What do Chemical Engineering Undergraduates mean by Sustainability?

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Abstract

In Australia and internationally, key stakeholders in the engineering profession are exerting pressure on engineers to move towards more sustainable practice. The Institution of Engineers, Australia (IEAust) recently overhauled the processes by which many Australian engineers attain two important professional milestones: undergraduate baccalaureate and professional certification/recognition. Sustainability now holds a prominent position in both processes. In this paper, using a student-centered framework for understanding learning, we investigate undergraduate chemical engineering students conceptions of sustainability, and their propensity to learn more about sustainability. We use the SOLO taxonomy to categorize students' conceptions of sustainability as naïve, intermediate, or sophisticated. We then use these categorizations as the lens through which we interpret the students' scale responses to intrinsic and extrinsic motivation factors, and a range of sustainability attributes. We demonstrate direct linkages between complexity of an individual student's conceptions and their interest in learning more about sustainability. This result has important implications for the design and implementation of activities for learning about sustainability in engineering.

1. Introduction

In Australia and internationally, key stakeholders in the engineering profession are exerting pressure on engineers to move towards more sustainable practice[1]. This pressure has contributed to the adoption and routine use of many conventions which complement, or are part of, sustainable engineering. These include environmental management, risk assessment, hazard analysis, quality assurance, due diligence, and community consultation[1]. Although the growing use and acceptance of these conventions has likely delivered more sustainable engineering outcomes, the profession still has some way to go. In the words of Thom[2], 'sustainable development cannot be achieved as an accidental outcome of an open-ended and technically based design process'.

Over the past two decades, The Institution of Engineers, Australia (IEAust), has moved decisively to promote sustainable engineering practice in Australia. IEAust recently overhauled the processes by which many Australian engineers attain two important professional milestones: undergraduate baccalaureate and professional certification/recognition. In 1999 revised National Competency Standards were introduced following an extensive peer review process. These Standards set out the competencies expected of professional engineers and provide the framework for assessment of engineers seeking chartered membership of IEAust. Sustainability issues were one of several key professional and ethical areas of responsibility which were recognized and systematically integrated into the new competency regime. Chartered membership provides access to National Registration, which formally recognizes an engineer as competent to practice in Australia without direct supervision. At the time of writing however, the guidelines that accompany the revised competency standards, and which set out the detail around how to incorporate sustainability within engineering practice itself and the assessment of engineering practice, had still not been actioned by the IEAust.

IEAust also overhauled the accreditation process for undergraduate engineering degree courses. The new accreditation process, which was first mooted in 1997, then reviewed and successfully implemented in 2000, requires that a student acquire ten attributes prior to graduating. Two of those ten attributes refer to sustainability:

- Understanding the social, cultural, global and environmental responsibilities of the professional engineer and the need for sustainable development; and
- Understanding the principles of sustainable design and development.

In light of this, engineering educators in Australia have to consider exactly what it is that graduates need to know, think or feel, to understand sustainable development. Existing literature provides some insightful descriptions of the sustainable engineering graduate[2 4 5 6]. The attributes described by Crofton, Thom, Clift and HE21 have been distilled by the authors of this paper, and are presented in Table 1. It is clear from Table 1 that a student must master a number of abstract and/or complex concepts to thoroughly understand sustainability.

Table 1. Graduate engineer sustainability attributes (derived from [2 4 5 6]).

Type of Learning	Sustainability Attributes
Factual	Know of the existence of natural, social and economic systems Know how component parts of natural, social and economic systems work Understand that limits and uncertainty exist Know the history and consequences of resource use by humans
Ways of thinking	Recognize the links within, and between, natural, social and economic systems Understand the complex nature of interactions within and between systems Consider the direct and indirect impacts of decisions Exercise critical thinking and judgement Understand how to communicate with engineers and others
Ethics	Believe in global equity and equity for future generations Be prepared to take personal and professional responsibility Have respect for the values, views and beliefs of others Be committed to serving the public good

