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Scoping metalearning opportunity in the first three years of engineering

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BACKGROUND

The present study is embedded in a wider, strategically funded, two-year educational research project situated across the Schools of Civil, and Mechanical and Mining Engineering. It has as one focus the design of learning experiences to develop students' *metalearning capacity*: the capacity to be aware of one's learning behaviour in a given situation (i.e., learning a particular topic) and to be in control of such behaviour. An essential requirement here is a conceptual model of learning engagement, accessible to students in terms of language and complexity, within which they can locate themselves. A specific metalearning activity based on the Reflections on Learning Inventory (RoLI) has been developed and linked to improvements in self-reported outcomes within first-year level economics courses. The application of the RoLI in an undergraduate engineering context is a new development in engineering education research.

PURPOSE

The primary research aim is to investigate whether or not data captured by the RoLI exhibits variation in learning behaviour across samples of undergraduate engineering students, both within courses and across courses. If this is so, a secondary aim is to determine if a RoLI-based metalearning activity provides useful information to individual students wishing to change their learning behaviour. Evaluating the usefulness of metalearning activity is a first step in demonstrating to both students and teachers the benefit of formally incorporating metalearning interventions into the curriculum.

DESIGN/METHOD

Data are drawn from three classes of students who completed the Reflections on Learning Inventory: first-year Engineering students (n=169; class size 423), second-year Mining students (n=97; class size 143), and third-year Civil students (n=138; class size 277). Exploratory factor analysis is used to identify patterns of variation in the learning strategies adopted by students. A subgroup of mining students were also asked to reflect on their experiences of a metalearning activity and comment on whether or not it changed their learning behaviours, and these results are analysed qualitatively.

RESULTS

Factor solutions are readily interpretable and provide conceptually clear evidence of variation in distinct learning strategies used by students that are consistent across the first, second, and third years of study. Metalearning activities can help teachers to identify the specific learning behaviours of individual students and offer them assistance on strategies to enhance understanding of material rather than memorisation. Individual student reflections and feedback on a metalearning activity clearly indicated that it was beneficial. Additional qualitative data indicated that some students changed their learning behaviours on their own following this activity.

CONCLUSIONS

The factor solutions and qualitative data provide insights into the learning behaviour of the student samples. In particular, there is clear evidence of patterns of fragmented and reproductive 'learning' engagement. The metalearning activity makes this finding visible to both students and teachers, which is an essential recognition step before either group will be prepared to invest time in improving practices that enhance students' approaches to learning. These results identify the need to include activities in the curriculum focused on helping students develop deep-level learning strategies.

KEYWORDS

Student learning, Metalearning activity, Engineering

Introduction

Applying education and learning sciences research to engineering education has been an important shift for the community in its effort to promote an intentional set of undergraduate engineering learning outcomes (Froyd, Wankat & Smith, 2012). Despite this shift, however, there is still the need to improve understanding of how undergraduate engineers learn (Johri & Olds, 2011) and how students themselves can be taught to recognise their own learning behaviours so that they may engage in deep-level integrative approaches to learning (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011). Only recently have empirical studies of metacognition within engineering education begun to emerge, and the conceptualization of this term has taken on multiple meanings (Lawanto, 2010), including awareness of knowledge, thinking, and organizing cognitive resources (e.g., Cuasay, 1992; Flavell, 1979; Marzano et al., 1988). Though preliminary work suggests a relationship between metacognition and engineering student learning outcomes (Case, Gunstone & Lewis, 2001; Lawanto & Johnson, 2009; Newell, Dahm, Harvey & Newell, 2004), a dearth of published studies leaves this a question to be answered (Brumback, Schumacker, & Fonseca, 2010).

These studies that seek to investigate students' metacognition often do not focus on '*metalearning,*' the much more specific aspect of individuals' awareness of their own approaches to learning and their capacity to control it. *Metalearning*, as operationalised in the present study, is a concept first proposed by Biggs (1985) within the broader psychological domain of metacognition, and the development of such capacity is associated with deep-level, self-regulated, integrative learning. Such development requires enabling mechanisms to be embedded in the learning environment to help students make their own learning visible for themselves for interpretive, reflective, and then actionable purposes.

