Complexity Makes Me Feel Incompetent and It's Your Fault

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STRUCTURED ABSTRACT

CONTEXT
Engineering is a challenging discipline to master. It is about applying science to design, solve problems, create solutions, invent, innovate, transform and ultimately make our society better. However, many students atomise their learning, focusing on passing individual assessments and subjects to achieve their degree and they fail to achieve the broader perspectives and awareness that allows them to apply their technical knowledge in professional practice. To address this issue and encourage students to take a deeper, more thoughtful and professional approach to their learning, a series of core interdisciplinary units known as Integrated Engineering have been introduced at the University of Sydney.

PURPOSE
In this paper we introduce a learning language and framework for working with complexity. The framework is aimed at instructors (to scaffold, articulate and model learning methods and expectations), students (to be able to discuss, evaluate their competence and understand their learning) and for instructors and students to co-construct their understanding of learning outcomes and expected academic standards.

APPROACH
Authentic engineering projects are complex in that they require engineers to use judgement, managing multiple possibilities, competing demands and having to make assumptions to develop considered and reasoned solutions. These solutions often have remaining uncertainty that may only be resolved, if at all, in retrospect after implementation. Hence, to authentically develop engineering skills, students need to learn to manage complexity. However, a learning activity that challenges and stretches students, asks them to think critically or use their judgement to deal with uncertainty and complexity, often induces resistance. Complexity challenges students' feelings of competence, inhibiting their learning motivation and interest in addressing and benefiting from complex learning activities. In this paper we present a framework and language developed from the Cynefin framework to improve learning outcomes, student's motivation and competence when managing complexity.

FINDINGS
At the time of writing, the framework has been used in training workshops for approximately 110 tutors and discussed with small student focus groups. The initial reactions from instructors, tutors and students have been positive. Early feedback suggests that the framework and language will improve students' feeling of competence by allowing them to understand, evaluate and monitor their learning with complexity. Instructors have said that the framework and language helps them to understand what students may be going through and has given them a language and method to better facilitate these tutorial activities.

CONCLUSION
We anticipate that introducing the complexity framework and language to students in their first year of study and using it throughout the degree, will not only increase students feeling of competence but allow them to discuss, evaluate and benefit from feedback (scaffolded using the framework) regarding their learning when managing complexity.

KEYWORDS
Integrated engineering, professional development, complexity, student's competence, open-ended projects.

INTRODUCTION

Engineering is a challenging discipline to master. It is about applying science to design, solve problems, create solutions, invent, innovate, transform and ultimately make our society better. However, many students atomise their learning, focusing on passing individual assessments and subjects to achieve their degree and they fail to achieve the broader perspectives and awareness that allows them to apply their technical knowledge in professional practice. To address this issue and encourage students to take a deeper, more thoughtful and professional approach to their learning, a series of core interdisciplinary units known as Integrated Engineering have been introduced at the University of Sydney.

The Integrated Engineering program was designed to promote an understanding of the nature of engineering and what it means to think and practice as an engineer by incorporating these ideas into students' studies. The four multidisciplinary subjects (one at each year level) are designed to develop and apply technical engineering and professional skills to address authentic, sustainable, real world projects and workplace practices. Authentic engineering projects are complex in that they require engineers to use judgement, managing multiple possibilities, competing demands and having to make assumptions to develop considered and reasoned solutions. These solutions often have remaining uncertainty that may only be resolved, if at all, in retrospect after implementation. However, learning that challenges and stretches students, asks them to think critically or use their judgement to deal with uncertainty and complexity, often induces resistance (Brookfield 2017).

Boud argues that learning is socially and culturally constructed by the learner (Boud 1993). However, these social constructions require a language allowing the learners to understand, reflect on and discuss their learning. Through discussions with instructors and students we realised that many lacked a language that allowed them to understand, evaluate and discuss their learning when engaging with complexity.

In this paper we propose a learning framework and language for instructors (to scaffold, articulate and model learning methods and expectations and convert their tacit understandings to explicit explanations), students (to be able to discuss, evaluate their competence and understand their learning) and for instructors and students to co-construct the learning outcomes and expected academic standards when managing complexity.