Having ascertained what graduates need to know, think or feel to practice engineering sustainably, we will now examine some educational implications of mandatory sustainability learning. Educational researchers who subscribe to a student-centered view of learning have found that the success of a student's learning outcome is positively correlated with a student's prior knowledge of, perceived personal competence in, intrinsic interest in, and extrinsic motivation to learn about a given topic[7 8]. This is because most students have different learning strategies they may call on to execute a particular learning task[9]. The learning strategy a student

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selects and applies will depend in part on the student's perception of the material or concept to be learned. In taking a student-centered approach to instilling the sustainability attributes described in Table 1, it would therefore be important to appreciate what students already know of sustainability, how accurately they judge their own competence, how interesting they consider it to be, and how motivated they are to understand it.

While a reasonable amount has been published on integrating sustainability and engineering education, very few studies have examined what students themselves think of sustainability. Studies on student perceptions of sustainability-related topics give us some indication of the interest and motivation students may have in learning about sustainability. Researchers at the University of Washington[10] examined engineering students' conceptions of their profession. The student group as a whole had conceptions covering all eleven of the United States Accreditation Board for Engineering and Technology graduate attributes[11]. There was, predictably, a strong focus on technical concepts and great variation in the range of outcomes included in individual schemas. The study suggests that students' conceptions of what it is to be an engineer vary widely, from a limited 'technician' role to a broad based 'generalist' role. The generalist role has features in common with the sustainability attributes described in Table 1. We return to this differentiation between student conceptions in our analyses and discussion.

The overall objective of the research presented here was to gauge our students' conceptions of sustainability, and their propensity to learn more about sustainability. To do this, we used three separate sets of questions. The first question called on the students' own words and perceptions. The second set of questions asked students to rate sustainability itself, and the third set of questions asked students to rate sustainability attributes derived from the literature (Table 1). The specific objectives associated with each set of questions were:

A. To investigate and assess the range of our students' conceptions of sustainability (*i.e.* their actual prior knowledge of sustainability)
B. To assess our students' perception of
    a. their own understanding of sustainability (*i.e.* their perceived sustainability competence)
    b. their level of interest in learning more about sustainability (*i.e.* their intrinsic motivation to learn about sustainability)
    c. the career relevance of sustainability (*i.e.* their extrinsic motivation to learn about sustainability)
C. To examine the interaction between students' sustainability conceptions and their perception of
    a. their interest in learning more about the literature-derived set of sustainability attributes
    b. the career relevance of the literature-derived set of sustainability attributes

2. Method

2.1 Survey

A survey was developed to examine the meaning, understanding, interest, and relevance of sustainability and sustainability attributes to engineering undergraduate students. The survey consisted of three sets of questions. The first question was open-ended and intended to capture students' conception of sustainability in their own words. Students were asked to respond in writing to 'In your own words, what is sustainability?'. In the second set of questions, students were asked to rate how well they understood sustainability, their interest in learning more about sustainability, and the relevance of sustainability to their future career. For the third set of questions, the sustainability attributes described in Table 1 were abbreviated (see Figure 1) and presented to the students. Students were asked to rate: their interest in learning more about each of the sustainability attributes, and the relevance of each attribute to their future career.

In the second and third sets of questions, students gave their answers using Likert-type rating scales. The Likert-type scales ranged from one through five; in all cases a rating of one was actively negative (e.g. student was very disinterested), three indicated indifference (e.g. student was neither interested nor disinterested) and five on the scale was actively positive (e.g. student was very interested)

Survey participants

The survey was administered to fifty two Chemical Engineering undergraduate students enrolled at the University of Sydney, Australia. All of the students who participated were in the third year of a four year program and had completed one compulsory unit of study (equivalent to about 6-8 hours per week over a 14 week semester) which included sustainability. They had also been exposed to the concept of sustainability through both oblique and direct references in other units of study within the degree program.