Though empirical research within engineering education on metalearning specifically has been quite limited, a few researchers have made efforts to develop a better understanding of engineering undergraduate student learning. At James Cook University (JCU), Turner (2001, p 415) advocated a 'Metalearning program utilising direct instruction' and proposed an outline for such a program as the basis for a pilot study. There are significant differences, however, in Turner's advocacy and the approach of the present study. The approach taken in the pilot study in the JCU engineering program was characterised by 'direct instruction in metalearning' to create a 'structured metalearning experience' (p. 419) covering six elements, only one of which referred to 'learning and motivation', as opposed to a more experiential learning approach. An aim in the present study is to evaluate approaches tailored to individual students that are embedded within individual courses and across the curriculum. In later research, Turner (2004) administered the Study Process Questionnaire (SPQ), a first-generation self-report instrument used to identify students' approaches to learning, to a sample of 65 engineering students. Results indicated that students engaged in a variety of learning strategies, including both surface- and deep-orientations. Because several 'aberrant' learning profiles (e.g., students reporting high usages of both orientations) emerged, Turner cited the need for further investigations before interventions could be developed. It was not apparent in this research design whether or not students were asked to consider a single context for learning when they completed the SPQ. Because approaches to learning are contextually dependent, 'aberrant' profiles may be explained by this limitation in the study's procedures and/or the phenomenon of 'dissonance' in learning behaviour after the work of Meyer (2000). In the present study, this limitation is addressed by setting the evaluation within the framework of a small part of each course, such that students are focused on a specific concept.

Other efforts within Australia have also been undertaken to introduce 'metalearning' activities into the undergraduate engineering curriculum to prepare students to engage as 'life-long-learners' in their professional engineering careers. Researchers in the Civil Engineering Program at Griffith University conducted a study to investigate variation in student learning approaches across several of the program's courses (Jenkins, Edwards, Nepal, & Bolton, 2011). Using a reduced form of the SPQ, students indicated (via aggregated numerical scores on the SPQ subscales) that they tend to engage in deep learning styles as opposed to surface learning styles. Within the conceptual constraints of the SPQ motive and strategy model, students' approaches to learning showed little variation across courses, regardless of the year in which the course fell within the curriculum sequence. Though the authors attributed deep learning approaches taken by students to a strong civil engineering focus within courses, their study did not explicitly test this assumption. The learning environments for the courses studied were all fairly similar, comprised of lectures and tutorials/workshops, so claims linking course content to student learning approaches are problematic. An improved research design might, for example, have compared learning approaches across courses characterized by different learning environments. Moreover, left open was the question of variation in learning approaches *within* courses – that is the degree to which students engage in different learning approaches based on the complexity of the concepts being discussed. Understanding how students approach learning some of the most difficult concepts within courses would be an important step forward from this research. This is one aim of the project within which the present scoping study is located.

The concept of metalearning embraces an individual student's knowledge of their own learning processes and the versatile capacity to regulate them in some given learning context. It follows that for students to develop their metalearning capacity, they need to be made *aware* of their own learning behaviour, *enabled* to conceptually interpret it, and *empowered* to change it according to contextual demands. Students cannot be expected to begin developing their metalearning capacity by simply, as a vicarious experience, being told about the known conceptual distinctions in the learning behaviours of other students. Rather, they must actively engage in activities that make them aware of their own personal learning behaviours. In summary, our overall long term research aim is to determine if students can act where necessary to improve their learning behaviours once these are made visible to them. The present study represents an important first step forward in how to operationalize metalearning within the undergraduate engineering setting. Specifically, we address the following questions:

1. Does an existing RoLI-based metalearning activity distinguish variation in learning behaviour across undergraduate engineering students, both within and across courses?
2. Does this activity provide useful information to students who wish to change their learning behaviour?

