curriculum review. Repeatability of the tool needs to be assessed. Professional development in sustainability thinking is recommended for staff involved in group supervision of groups undertaking PBL design courses.

KEYWORDS
Sustainability, problem based learning, concept maps.

Introduction

This paper reports on the effects on student learning outcomes of developing the attribute of sustainability in students over a number of increasingly complex projects from second to final year.

Surveys of employers continue to show gaps between employer expectations and graduate professional attributes (Spinks et al 2006). Problem based learning has been implemented in many engineering programs to address this deficit. The RMIT University Chemical Engineering program has a stream of project based learning design courses from first to final year. These projects are used to develop the student's ability to apply fundamental knowledge to industry problems as well as develop generic skills such as communication, team work and sustainability. The projects all have a similar format – students work in groups to identify the best design for a given scenario. Each group is assessed on a draft and final report and presentation. Each group member receives a mark from group (60%) and individual (40%) work: the group mark for each group member is moderated by a peer assessment factor, and the individual work is based on conventional timed tests. The tests are held on a core technical aspect of the project. An example of a project topic is "Select the best technology to supply sulphuric acid for a remote nickel mine in WA". The technical aspects of the project include mass balance in first year, energy balance in second year and process control in third year.

Development of the generic skill of sustainability is more problematic. There is no consensus among teachers on the best pedagogical approach to teaching sustainability. The few Australian studies on sustainability in engineering education focus on identifying relevant content rather than pedagogy, such as Baillie (2006) and Cavenett (2011). In Europe, the regular SEFI conferences have led to more work being reported. Segalas, Ferrar-Balas and Mulder's 2009 study of five leading technology universities in Europe found that their pedagogical approach to teaching sustainability varied very significantly, from passive learning with traditional lectures, to active learning such as problem and community based learning. Their research showed that problem and community based learning led to better learning outcomes for students, although there was a broad spread of data. A study of RMIT chemical engineering graduates' work readiness (based on interviews with our recent graduates and their managers) showed high level of skills in many areas, but a gap was identified in their ability to apply sustainability principles to their current work projects (Jollands, Jolly and Molyneaux 2012).

Hence we adopted a "renewed" approach to teaching sustainability (in 2010). We use a sophisticated industry approach to the identification of key performance indicators and metrics – called The Metrics Navigator™ – as a tool to assist students to apply sustainability principles in a more systematic, rigorous evaluation of alternative designs (GEMI 2007). The Global Environmental Management Initiative (GEMI) is a non-profit organization of leading companies dedicated to collaborative efforts to foster environmental, health and safety excellence and corporate citizenship. The Metrics Navigator™ provides an approach that assesses the "materiality" of issues, defined as "the relevance and substantiality of an issue to the organisation" (GEMI 2007). Input from internal and external stakeholders is used to analyse business success factors, business impacts, stakeholder concerns and the perceived degree of organisation control of each issue. Worksheets are used to help analyse business issues in terms of triple bottom line (TBL) life cycles. The Metrics Navigator™ approach consolidates knowhow used widely in industry, but relatively little has been published. One case study on The Metrics Navigator™'s application to the minerals industry was published by Latham, Jones and Tanzil (2009). GEMI's is the only tool in the public domain that facilitates comprehensive consideration of all three pillars (economic, social and environmental) of the TBL along with corporate governance considerations. Other publicly available tools such as **B**uilding for **E**nvironmental and **E**conomic **S**ustainability (BEES) software have a predominantly environmental focus (Schuster 2007) so fail to take a balanced approach to the TBL.

Three compulsory (core) PBL courses, in second, third and final year, were selected to implement the new approach. We have previously reported on its use in a second year (Jollands, Parthasarathy and Latham 2011a) and a final year course (Jollands, Parthasarathy and Latham 2011b). The cohort of third year students in 2011 arrived in their final year in 2012, having completed two projects using the GEMI approach in two successive years. Hence this is the first opportunity to investigate the development of sustainability learning outcomes across a number of projects.

Research Question

This study focused on the question, can the use of a sophisticated industry decision-making tool by students taking PBL design courses over consecutive years enhance students' learning in sustainability?

Design/Method

Sustainability is taught in three selected core PBL courses using the following approach. A feasibility study on building a chemical process plant is a key assessable task in each course. Students are required to evaluate the feasibility of at least two alternative process designs against triple bottom line criteria. Students must use the GEMI approach to establish criteria on which their options are evaluated and recommendations developed . GEMI includes a series of worksheets that guide students to systematically identify the business success factors, define the plant life cycle, and identify issues of critical relevance to the business and to external stakeholders.