2.3 Analysis of Open-ended Question

Responses to the open-ended question were analyzed using a modified version of the Structure of Observed Learning Outcomes (SOLO) Taxonomy[12]. The SOLO approach enables analysis of responses to open-ended questions on the basis of two dimensions: structural and referential. Here, structural refers to the level of complexity in the form of the response, and referential refers to the actual content of the response. Sustainability is a complex, not necessarily well defined concept. So, although we did include both dimensions in our analysis, we favored the structural dimension over the referential dimension, in keeping with the nature of the concept of sustainability. The SOLO Taxonomy provided a measure of the sophistication of each student's conception of sustainability and students were classified on the basis of their SOLO scores as having a naïve, intermediate, or sophisticated understanding of sustainability. Results of the SOLO analysis are presented in full elsewhere[13].

2.3 Analysis of Sustainability and Sustainability Attribute Scale Responses

Forty-nine complete Likert-type scale response data sets were obtained. For the second set of questions (understanding of, interest in, and career relevance of sustainability) means and standard errors were calculated for the whole student group (n=49). Differences between the ratings for understanding, interest and career relevance were identified using T-tests. The whole student group was then divided into three groups on the basis of their SOLO scores. Our assessment of an individual student's conception of sustainability (SOLO analysis) became the independent variable in our analysis. The groups were naïve (n=16), intermediate (n=18), and sophisticated (n=15). Means and standard errors were then calculated for each group's ratings for understanding of, interest in and career relevance of sustainability, and T-tests were used to examine for differences between group ratings. Responses to the third set of questions were treated similarly. The students' responses to these questions were divided into the three SOLO groups and means and standard errors were calculated. T-tests were used to compare between-group ratings for interest in, and career relevance of each sustainability attribute.

3. Results and Discussion

Survey results can be interpreted in various ways. The simplest approach would be to report whole group means and standard errors for all the Likert-type scale responses, using means as a measure of the overall group response and standard errors as indicative of within-group variation. This approach assumes that all respondents are answering the same question. In other words, that all respondents hold the same conception of, in this case, sustainability. This obvious shortcoming is explored in more depth below. A more sophisticated approach, which enables greater differentiation of the response, is to view the scale responses through the lens of the open-ended question responses. When we take this approach, the survey results yield significant insights for the teaching and learning of sustainability within engineering.

3.1 Sustainability Scale Responses

When the whole group data was examined it appeared that on average students rated their understanding of sustainability marginally above 'neither well nor poorly' ($x=3.47$ $SE\pm0.15$) and their interest in learning about sustainability marginally above 'neither interested nor disinterested' ($x=3.56$ $SE\pm0.17$). The relevance of sustainability to future career ($x=4.08$ $SE\pm0.13$) was rated significantly higher than understanding ($p=<0.05$). These findings suggested that while the students believed that understanding sustainability would help them in their career, they were not very confident in their understanding, and fairly indifferent to learning about sustainability.

At this juncture we would like to point out an important shortcoming of closed questioning in survey research. Our survey asked students 'How interested would you be in learning about sustainability in your Engineering course?'. Research by Marshall and others[14] found that engineering students held widely varying conceptions of what it is to 'learn'. These conceptions ranged from 'memorizing definitions, equations and procedures' to 'learning as changing as a person'.

The SOLO analysis of student responses to the open-ended survey question found that students also held widely different conceptions of sustainability[13]. In other words, the question 'How interested would you be in learning about sustainability in your Engineering course?', would have a different meaning to each student, depending on what they understood by 'learning' and 'sustainability'. Qualitative surveys about sustainability have suffered through failure to recognize this, in the construction of the survey's approach and/or in interpretation of results[15]. We addressed this issue by separating the students into three groups on the basis of their SOLO scores. The SOLO scores acted as an external measure of the existing sophistication of student conceptions of sustainability (prior knowledge). The differences between whole group findings and findings based on SOLO group data were marked, and strongly illustrated the differences in attitude and preference between groups of students within a larger group.

Table 2 shows the mean ratings given to understanding of sustainability, interest in learning about sustainability and career relevance of sustainability, by each of the three SOLO groups - naïve, intermediate and sophisticate.