Methodology

An ongoing research program at the at the University of South Australia has developed an online portal (**www.rolisps.com**) that allows individual students to log on and self-generate a personal learning profile by disclosing discrete aspects of their learning behaviour within some given context. The profile reflects the domain of the Reflections on Learning Inventory (RoLI), an instrument psychometrically developed by Meyer (2004) for metalearning purposes. Metalearning activities, in the first stage of developing metalearning capacity, focus on making students aware of their own learning in a given context. Students have to be able to 'see themselves' through such a learning profile as depicted in their own terms within the learning context. Figure 1 shows an example profile that an individual student would receive, where maximum scores on each observable is 20. Higher scores on negative learning behaviours (red bars) and lower scores on positive learning behaviours (green bars) show students that they may want to consider adopting new and better strategies for approaching learning. Amber bars denote culturally sensitive observables that can be either positive or negative. Developing this awareness is supported by a detailed explanation of the constructs embedded in the domain of the RoLI, available online at the time the learning profile is generated.

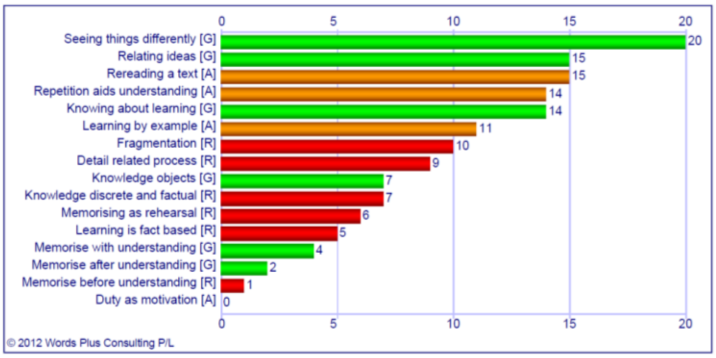

Figure 1: Example of an individual RoLI learning profile

Sample. Students enrolled in the following courses completed the RoLI early in the semester after one specific topic had been completed:

Introduction to Fluid Mechanics (n=138; class size=277): A compulsory course for third year Civil Engineering students in a four year program. The students have completed all basic theory courses (mathematics, mechanics and physics) and by this time are well-versed with momentum concepts for solids that are stationary (completing four courses containing this fundamental concept). This course is the first time students are faced with momentum concepts related to fluids including its movement and acceleration.

Introduction to Mining (n=97; class size=143): A compulsory second year mining course; it is the first mining course taught to students who have had little or no exposure to the mining industry. It is intended to introduce students to mining terms, descriptions, operations and equipment. This course forms a base for many mining courses that mining students need to study as part of their curriculum. The second-years were invited to complete the RoLI twice, at the beginning of, and following, a class learning episode. Students who thus participated twice in the metalearning activity were asked to write a short, reflective, and open-ended account of their experiences indicating what, if anything, they might do as a consequence. These reflective accounts comprise the qualitative scoping data presented further on.

Engineering Mechanics: Statics & Dynamics (n=169; class size=423): A compulsory first year course, this course aims to develop a basic understanding of the mechanics of physical bodies under the action of static and dynamic force systems. Based in applied mathematics, it applies to all engineering disciplines and is fundamentally important to the development of courses like solid mechanics and dynamics which themselves form the basis of structural analysis in Civil, Mechanical, Aerospace, Mechatronic and Mining Engineering.

Research question 1. What is the dimensionality of variation in student learning across the samples? We answer this question directly by factor analysing aggregated RoLI data. The dimensionality of variation is expressed by the number of factors in a given solution. Exploratory factor analysis basically exhibits variation in response patterns on empirically discrete subsets of observables that respectively 'define' any particular factor in terms of high absolute 'loadings'. The observables in each such subset are linearly related. Generally the defining features of factors can be used to isolate multiple related observables that can be used to construct an internally consistent higher-order construct. Factor solutions also provide teachers with quantitative and conceptually interpretable insights into the aggregated patterns of their own students' learning engagement; for example learning within a particular topic or learning a particular concept.

Research question 2. Does metalearning activity generate capacity for improvement? We explore the qualitative reflections of a subgroup of second-year students who participated twice in a metalearning activity. The short reflective accounts of their metalearning experiences are analysed for evidence of individual student capacity to self-initiate changes in their learning behaviour. We provide qualitative data supporting the three major themes that emerged from these accounts.

