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What Do Students Say About Complexity?

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ABSTRACT

CONTEXT

Practicing engineers solve problems in complex environments that are dynamic, nonlinear and where cause and effect may only be clear in retrospect. They use engineering science, creativity, critical curiosity and engineering judgement to understand the context, define problems, manage trade-offs and develop solutions for competing and evolving needs. When faced with complex tasks, students often experience difficulty and resist these assessment tasks. Perhaps because working with complexity pushes them outside their comfort zone, requiring a different approach to evaluate their knowledge and skills. Students' feelings of competence are challenged and their motivation is affected. Few activities in engineering education authentically assess students' development of managing complexity. Students need opportunities to engage with and manage complexity, measure their progress and develop feelings of competence in dealing with complexity.

PURPOSE OR GOAL

This research is one phase of a study investigating students' experiences of working with complexity. The full study aims to increase understanding of students' experiences dealing with complexity and inform activity design and assessments for authentic engineering practice problems intended to develop their skills. To structure a future phenomenographic interview protocol and determine a representative sample, students' perceptions of complexity need to be better understood. In this phase, we aim to identify students' capacity to distinguish between complicated and complex problems with the goal of pinpointing their understanding of elements that make a problem and/or task complicated or complex.

APPROACH OR METHODOLOGY/METHODS

This research used a survey with a range of demographic, select response and open-ended questions to elicit students' experiences of working with complexity. The researchers used the language of learning in complexity and complexity frameworks to analyse the responses for themes and features that convey students' perceptions of complexity.

ACTUAL OR ANTICIPATED OUTCOMES

This research revealed varying but generally low levels of students' ability to recognise complexity and the approaches needed to solve complex problems. The results highlight the need to present engineering students with activities that give them the opportunity to engage with complexity, and which explicitly conveying that the skills and approaches needed for addressing problems and assessing solutions that are complex, will usually differ to those most frequently used in their engineering science subjects.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The research points to an opportunity for educators to use the complexity inherent in group work to introduce students to complexity frameworks. It can give students a language and context to understand different environments and foster development of their capacity to manage and solve complex problems.

KEYWORDS

Complexity, professional skills, group work

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Introduction

Practicing engineers solve problems in complex environments that are dynamic and nonlinear and where cause and effect may only be clear in retrospect. They use engineering science, creativity, critical curiosity and engineering judgement to understand the context, define problems, manage trade-offs and develop solutions for competing and evolving needs.

Graduate engineers leave university with specialised technical knowledge forming part of their identity. However, the ability to solve the complex problems that face practicing engineers requires experiences and knowledge unlike those typically acquired in university engineering science subjects. Engineers learn to operate in complex contexts over time through exposure to complexity and by working with others who model approaches needed to solve complex problems.

Few engineering education activities authentically assess students' progress towards effectively dealing with complexity within broader applications of engineering knowledge. The capacity for working with complexity develops through practice and reflection, including recognition of when problems require familiar thinking or need entirely new thinking. We argue that, in terms of developing professional skills at university, 21st century students will be well served by directly engaging with complex problems during their studies, so that they develop capabilities for solving such problems at an earlier stage. Students need opportunities to engage with and manage complexity, measure their progress, and develop feelings of competence in dealing with complexity.

At University of Technology Sydney (UTS) and The University of Sydney students complete a series of project-based subjects intended to develop professional practice skills. Our experience in designing and teaching these subjects has been that, when faced with tasks we consider to be complex, students often resist. It is becoming evident that such resistance links to the fact that working with complexity needs a different approach to evaluating knowledge and skills (Brookfield, 2017). Students' feelings of competence are challenged by such a change, and their motivation is affected (Willey & Machet, 2018, 2019).

This paper investigates the extent to which students can describe complex problem-solving contexts (as opposed to more familiar complicated contexts) and whether they can identify strategies most suitable for solving complex problems.

Complexity Framework

The Cynefin Domains of Knowledge frame knowledge in a way that uncovers relationships among apparently irreconcilable clashes and gaps. It emerged from research aiming to 'understand how informal networks and supporting technologies allow greater connectivity and more rapid association of unexpected ideas and capabilities than formal systems' (Snowden & Curry, 2007). This gradually morphed into a framework challenging 'the universality of three basic assumptions [about] order, of rational choice, and of intent' (Kurtz & Snowden, 2003) underlying the belief systems of many orthodox approaches to education.

The Cynefin framework differentiates among five decision making contexts: Clear, Complicated, Complex, Chaotic, and Confusion. Each context, has characteristics that affect how decisions are made. Of particular interest to us are the 'Complicated' and 'Complex' Domains. 'Complicated' problems have right answers needing work to be identified, and all unknowns can be resolved with expertise. Conversely, in the 'Complex' domain there is no known 'right' answer, and cause and effect may only be ascertained in retrospect and there will continue to be remaining 'unknowns' (Kurtz & Snowden, 2003).