Table 2 SOLO group ratings of understanding, interest and career relevance of sustainability.

		Mean Ratings (Standard Error)		
SOLO Group	**n**	**Understanding**	**Interest**	**Career Relevance**
Naïve	16	2.81 (0.26)*	3.44 (0.30)	3.81 (0.21)
Intermediate	18	3.67 (0.23)	3.11 (0.30)	3.83 (0.25)
Sophisticated	15	3.93 (0.21)	4.20 (0.20) *	4.60 (0.16) *

* significantly different

In contrast to the whole group results reported above, it is clear that student attitudes to sustainability are strongly influenced by their prior knowledge of sustainability. The naive group rated their sustainability competence (understanding) significantly lower than either intermediate or sophisticated ($p=<0.05$). There was, however, no significant difference between the intermediate and sophisticated groups in terms of how they perceived their own sustainability competence.

The whole group mean suggested that students in general were not very interested in learning about sustainability. The SOLO analysis, however, reveals that students in the naive and intermediate group are generally indifferent to learning about sustainability, but the sophisticated group show significantly more interest ($p=<0.05$). In formulating activities for students to learn about sustainability, the naive and intermediate groups would likely prove harder to motivate.

The sophisticated group also rated sustainability as being significantly more career relevant ($p=<0.05$) than did naive and intermediate groups (Table 2). Students in the sophisticated group may have different career aspirations, or, paralleling the University of Washington results[10], may have different conceptions of what it is to be a professional engineer. The students who perceive sustainability as less career relevant are less likely to consider it worthwhile learning.

As was discussed earlier, factors such as prior knowledge, perceived personal competence, and intrinsic and extrinsic interest in a topic strongly influence the success of a student's subsequent learning about that topic. In examining engineering students' attitudes towards sustainability we have selected and employed four rough proxies for these four factors. The SOLO analysis provides an external measure of students' prior knowledge of sustainability. Student ratings of their own understanding provide us with a measure of students' perceived sustainability competence. Ratings of interest in learning more about sustainability, and perceived career relevance of sustainability are rough proxies for intrinsic and extrinsic motivation, respectively. In learning about a topic, Marton and Säljö[9] hold that students can select one of two basic learning strategies – deep or surface, and this selection is made on the basis of such factors as those discussed above[7 8]. The deep approach assists students in attaining well integrated, comprehensive and sophisticated understanding, whereas students using a surface approach tend to attain shallow, non-integrated or memorized understandings[9].

Our results suggest that the sophisticated group are likely to employ deep approaches in future learning about sustainability, and consequently attain more sophisticated conceptions of sustainability. The likely approach to and outcome of future sustainability learning for the intermediate group is less clear cut. The intermediate group ratings were the same as the sophisticated group for perceived understanding but mirrored the naïve group for interest and career relevance. A follow up study examining the development of this groups' sustainability conceptions would allow us to identify which of the factors is more important in mediating learning approach and learning outcome. The naïve group, who rated understanding, interest and career relevance low, will probably favor surface approaches which are unlikely to assist these students in attaining sophisticated conceptions of sustainability. The findings do not bode well for the prospect of naïve students satisfying the new IEAust graduate attribute requirements for an understanding of sustainability[3]. In considering how to address this potential problem, we examined the attitudes of the different SOLO groups to each of the sustainability attributes described in Table 1.

3.2 Attribute Scale Responses

3.2.1 Interest in learning about sustainability attributes

Figure 1 shows the mean interest ratings given to sustainability attributes viewed through the lens of our assessment of the individual student's conception of sustainability (SOLO groups).