Results

Quantitative Data

For the third-year class (n=138), factor analysis empirically identifies three interpretable dimensions of variation in learning (Table 1); these dimensions show which observables in the learning profiles constitute discrete entities of conceptual interest. For example, Factor 1 represents deep-level learning behaviour that is clearly defined by the six highest loading observables which also separately exhibit an acceptable level of internal consistency (alpha= 0.70). The subset of observables defining Factor 1 furthermore implies the presence of variation in self-regulated learning behaviour. Following the modelling work of Meyer, Ward & Latreille (2009), four of the observables are of particular interest because they may also be regarded collectively as a proxy for variation in metalearning capacity: Knowing about Learning, Relating Ideas, Knowledge Objects, and Seeing Things Differently.

Table 1. Factor solutions: Third-year (bold), second-year (italic), first-year (underlined)

Observables: In the given response context 'learning' is about variation in...	F1	F2	F3	F4
Seeing Things Differently	**64** *76* 67			
Knowing about Learning	**60** *70* 68	-27		
Memorising with Understanding	**56** *70* 54	*28*		
Relating ideas	**56** *68* 73			
Using Knowledge Objects	**47** *62* 60			
Memorising after Understanding	**45** *66* 41			
Re-reading of Text(s)	**38** *32* 44		**41** *57* 37	*-27*
Learning by Example	**34** 29	**28** 28		*53*
Fragmentation		**81** *85* 80		
Learning Motivated by Sense of Duty		**56** *60* 47		
Detail Related Process		**49** *74* 79		
Memorising before Understanding		**45** *26* 56	**35** *51* 33	*34*
Knowledge is Discrete and Factual		**40** *39*		57
Repetition Aiding Understanding			**96** *82* 98	
Memorising as Rehearsal (i.e., rote learning)		38	**68** *79* 49	*-31*
Fact-based Learning		**33** *38*	**47**	86
Inter-factor correlations				
F1		**-04** *10* 02	**11** *35* 10	*-09* 11
F2			**40** *33* 29	*14* 52
F3				*0* 34

Note: (a) First three eigenvalues (third-year) are 6.76, 3.12, 1.50. First four eigenvalues (second-year) are 8.65, 4.74, 2.37, 1.04. First four eigenvalues (first-year) are 8.37, 4.40, 1.89, 1.05.
(b)Factor loadings and correlation coefficients are multiplied by 100 and rounded to two places.
(c) Factor loadings with an absolute magnitude < 25 not tabulated.
(d) Some observables exhibit cross-factor loadings, signalling either a differential or cultural effect.
(e) Each factor in a given year-solution is dimension of variation for all students in that year-sample.

All students contributing to the analysis can be 'located' within Factor 1. By summing students' inventory scores on the six observables that define this factor (maximum score of 120, or 6 observables multiplied by 20 possible points apiece), students may be located within the distribution of this deep-level dimension of learning, as presented in Figure 2. The figure illustrates how students' use of deep-level learning varies within this course. A greater number of students reporting higher levels of metalearning capacity would have negatively skewed the distribution (resulting in a 'bulge' on the right, and a 'thinner' tail end on the left). As it stands, however, the need to develop such capacity is exhibited in the low-score tail end of the frequency distribution – these are the students who may benefit most from some form of intervention. These data provide an answer to one of the key aims of the research: for this sample of students: variation exists in the use of deep-level learning behaviour. And because the research methodology can focuses on the learning of a single concept, repeated metalearning activities can contrast variation in the learning of different concepts.

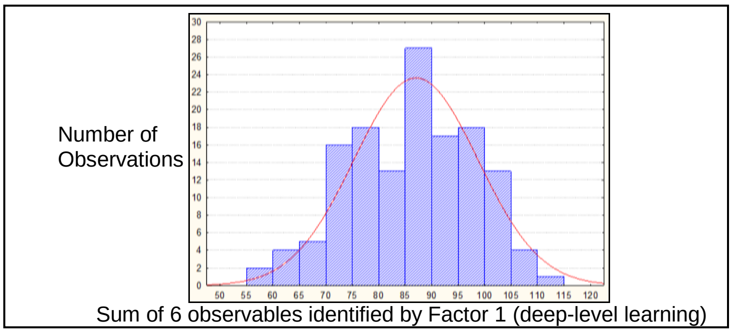

Figure 2. Students' summed deep-level learning scores on a 0-120 scale

In contrast to Factor 1, Factor 2 is substantively defined by learning motivated by a Sense of Duty, Fragmentation, Detailed Related Process, Memorising before Understanding, and Knowledge perceived as Discrete and Factual (Table 1). This factor captures variation in 'learning' behaviour that bears no resemblance to the learning described by Factor 1. Factor 3 substantively captures 'learning' in terms of Re-reading of Texts, Repetition Aiding Understanding, Memorizing after Rehearsal, and Fact-based Learning.