An industry expert facilitates a series of workshops in each course, 2 hours per week for 3 weeks. The workshops use a mixture of lecture and group work. Potential sustainability issues are identified along the time horizon of the plant life cycle. The materiality of issues is ranked with various techniques such as pairwise comparison or with input from meetings with stakeholders. The students develop suitable key performance indicators to measure the impact of the key issues. A sample issue for construction of a gas processing plant in remote WA is shown below:

Table 1: Sample issue

Issue	KPI	Consequences	Ranking	Risk rating
Employment of the local workforce	Working conditions	Lawsuits, strikes, absenteeism	3rd after "OHS" and "economics"	Low risk

Each group presents the metrics, analysis and justification of their choice of design as part of their project feasibility study.

The learning outcomes on sustainability are compared using Concept Maps (Cmaps). Cmaps measure student knowledge of sustainability by comparing the breadth and depth of knowledge across a range of categories, and the interconnectedness of the categories. Segalas, Ferrer-Balas and Mulder (2008) define a taxonomy with ten sustainable development (SD) categories including "Environmental aspects", "Cultural and Value aspects", "Future generations", "Economical aspects", "Education aspects" and so on.

The research design is a quasi-experimental pretest-posttest design. Each group of students complete a Cmap before the course and the same group completes a second map after the sustainability workshop series. Each group has the first map to review when they draw the second. The first map is drawn by hand, as it is done during class time, while the second is usually produced using one of the many available CMap software programs. It is then submitted along with the other assessable tasks in a group report. The Cmaps should include sustainability issues (concepts) relevant to the project, and identify links between issues. Each Cmap is assessed for the number of concepts per category, the number of categories represented, and the connections between categories. The final score for each Cmap is in two dimensions: category relevance (CR), which reflects the number of concepts per category as well as the distribution of concepts across categories, and complexity (CO), which reflects the number of connections identified between categories. A comparison between the “before” and “after” maps indicates how far students' knowledge has developed. The scores are calculated as follows (Segalas, Ferrer-Balas and Mulder 2008):

CR = the percent of concepts that fall into each category

$$CO = NC.\ NL_{Int\text{-}Ca} / (NC_{Ca} * NS)$$

where NC is the average number of concepts per student in the group; $NL_{Int\text{-}Ca}$ is the total number of links; NC_{Ca} is the total number of categories; and NS is the number of students in the group.

Ideal results are when CR ~10% for each of the 10 categories, that is, concepts are well distributed across all categories, and when CO approaches 25, which was the CO achieved by a panel of European sustainability experts (Segalas, Ferrar-Balas, Mulder 2008).

Each student group submits two Cmaps. The first is submitted before they attend the series of workshops, and the second is submitted after the workshops, with their draft report, due in mid-semester. The evolution of their thinking in sustainability is captured by comparing these “before” and “after” Cmaps.

Three PBL courses in 2nd, 3rd and final year were selected to implement GEMI. As part of their assessment, students in the 2nd year and final year PBL courses were also asked to submit Cmaps. Comparing the Cmaps from the 2nd and final year reflects the evolution of thinking in sustainability over consecutive projects.

Report marks are also collected every year for each course. However, these marks reflect the subjective views of the marker as much as the learning outcomes of the students, so will not be presented here.

Results

Results are presented here for Cmaps drawn by 2nd year students in 2011 and 2012, and by final year students in 2012. 3rd year students also use the GEMI approach but Cmap results are not available for that course.

The 2012 cohort of final year students have undertaken two PBL courses selected to implement GEMI. Hence a comparison of the 2nd and final year students Cmaps compares students who have never used GEMI (the 2nd years) with students who have used the GEMI approach in two projects.

Figures 1a and 1b show that results for students in the 2nd year class in 2011. The complexity indicator (the number of links between concepts) increased significantly after the workshops. This suggests the workshops enhanced the students understanding of the interconnectedness of concepts about sustainability, although there likely to be other factors at play, such as student skill at drawing Cmaps. The category relevance also showed improvement: the number of concepts in each category was more even. Figure 1a shows the spread of results for complexity index was high, showing some groups had developed their ideas about the complexity of sustainability more fully than others. Figure 1b shows that while there was an improvement, “environment” was over represented in the Cmaps, and “future” and “inequity” were under-represented. Under-representation of these two categories was also reported in the European courses evaluated by Segalas, Ferrer-Balas and Mulder

(2009) and is not surprising, given the focus in engineering courses on technical issues, economy and the environment.