Engineering science can be technically challenging, and students gradually acquire knowledge to help them solve problems that are impossible to resolve until they have that knowledge (or know where to find it). Such problems meet the criteria for Cynefin's

‘Complicated’ domain, and students resolve these problems by making sense of the problem, analysing what needs to be done and responding appropriately to reach a resolution (Kurtz and Snowden, 2003). Problems existing in the ‘Complex’ domain require that students probe widely and deeply to find the real nature of the trouble and only then can they make sense of the context and devise appropriate responses. In this domain, the nature of the context ensures that it is not possible to determine, in advance of enacting it, whether a solution will be successful or not. Transitioning to this mode of identifying problems and assessing solutions, challenges students’ sense of their own competency, leading to resistance.

Willey and Machet (2018) describe using the Cynefin framework to develop a complexity framework for engineering students. They applied the Cynefin framework to characterise working in complexity as involving: no single correct solution; no clear cause-and-effect relationship to be determined in advance; no possibility of resolving all uncertainties in the system, and no single person already ‘knows the answer’ to the problem.

The complexity framework for engineering students differentiates between ‘learning absolutes’ and ‘learning with complexity’ emphasising that in familiar contexts students are operating in ‘known’ situations with few uncertainties all of which they can expect to eventually be resolved. In the complex domain, even after a learning activity, there will always be some degree of uncertainty which is acceptable and expected. The framework is illustrated in Figure 1 where the difference between domains is shown before an activity or assessment (a) and after the activity (b) along with the processes used to manage the uncertainty in the problem context (Willey & Machet, 2018). The left hand side of the figure represents learning in complexity and the right, learning with absolutes. After the learning activity it is clear that in a complex context there is residual uncertainty, whereas the absolute domain results in all uncertainties and unknown components being resolved as “known”.

In professional practice subjects at The University of Sydney and UTS, tutor training includes an explanation of the framework and students are exposed to this to help them understand the context of their learning. Students learn a language with which to discuss and understand their learning experiences and explore any discomfort and loss of feelings of competence with the aim of moving to a mindset of *I can succeed in doing this* reducing their resistance to such contexts (Willey & Machet, 2018, 2019). Despite this, we find some students, and tutors, do not make use of the language or framework and are still resistant to working in a problem space where there is residual uncertainty and no single correct answer.

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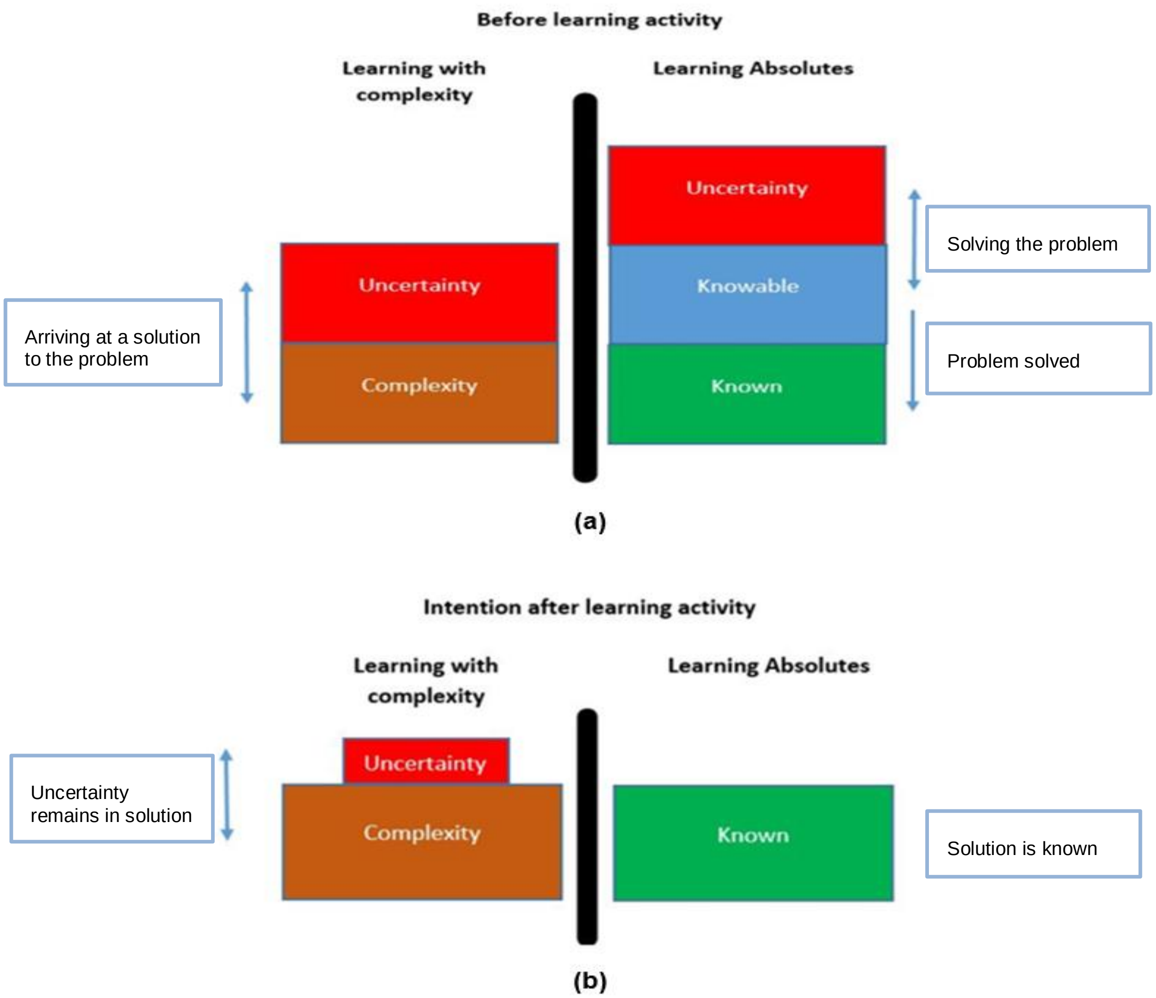