Background

The Integrated Engineering program is a series of four subjects that are part of the core requirements of undergraduate engineering courses at the University of Sydney. The program was introduced, in part, to address the atomised approach many students are able to take to both their learning and assessment within their engineering studies. The program aims to build an understanding of the nature of engineering and what it means to think and practice as an engineer. It does this through linking (integrating) the learning in the discipline subjects by applying it in authentic, multidiscipline activities and practices. The four units were conceived to move student's through the following four stages:

- understand and analyse the concepts that underpin engineering;
- think like an engineer in undertaking design of technologies;
- act as an engineer to solve problems through creating systems;
- lead engineering innovation in solving societies challenges.

In addition, to developing specific technical and professional skills (such as teamwork, communication, and an understanding of ethical and professional practice) the Integrated Engineering units endeavour to develop core fundamental skills such as a student's ability to analyse their own capabilities, plan their development and manage their own learning.

In line with the curriculum development team's belief that students learn more effectively when they discover answers for themselves and that lectures with 500+ students are potentially less engaging; the units are flipped. While the first year unit has some lectures the 2nd, 3rd and 4th year units have no lectures. These units combine online instruction with pre-work and a series of two-hour 50 student workshops facilitated by two instructors. Collaborative learning as well as self, peer and instructor review are used to build learner independence and judgement, provide feedback and to help students to understand the, often tacit, professional and academic standards. Assessed reflective portfolios are used as a means for students to plan, monitor and evaluate their learning methods and approaches and their associated skill development.

In comparison to the more traditional engineering ‘chalk and talk’ delivery, flipped learning relies heavily on students being able to take more responsibility for their own learning (Reidsema et el 2017). Recent studies of engineering students (Willey and Gardner 2014a, 2014b) found many who struggled with these more independent approaches had become accustomed to expecting specific guidance in their learning, being told what to think, learn and do. They felt unsupported when they had to exercise their own judgement, often blaming the instructor or perceiving the instructor as incompetent rather than recognising their need to develop their own skills. Brookfield (2017, p48) remarks that “any learning that stretches students beyond where they are, that introduces them to complexity, or that asked them to think critically can pretty much be guaranteed to induce resistance” on the part of some students. This resistance can result in instructors becoming demoralised and feeling their efforts are not appreciated, especially when confronted with complaints and poor student satisfaction scores. Putting aside this disappointment, we suggest the way forward is for instructors to focus on developing ways to help students to examine their habits and bias and to open their mind to new approaches (Brookfield, 1995 p223).

Managing Complexity and Feelings of Incompetence

Practising engineers are required to be independent learners, using their judgement and creativity to arrive at solutions to complex real-world problems. Research reports that these skills are currently underdeveloped in engineering students (Trevelyan, 2014). This is not surprising given that most engineering students have undertaken mainly science and maths subjects in which they apply their mathematical knowledge to arrive at unique solutions. Conversely, in engineering practice, activities are rarely characterised by an ideal answer but rather they are complex, requiring trade-offs and/or the combining of non-optimum solutions. Hence, to authentically develop engineering skills, students need to learn to manage complexity.

To address this the Integrated Engineering program includes a series of open-ended, multidiscipline projects. Many students have welcomed this opportunity:

> *“The project felt very real-world and it was very helpful that it was a real scenario from a real company, and something so different from anything we've done before…”.*

Others, however, have called for change in the project from being “*open-ended to something much more defined”* describing it as too difficult, too much work, less valuable and not real engineering:

> *“Whilst the project was very open-ended, there were details that felt just a too vague and general which was hard because it meant that there wasn't a good sense of limits or expectations”.*
>
> *[The project should be]* “*more technical and mathematics”.*

We had previously theorised that the main drivers behind this resistance were a combination of a mismatch in expectations, differing views as to what constitutes legitimate learning and/or an underdeveloped capacity to use one’s judgement because of previous experiences of transmission teaching, knowledge receptive learning and binary or procedural assessment. We implemented improved tutor training, scaffolding, assessment descriptions and feedback processes. While this reduced student resistance and increased their perceived value of engaging with complex activities, some students continued to struggle.

In reading the literature we came across the Cynefin framework (Kurtz and Snowden 2003) and realised there were deeper issues that involved students learning to manage and becoming comfortable with dealing with complexity.