Each factor represents how *all* students vary within that dimension of learning behaviour. The three factors under discussion illustrate the presence of contrasting patterns of learning for the third-year students. In varying degrees, individual students thus reported engaging in possibly transient, preferential, or habitual forms of learning. It follows that at an individual level there will be students who stand to benefit from activities enabling them to examine, interpret, and reflect on their own learning in context. By linking their own learning profiles to temporal outcomes and related experiences, they may also be persuaded to self-initiate changes in their learning behaviour.

Similarities between the solutions across the year groups and engineering disciplines are clear in Table 1. Factors 1, 2, and 3 respectively share a common structure (with only some differences in emphases in terms of the higher loadings). This commonality, in particular, signals multiple dimensions of learning behaviour across the student cohorts. In terms of finer nuancing, Factor 4 in the second-year solution also draws attention to a dimension of variation in learning as Learning by Example, Memorising before Understanding, Re-reading of Texts (weak negative influence), and Memorising as Rehearsal (weak negative influence). The relatively low loadings overall suggest that Factor 4 may simply be a statistical artefact, but it is nonetheless independent of the other three factors.

Qualitative Data

A subgroup of 60 second-year students who participated twice in this metalearning activity wrote short reflective accounts based on their experiences.

Extracts of some of these accounts are presented in Table 2, in which each entry represents a different individual. Three main themes emerged from the qualitative data. First, students reported that usage of surface-level, memorisation learning techniques is largely driven by preparation for course assessments. They suggested that memorisation was the only way to attain high marks on exams, largely because of the limited time to prepare for assessments. This theme suggests that there is an opportunity for academic staff to adjust assessment techniques or to explain more explicitly to students that developing a deep understanding of concepts – as opposed to remembering discrete pieces of information – may be a better strategy for scoring high marks and ultimately learning a subject. Second, students reported that the metalearning activity promoted self-awareness of their learning approaches. This awareness was an important goal of the present study, so it was encouraging to see it reported.

Table 2. Reflections from second-year students following a second administration of the RoLI.

Emerging Themes	Evidence from Qualitative Reflections
Learning as Memorising for Exams	I have form[ed] a concept that study is memorizing facts.
	I have limited times to study as international student...I tried to spend times to understand the really [big] ideas behind the lectures and questions...But the result is disappointing, it cost more time than simply memoris[ing] the facts...Moreover, understanding real ideas seems not to obtain better marks in exam[s] in terms of the energy and time I spent.
	Memorising before understanding is a shortcut for me to cope with exam[s]
	Memorising as rehearsal seems to be my only way to prepare [for] my exam. Though not all negative learning habits and areas were changed, there were some positive changes that could be worked on further.
	Memorising has become more important as the exams are just around the corner
	Even if I do not fully understand the material, I still want to get good marks; memorising [becomes] the only thing that can help in this situation.
Promoting Students' Self-Awareness	[The metalearning activity] also gave me knowledge about how some of my learning styles may be hindering my ability to perform at university. I still do not know how to promote memorising reversal and the learning based on fact...However, although I have these problems I still [am] trying to change and have influenced result slightly...In summary, I still have the problems as [first profile]...But they are changing by me gradually. Astonishingly, the [second profile] tells me that I'm doing too many things like 'memorising as rehearsal' as it stays on the No 1 entry on my profile.
	The first [profile] gave me data to think about how I was learning, and the second has confirmed more accurately how exactly I learn. [The exercise] allowed me to actively explore various learning methods and gain some insight into their effectiveness.
	I would agree with the results. I feel that my learning strategy is effective...however there [are] some areas that can be improved upon. I think the biggest change would have to be…committing material that I do not understand into memory...In my studies now, I believe I'm becoming more aware of how I memorise something.
	I am pleased with [my] learning profile as it hasn't changed much...I did note that there were some bad habits that have crept into my learning, but I will take note and adjust accordingly. Overall [this exercise] has revealed my strengths in learning.
Promoting Change in Learning Behaviour	Overall I am pleased with the results of my second profile. My change in my learning strategy after [first profile] is visible in the second [profile], and I am now more aware about how to proceed with my learning.
	My [learning profile]…indicates that my learning engagement is likely to be unproblematic; however [there is a suggestion] that not all my aspects of learning seem to be productive. Comparing these two [profiles], the outstanding improvement I have achieved is that I have realised repeating [repetition] is not really helpful to my study...The only way for learning new knowledge is trying to understand their meanings instead of repeated reading or writing them down on papers.
	Overall my learning habits have changed for the better, as shown in [the profiles]...I used to memorise things I needed to learn…now I strive to understand what I am learning [which] helps me understand and do problem solving questions more effectively.
	The [metalearning activity] was helpful in that it did give me a perspective on my learning and my learning experiences...By perusing the [explanatory] guide and analysing [my profile] I was able to effectively judge how my learning was progressing and make any necessary amendments to my learning.