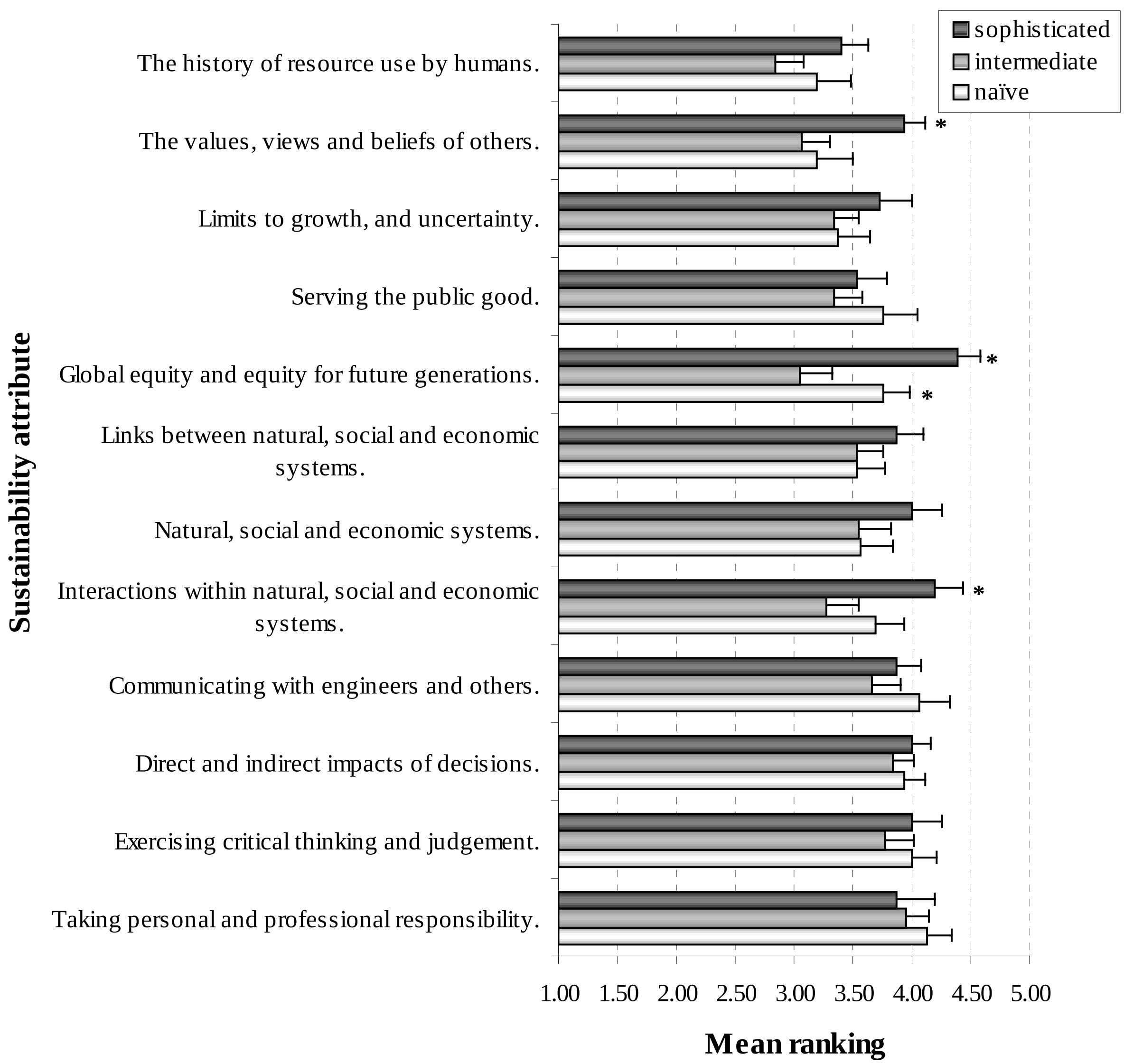

Figure 1 Interest in learning more about sustainability attributes for the three SOLO groups (mean ±SE). * significantly different

For nine of the twelve sustainability attributes, interest in learning about the attributes was the same across all three SOLO groups. The attributes rated highly by all groups were: taking personal and professional responsibility; exercising critical thinking and judgment; direct and indirect impacts of decisions; and communicating with engineers and others. These attributes are the ones which relate most immediately to students own actions as (future) engineers; they are the most obviously applied attributes. All three groups rated learning about the history of resource use by humans as least interesting.