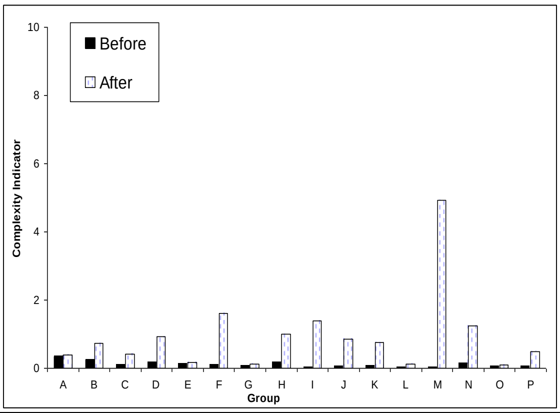


Figure 1a: Evolution of Complexity index (CO) for 2nd years (2011 data)

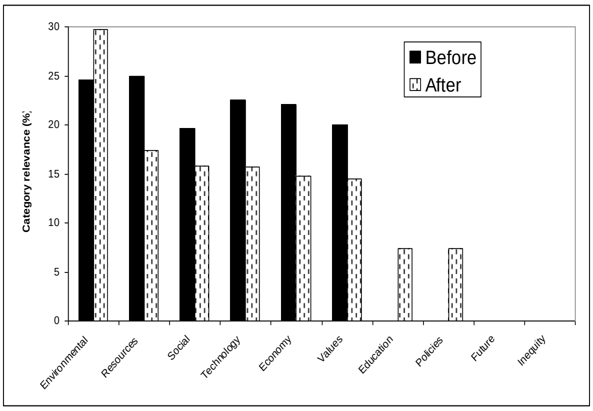


Figure 1b: Evolution of Category relevance (CR) for final years (2011 data)

Figures 2a and 2b show the results for the same course the following year. The trends in the data were similar to 2011: very significant enhancement in complexity after participating in the workshops, the distribution of concepts among categories improved, the same categories are under-represented. The main difference between the two sets of results is the magnitude of the complexity indicator. In 2012 student Cmaps contained significantly more concepts and more interlinks than the previous year. Student learning progressed to a much higher level. This may be attributed to several causes. The student cohort was different, the project topic was different, and the lecturers were more experienced as they were teaching the class for the second time. The literature does not report on the repeatability of Cmaps. Confounding factors are often present in education research, so it is recommended that learning outcomes are studied over several years before firm conclusions are drawn.

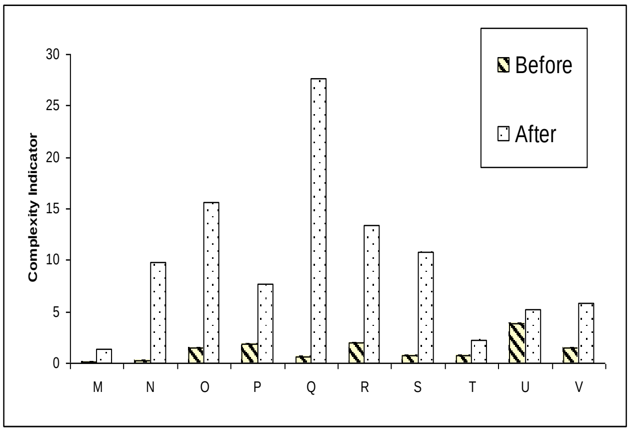


Figure 2a: Evolution of Complexity index (CO) for 2nd years (2012 data)