Figure 1: Complexity Framework: Representing learning with complexity vs absolutes (adapted from Willey & Machet, 2018)

Teaching Complexity

For educators, understanding the difference between Complicated and Complex, and being able to articulate this and manage learning in each context, brings a need to develop new skills and competencies. These include the ability to design, manage, assess and provide feedback on less familiar complex learning activities. It is clear that integrating complex learning and assessment activities into familiar applications of engineering science programs inevitably brings a degree of uncertainty for all.

Design problems are often seen as a good choice for providing a context for students learning how to manage and deal with complexity. Cennamo et al (2011) describes the studio learning environment as having an expectation that students will learn to experiment, iteratively generate and refine solutions, communicate effectively and collaborate with others. While instructors use prompts, reminders, modelling and coaching to help students grapple with complex problems. Jonassen and Hung (2008) conclude that 'the extremely high level of ill-structuredness [of design problems] may present challenges or even negative effects on students' learning' as they involve multiple possible solution paths. Jonassen and Hung (2008) emphasise the need to solve design problems in professional practices, indicating

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that engineering education should also prepare students to solve complex, ill structured problems which they will have to grapple with in their professional practice.

It is worth noting that the teaching of complexity is, in itself, a complex task rather than a complicated one. For example, the individual stages of skill development of each student, their previous experiences and the educators own pedagogical content knowledge all play a part in creating a context where there is unresolvable uncertainty, and the outcome cannot be determined in advance. Together with the combination of large class sizes, the lack of suitable teaching spaces, instructors without required skills and with a preference for avoiding student resistance, these factors contribute to the avoidance of designing tasks that could contribute to assessing complexity in engineering studies.

This research aims to further inform good practice teaching approaches to developing complexity skills, through building on the use and application of the Willey and Machet application of the Cynefin complexity framework. It reports on a preliminary study into whether students can identify complex contexts within which they will need to apply decision making and problem-solving techniques suited to the Complex rather than the more comfortable Complicated domain.

Methodology

This research used a survey containing demographic, select response and open-ended questions to elicit responses to working with complexity. The survey was validated using a pilot group of five students. The group were asked to complete the survey while participating in a one-on-one dialogue with the researcher to understand how they were interpreting the questions and to identify ambiguities.

The final survey was sent to undergraduate engineering and IT students at UTS. Some students had previously been exposed to the complexity framework and had therefore been provided with access to a language for describing learning in complex contexts.

Students were asked to identify a complex problem they had had to solve at university, indicate why they believed it was complex and then describe their strategies for solving the problem and dealing with uncertainty in the problem. The initial prompt was a statement mentioning uncertainty and the ‘practice’ of engineering but not explaining what was meant by complexity:

> *In practice, engineers and IT professionals have to use their judgement to manage uncertainty to solve complex problems.*

Not providing a definition of a complex problem was intentional. We are seeking to understand how students perceive this concept currently and, in part, to identify whether those exposed to the complexity framework and its language are more able to identify the kind of contexts most likely to generate a complex problem.