Cynefin Framework

Dealing with complexity requires a certain level of mindful agency and self-efficacy. Students need to use judgement, subjectivity, and reasoning to make decisions instead of relying primarily on the scientific evidence and facts that are often more highly valued by engineering academics and students. Complexity requires students to probe, sense and respond, as opposed to the more practised ‘knowable’ understanding response where students sense, analyse and respond (Kurtz and Snowden, 2003). Many engineering students resist this change expecting their learning to be the simple transition from the ‘knowable’ to the ‘known’ (Kurtz and Snowden, 2003), finding it difficult to make the transition from dichotomous reasoning to thinking contextually and dialectically. This transition challenges students’ feelings of competency. Self-determination theory (Ryan and Deci, 2000) lists competence, as one of three basic cognitive needs required for motivation. Reduced feelings of competence inhibits students’ learning motivation and their interest in addressing and benefiting from complex learning activities.

Rust et al suggest that academic standards are best learned through a process of socialisation and experience they call ‘connoisseurship’ “involving observation, imitation, dialogue and practice” (Rust et al, 2003) that requires instructors to model the desired learning approaches and behaviours. While our flipped classes provide opportunities for instructors to model, and for students to practice and receive feedback on managing complexity, some ongoing student resistance suggests we need to find ways to improve how we articulate and scaffold their learning experience and our expectations.

Boud argues that learning is socially and culturally constructed by the learner (Boud 1993). In the flipped classroom, learning can be described as a co-constructed partnership between instructors and students. However, these social constructions require a language allowing the participants to understand, reflect on and discuss their learning. Learning how to work with complexity requires a language and framework for instructors (to scaffold, articulate and model learning methods and expectations), students (to be able to discuss, evaluate their competence and understand their learning) and for instructors and students to co-construct the learning outcomes and expected academic standards. Through discussions with instructors and students we realised that many, including the authors, lacked this language.

We theorise that many students resist dealing with complexity because they don’t understand the learning processes (which may be quite different from their previous experience), nor possess the available learning language to enable engaging with the expected learning outcomes and to judge their competency in meeting these outcomes. The reduced feelings of competence and or feelings of incompetence result from not being able to describe or understand what one is experiencing, reducing their learning motivation and satisfaction.

The Cynefin framework was developed to help people make sense of the complexities in knowledge and organisational management (Kurtz and Snowden, 2003). It is designed to help people break out of old ways of thinking and to consider intractable problems in new ways by providing constructs that can be used to make sense of a wide range of problems. Significantly, the framework presents a visual representation and a description of practices with which to navigate decision making.

The framework offers four decision-making contexts or domains, each offering a perspective from which to analyse behaviour and make decisions. The domains were originally designated:

1. Known: cause-and-effect relationships repeatable, perceivable and predictable
2. Knowable: cause-and-effect separated over time and space
3. Complex: cause-and-effect are only coherent in retrospect and do not repeat
4. Chaos: no cause-and-effect relationship perceivable

The Known and Knowable domains are those of order, while Complex and Chaos represent unordered domains. The fifth or central domain between the other four domains is called the domain of disorder. (see Kurtz and Snowden, 2003 p468 for an image of the Cynefin framework, which the authors do not have permission to reproduce).

The Cynefin framework concepts are useful and provided another perspective for us to better understand our student’s resistance to dealing with complex problems. To assist with scaffolding and students being able to relate the concepts of the Cynefin framework to their experience, we decided to adapt the language, context and visualisation to meet our student engineering situation. We developed (through several iterations and discussions with both instructors and students) a simple framework that differentiates between learning absolutes and learning with complexity.

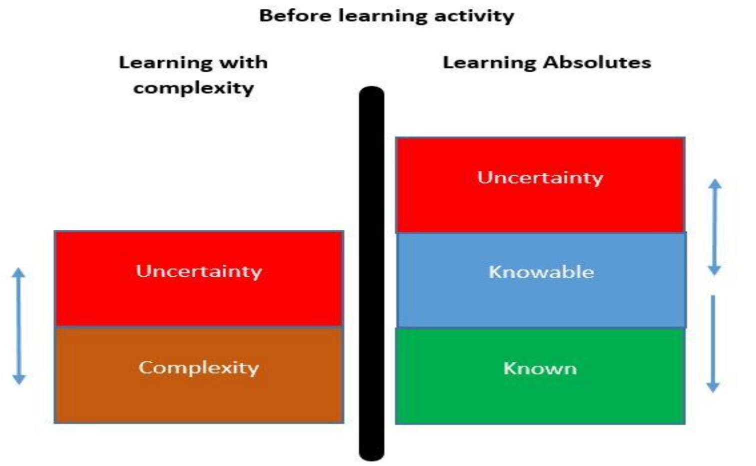
The aim of this framework design is to:

- Provide a vocabulary to understand, reflect on and discuss learning when managing complexity in order to improve students’ feelings of competence and their capacity to evaluate their competence.