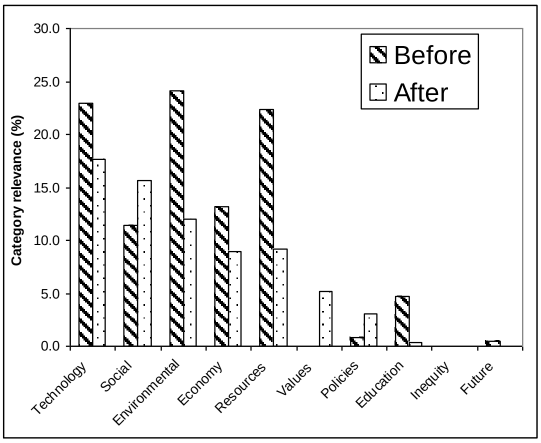
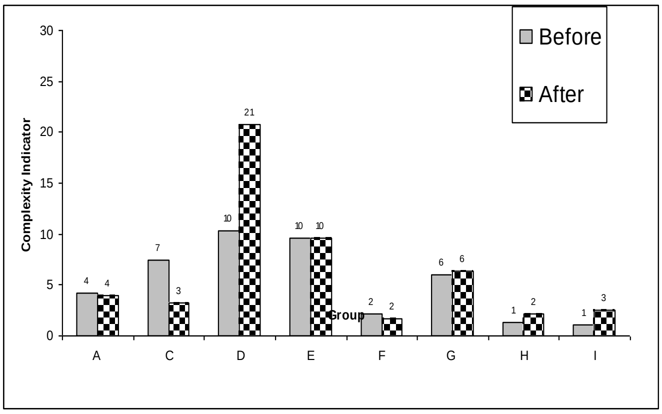


Figure 2b: Evolution of Category relevance (CR) for 2nd years (2012 data)

Figures 3a and 3b shows the results for the final year groups. The groups started at a higher level of CO than 2nd years, as expected. The trends were similar to those in the 2nd year data although not as pronounced. Some groups improved after the workshops: for example, group D identified significantly more concepts after the workshops. In some groups there was a decline (group C). This is similar to results reported by Segalas, Ferrar-Balas and Mulder

(2009) who found that CO increased most markedly for cohorts of students who started at a low level of understanding, and in some cases, even decreased for a whole cohort of students. Figure 3b shows that the category relevance of final years started quite broad (with 9 categories represented) but didn't improve (ideally each category is represented with about 10% of concepts in each). "Inequity" and "future" were under-represented, as for the 2nd years. "Technology" was over-represented at the start, and even increased. This suggests that the focus on technical issues is stronger in this final year project than in second year. In the final year course each group is allocated a supervisor (not the sustainability lecturers), who meets with each group each week for about 30 minutes. The supervisors are chemical engineering discipline staff members who are technical experts but have limited knowledge of sustainability issues. The results suggest that while students evidently arrived in the class with an enhanced knowledge of sustainability, the strong technical focus of the short informal weekly meetings counteracts the learning on sustainability in the longer formal workshops. Some professional development (PD) may be needed to enhance the sustainability knowledge of the staff who are supervising the final year projects. Such PD does not exist currently at RMIT, but is under development by the authors.



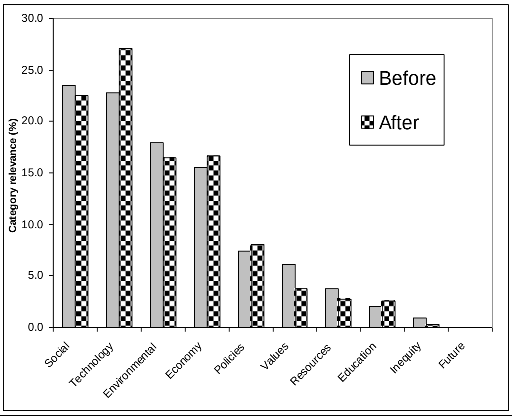


Figure 3a: Evolution of Complexity index (CO) for final years (2012 data)	Figure 3b: Evolution of Category relevance (CR) for final years (2012 data)

Another difference between 2nd and final year is the ranking of categories. While 2nd years thought there were a significant number of issues about (depletion of) resources, the final years did not.

Table 1: Comparison of breadth and interconnectedness of concepts in different year levels

Year level	*Course (year)*	*Sample Size*	*Before*			*After the GEMI workshops*		
			NC	**L_{Ca}**	**CO**	**NC**	**L_{Ca}**	**CO**
2^{nd}	PROC2078 (2011)	85	1.6	0.1	0.1	3.8	0.2	1.0
2^{nd}	PROC2078 (2012)	50	3.3	0.3	1.3	8.4	1.0	9.9
Final (4^{th} or 5^{th})	PROC2091 (2012)	50	5.1	0.6	4.2	5.9	0.7	5.6

Table 1 summarises some of the complexity index data for the 3 cohorts of students. The enhancement in all three indicators after the GEMI workshops was very significant in both second year classes (up to an order of magnitude). This reflects that the students started at a low base. The final years outscored the 2nd years at the start of the course: they had a higher complexity index (CO), higher number of concepts per student (NC), and higher number of links per student per category (L_{Ca}). This suggests the final years had retained some of what they had learned in earlier projects.