The attributes which elicited significantly different interest ratings among the SOLO groups were: global equity and equity for future generations, the values, views and beliefs of others, and interactions within natural, social and economic systems. The sophisticated group judged global equity and equity for future generations to be the most interesting of all of the sustainability attributes. The naïve and intermediate groups rated this attribute significantly lower than the sophisticated group ($p=<0.05$ and $p=<0.01$ respectively). The sophisticated group also rated learning about the views, values and beliefs of others as significantly more interesting than did the naïve and intermediate groups ($p=<0.05$ and $p=<0.01$). These findings are interesting as equity and consultation (views, values and beliefs of others) are two of the strongest ethical considerations inherent in sustainability thinking[1]. While further investigation is required, one hypothesis for this finding would be that these sophisticated students have reached a stage of intellectual development called 'commitment'[16]. In the commitment stage, students seek an understanding of reality which encompasses more than just factual information. The sophisticated group also considered interactions between natural, social and economic systems to be more interesting than did the intermediate group ($p=<0.05$).

While most of the relationships are non-significant, Figure 1 seems to indicate that the intermediate group displayed less interest in some of the more conceptual (less applied) aspects of sustainability learning than both naïve and sophisticated groups. This trend may warrant further investigation.

3.2.2 Career relevance of sustainability attributes

Figure 2 shows mean career relevance ratings given to sustainability attributes by students according to their sustainability conception (SOLO score).