Third, some students reported actively changing their approaches to learning following the first administration of the RoLI. Again, a key aim of the research was to determine if this occurred. Beyond making students aware of their own learning, prompting indicated changes in learning behaviour is the ultimate goal of metalearning activities. The written accounts clearly indicate that some students were able to effect indicated changes on their own, an important result of this research. It is not claimed however, that when indicated via self-diagnosis, such self-driven changes would be within the grasp of *all* students. Additional interventions may be required to help such students.

Discussion and conclusion

The present scoping study is based on self-selecting samples of volunteer students, and the reported findings may accordingly be biased. There is nonetheless an overall impression of consistency and comparability in the factor solutions across cohorts and engineering disciplines. Results indicate the presence of multiple dimensions of variation in student learning engagement, each of which signals a basis for proposing the incorporation of metalearning activities across the first three years of undergraduate study. This answers one of the research aims: the metalearning activity quantifies variation in learning behaviour so it is visible to academic staff and students. Problematic patterns of learning behaviour that may place students at risk of low academic achievement can furthermore be identified. Therefore, the research also demonstrates that the metalearning activity is useful for determining that an intervention may be necessary to help students adopt deep-level learning behaviours. Future work will determine whether or not specific aspects of curriculum and assessment practises may induce transient patterns of ‘at risk’ behaviour or reinforce stable ‘at risk’ predispositions to ‘learning’.

Incorporating metalearning activities into the educational experiences of undergraduates has several implications for the development of undergraduate engineers. First, students who are aware of their own learning tendencies will be able to adjust how they process, interact with, and instil information when they encounter new and difficult concepts. Because learning complex conceptual knowledge is critical for developing expertise, engineering education researchers have called for such links to cognitive psychology (Streveler, Litzinger, Miller, & Steif, 2008). Second, purposefully developing students’ metalearning capacities will enable them to become more self-aware across contexts in which they engage, which may improve additional skill areas, such as problem solving. Previous research supports this notion, as engineering undergraduates who were taught how to be aware of their own problem solving strategies were more aware of a wider range of problem solving procedures when compared to students who focused on problem solving content (Ko & Hayes, 1994). Third, helping students become aware and take control of their own learning may facilitate more effective *team-learning processes*, an important development area within undergraduate engineering education. Researchers at Rowan University have shown that providing instruction to enable students to become aware of their own and their teammates’ learning ‘styles’ improves both team performance and students’ attitudes toward teaming skills (Dahm, Newell, Newell, & Harvey, 2009). Finally, there are implications for academic practice in extending the locus of individual teachers towards an awareness of variation in their own students’ learning. Using metalearning data to inform practice can enhance the student learning experience, as supported by Jackson’s (2004) review of studies on metalearning:

> These studies also show that teachers can use this new knowledge about how their students are learning to help individual students develop learning strategies that are more appropriate for particular study contexts. They show that students develop personal knowledge about the ways they are learning (their own metalearning) and that in some cases this new knowledge can change beliefs and values and result in new ways of learning that are more consistent with the demands and requirements of the learning environment (Jackson, 2004, p. 400).

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