Table 1 also shows some unexpected results. As seen in the Figures, the 2nd year class of 2012 performed better than the class of 2011: they started at a higher level (all 3 indicators were higher) and improved to a higher level. The 2012 2nd year class even performed better than the final years. As discussed above, several factors may be at play, such as the results are for different cohorts of students, the growing experience of the lecturers in teaching sustainability, and different supervision arrangements for groups in 2nd year compared to 4th year.

The CO reported for a reference group of European experts was 24.8, and the average CO was 3.2 before and 10.7 after the course, for a set of 9 sustainability courses at a variety of European universities (Segalas, Ferrar-Balas and Mulder, 2009). The results reported here are in a the middle of the range of results found in the European study. Hence we may tentatively conclude that our approach is shifting the conceptualisation of sustainability by the students, but there is room for improvement, especially in the 4th year course. Gaps in knowledge are evident and there is wide variability between outcomes for different groups in the same year level and less progress in final year than expected.

The following areas have been identified for further work:

- curriculum review to increase focus on needs of future generations, and equity between stakeholders
- a longitudinal study of results from the same course
- professional development in sustainability for the staff members who supervise the final year projects.

Conclusions

Employers continue to find gaps between their expectations and engineering graduate attributes, particularly concerning sustainability. Problem based learning is an effective way to address these gaps. RMIT University introduced a new approach to teaching sustainability, using the Industry sustainability metrics approach developed by GEMI. The metrics development approach facilitates a more systematic and rigorous framework for management decision making, including selection of process technology. Students demonstrated a higher level of sustainability knowledge and understanding after participating in sustainability workshops, although the improvements were much more pronounced in 2nd than final year. Students identified a greater number of concepts and links between concepts. Students who had participated in multiple projects demonstrated a higher level of knowledge at the start of the class. Not all groups achieved the same progress, some identified fewer concepts and focused more strongly on technology after the workshops than before. Curriculum review is needed to address gaps in knowledge of aspects relating to future generations and equity between stakeholders. Professional development in sustainability is needed for project supervisors.

References

Baillie, C (2006). *Engineers within a local and global society*. Morgan and Claypool Publishers: US

Cavenett, S. (2011) *Sustainable Engineering and Curriculum Design in Undergraduate Education.* Paper presented at The Society for Sustainability and Environmental Engineering SSEE International Conference, Brisbane, QLD

GEMI. (2007). *The Metrics Navigator^{TM}*. Retrieved 8 July 2011 from http://www.gemi.org/metricsnavigator/

Jollands, M., Jolly, L., & Molyneaux, T. (2012). Project Based Learning as a contributing factor to graduates' work readiness. *European Journal of Engineering Education,* 37(2), 143-154. DOI:10.1080/03043797.2012.665848

Jollands, M.,Parthasarathy, R., & Latham, M. (2011a) *Implementation of industry sustainability metrics in undergraduate design projects.* Invited Paper presented at the Australasian Association for Engineering Education Annual AAEE Conference, Fremantle, WA

Jollands, M.,Parthasarathy, R., & Latham, M. (2011b) *Implementation of industry sustainability metrics in a final year undergraduate design project*. Paper presented at The Society for Sustainability and Environmental Engineering SSEE International Conference, Brisbane, QLD

Latham, M., Jones, H. and Tanzil, D. (2009). *Applying The Metrics Navigator™ to Establish Strategic Indicators for Mining*. Paper presented a the Sustainable Development Indicators in the Mining Industry SDIMI 2009 Conference, Gold Coast, QLD

Schuster, D. (2007) The Road to Sustainability, *CEP Magazine, An AICHE publication, 103(6),* 34-36

Segalàs,J., Ferrer-Balas, D., & Mulder K. F. (2008). Conceptual maps: measuring learning processes of engineering students concerning sustainable development, *European Journal of Engineering Education*, *33*(3), 297-306

Segalàs,J., Ferrer-Balas, D., & Mulder K. F. (2009).Introducing sustainable development in Engineering Education: Competences, Pedagogy and Curriculum. Paper presented at the European Society for Engineering Education SEFI2009, Rotterdam, Netherlands.

Spinks, N., Silburn, N., & Birchall, D. (2006). *Educating engineers for the 21st century: The industry view.* Henley-on-Thames, Oxfordshire: Henley Management College.

Copyright statement