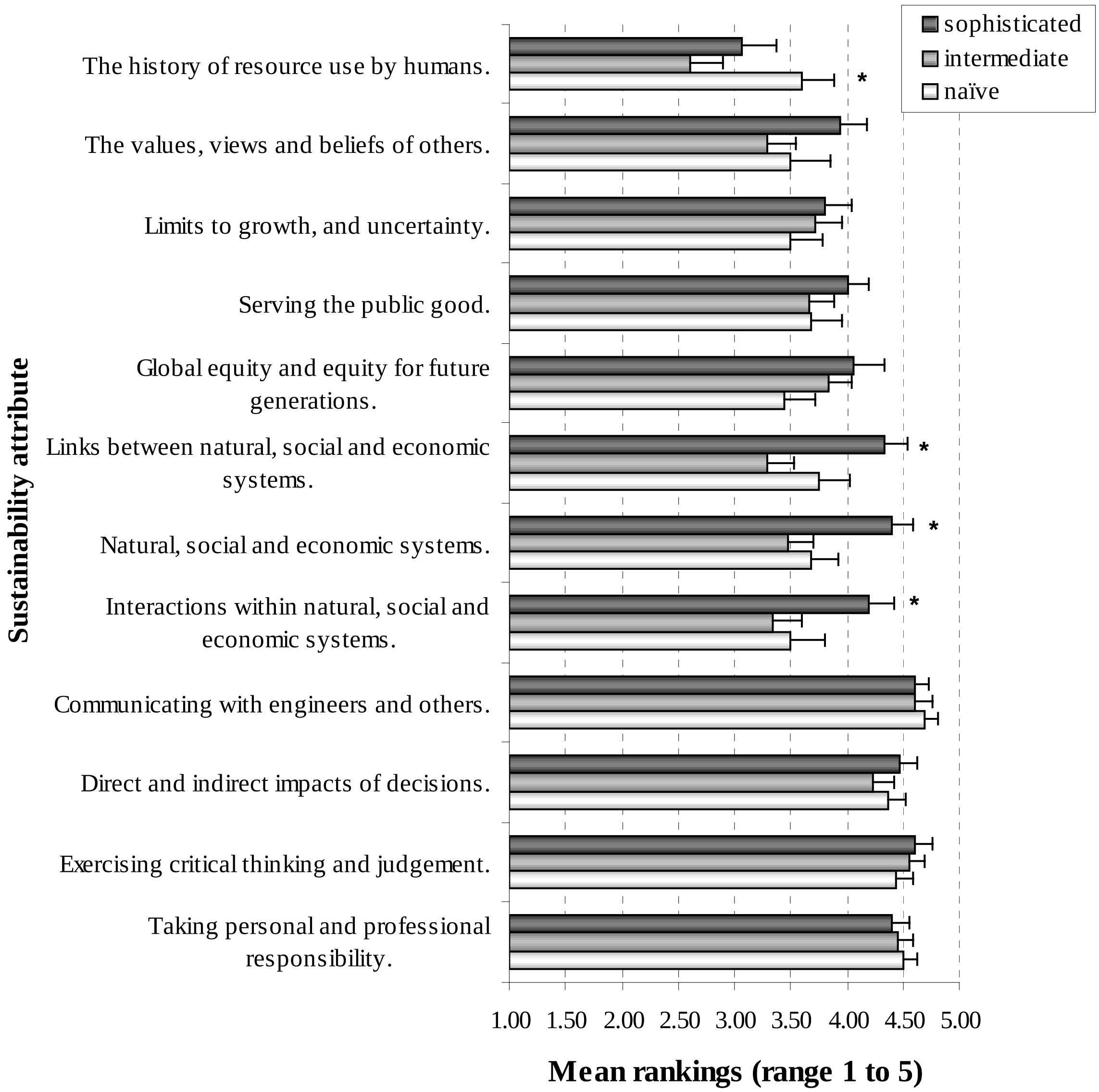

Figure 2 Career relevance of sustainability attributes for the three SOLO groups (mean ±SE). * significantly different

The results resemble those obtained for interest in learning about sustainability attributes. The attributes rated highly career relevant by all groups were: taking personal and professional responsibility; exercising critical thinking and judgment; direct and indirect impacts of decisions; and communicating with engineers and others. So in general students consider these attributes to be both interesting and career relevant indicating that students are likely to respond most positively to learning about these attributes.

Students with sophisticated and intermediate SOLO scores rated the history of resource use by humans as least career relevant. Interestingly, the naïve group rated this attribute as significantly more career relevant than did the intermediate group (p=<0.05). This suggests the naïve group would show a stronger extrinsic motivation to learn about the history of resource use by humans.

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The sophisticated group consistently rated those attributes which referred to natural, social and economic systems as more relevant to future career than students in the intermediate group ($p=<0.05$). Students in these two groups may have different career plans or perceptions of the engineering profession. Alternatively, the students could be mirroring the strong focus on systems thinking as a pivotal part of sustainability within their Department of Chemical Engineering.

The ratings shown in Figures 1 and 2 give us an indication of what component parts of sustainability learning students are most likely to respond to, and what parts they may reject. The findings also clearly illustrate the existence of distinctive preferences on the basis of students' prior knowledge of sustainability.

4. Conclusions

We showed that our 3rd year chemical engineering students hold a range of different conceptions of sustainability, varying from naïve to sophisticated. We also showed that these different conceptions correlate with factors such as perceived competence, and intrinsic and extrinsic motivation. This is a significant finding for engineering educators who subscribe to a student-centered approach to teaching and learning, because these factors dictate the likely approach that students will take in learning about sustainability. If students are to build a sophisticated conception of sustainability to meet emerging societal expectations and attain the new IEAust graduate attributes, they must employ deep learning strategies, and their sustainability guides and role models (also known as teachers) must enable them to do so.

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Biography

Anna L Carew is a doctoral student in the Department of Chemical Engineering at The University of Sydney researching the integration of sustainability and engineering education. Anna trained as a microbiologist and worked in wastewater engineering, industrial training and sustainability consulting prior to commencing graduate studies.

Cynthia A Mitchell is currently President of the Australasian Association for Engineering Education. She is also the Director of Teaching and Learning in the Department of Chemical Engineering at The University of Sydney, where she holds a Senior Lecturer position. Her desktop screensaver is 'engineering as if sustainability mattered'. Her heroine is Margaret Mead, who has been credited with the following quote

'Never doubt that a small group of thoughtful committed citizens can change the world: indeed, it's the only thing that ever has'