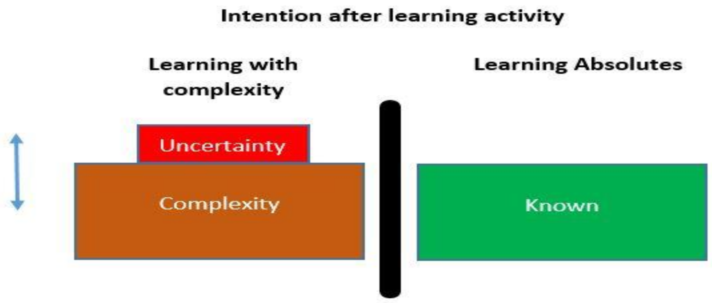
- Use these improved feelings of competence to reduce learner resistance, improve motivation and thereby improve student's learning and their learning experience
- Enable instructors to build a case for, and students to value, learning to manage complexity and view it as a legitimate and important part of professional practice.
- Enable instructors and students to co-construct their learning environment

Engineering Complexity Framework

The proposed framework (Figure 1) differentiates between 'learning absolutes' (right hand side, RHS) and 'learning with complexity' (left hand side, LHS). The framework reflects how engineering students' learning is often associated with absolutes, moving from the 'knowable' to the 'known' using predetermined rules, facts and analysis to manage encountered uncertainty (RHS Figure 1a). After learning both knowledge and competence are attained (Known) (RHS Figure 1b).



(a)



(b)

Figure 1: Pre-and post-learning objectives and transition paths when learning absolutes and managing complexity

In contrast, managing complexity requires using judgement, subjectivity, managing multiple possibilities, competing demands and having to make assumptions to develop considered and reasoned solutions to complex problems (LHS Figure 1a). Uncertainty is managed through probes (testing an assumption or theory) to improve the visibility of potential cause and effects before using this feedback to choose a course of action. The outcome (LHS Figure 1b) is a solution with some remaining uncertainty that may only be resolved, if at all, in retrospect after implementation.

The black separator between the two learning pathways (Figure 1a & b) indicates that the methods and techniques of the 'known and knowable' domains do not work when managing complexity and that you cannot move from a truly complex problem to a known solution.

We have introduced this framework to instructors in a pre-semester workshop where they also learn about educational theories such as self-determination theory, collaborative learning and assessment methods and affective processes (self-efficacy, mindful agency et cetera). Scenarios and role-plays are used for instructors to practice using these resources, to scaffold learning expectations to students and convert their tacit experiences and understandings to explicit explanations.

Our aim is to assist instructors to help students to improve their confidence and competence in tackling complex problems. Students' motivational need for competence will be addressed by providing them a language and framework to discuss and appreciate the challenges of managing complexity.

From 2019, a number of short videos will be used to introduce students to this frameworks, language and perspectives that will then be explored through pre-work and in class activities. This will be followed by activities and project work that provide opportunities for instructors to model, and students to practice and receive feedback on, managing complexity. Hence the language and framework will be embedded into student workshops, activities and assessment rubrics to both improve their feelings of competence and their capacity to evaluate their competence. Students will also explore managing complexity through discussing case studies in regard to current engineering projects.

Findings

At the time of writing the framework has been used in training workshops for approximately 110 tutors and discussed with small student focus groups. The initial reactions from instructors, tutors and students have been positive. Early feedback suggests that the framework and language will improve students feeling of competence by allowing them to understand, evaluate and monitor their learning with complexity.

Instructors have said that that the framework and language is a help for them to understand what students may be going through and it has given them a language and method to better facilitate the tutorial activities. One tutor commented that they could simply say to students who were trying to take a dichotomous, sequential approach that they were thinking on the wrong side of the line (referring to being on the left-hand side of the black separator instead of the right-hand side in Figure 1).

Conclusion

Students need more formative opportunities to make mistakes and to reflect and receive feedback from their peers and instructors to enhance their capacity to learn and develop professionally. Such discussions and the capacity to use feedback depends on an agreed construction and understanding of often tacit academic standards and meaning. We predict that introducing the complexity framework and language to students in their first year of study and using it throughout the degree will not only increase students feeling of competence, but allow them to discuss, evaluate and increase benefits from feedback in regard to their learning when managing complexity.

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