A ‘group and rank’ question allowed students to rate a series of problem-solving strategies using categories from ‘most important’ for solving complex problems, through ‘helpful’, to ‘not useful’ or ‘should not be used’. An open-ended question invited students to justify their reasons for identifying the most important strategies. The chosen strategies were derived from literature on dimensions that factor into learning how to learn, the effect of prior experiences and natural attributes (e.g. curiosity and creativity), and the language of learning in complexity (Crick et al, 2013).

Only those responses from students who answered all questions were included in the analysis. These were analysed to find themes and patterns emerging from the open-ended questions. Of particular interest was discovering whether the data would indicate whether students a) identified complex (rather than complicated) problems, b) could identify suitable strategies to solve complex problems, and c) used appropriate language for discussing complex problems and the strategies to solve them.

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Determining whether a student identified a 'real' complex problem was based on their own description of the problem, their justification for its complexity and steps taken to resolve the problem. We looked for key terms including *uncertainty, lack of information, unpredictable outcomes, conflicting demands* or *no single optimal outcome* and any references to the literature on complexity, or the use of the complexity framework language

In analysing rank order responses for usefulness of strategies in solving complex problems, we looked for patterns indicating an understanding - or not - of complexity. To find indications of an appreciation of complexity we looked at whether students categorised the following two approaches as being of 'little' or 'no' help to resolving complex problems:

- *"Checking your decisions along the way with someone who knows the solution"* implies there is a knowable solution in advance and therefore the problem is not complex
- *"Resolving all the uncertainties before trying to solve the problem"* suggesting that this is possible which indicates it is not a complex problem context

We analysed the data to determine whether the ability to identify problems in the complex domain improved over time spent at university.

Results and Discussion

The results of the survey include 27 full responses from students in their second to fourth year of study. No students managed to identify a complex problem while also avoiding identifying as useful the types of strategies that are unsuitable for solving complex problems.

We anticipated (based on the literature and our own teaching experiences) that students would confound 'complex' and 'complicated' and our assumption was supported by the data (Willey and Machet, 2018, 2019). Twelve students clearly associated complexity with 'encountering a difficulty' leading them to incorrectly identify complicated (or in some cases simple) activities as complex. As an example, a student identified the following problem and associated justification:

> *XXXX was probably one of the most complex projects I had so far. It had involved programming a robot, in C, to map its way through a maze and identify and collect goals in order.*
>
> [It was complex because] *there was very little information online on how to do it and working with arrays was difficult*

The problem may have presented challenges to the student, but it is not complex. How to produce a programmed robot is well known and the difficulties identified were about gaining the right skills and knowledge. There are no 'residual unknowns' in the process. The strategies students chose to solve such incorrectly classified problems were in line with solving complicated problems and include such approaches as trial and error, persistence, asking for help to arrive at a known solution (sensing, analysing and responding).

If students cannot differentiate complex problems from complicated ones, they are highly likely to employ unsuitable approaches for solving problems in the Complex domain. They may have unrealistic expectations of having no uncertainty in a solution to a complex problem. Assumptions about problems as always being amenable to known solutions limit their knowledge. Students given a truly complex problem may assume that not knowing a solution indicates a lack of personal knowledge, skill, available information or resources and be unaware that there is no optimal solution. In this case, the problem would be one needing thinking and learning strategies that are also unfamiliar to the student. Until they recognise the need to explore the problem context to understand which approaches may be suitable, students may continue frustratingly applying known solutions - in vain.

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The colloquial use of ‘complex’ as an incorrect synonym for ‘complicated’ is likely to contribute to this observation of confounding the contexts. However, most respondents (n=23) had been introduced to the simplified complexity framework for engineering students and all respondents had done a subject requiring them to solve a complex problem. That so few students could identify a complex context for problem solving indicates that the exposure to the framework and its language had been insufficient. Students’ failure to make the connection between the complex context in their subjects and “a complex problem they had solved” suggests ongoing misunderstanding of complex environments and/or misunderstanding of the assessment context for these subjects. A single encounter seems insufficient, emphasising that the concepts need to be embedded throughout an undergraduate degree. In support of this, there was no obvious pattern to the understanding of complexity between senior students (3rd and 4th year) and those in earlier years of study.

Three students identified a complex learning activity and gave a suitable justification for its complexity, describing approaches to problem solving consistent with operating in this domain. However, each one chose strategies indicating their belief in a ‘correct’ answer. To illustrate, one fourth-year student identified the problem of having to ‘identify the complex system of schooling and … to find the holes and fix it’ as complex, and also explained that ‘being okay with sitting in uncertainty’ was important for solving problems in complex environments. This same student, however, put both ‘checking your decisions along the way with someone who knows the solution’ and ‘resolving all the uncertainties before trying to solve the problem’ as helpful to solving complex problems. This suggests that the student believes there will be a single correct solution and that all uncertainties can be resolved.

A large number of students (n=11) identified group work as a context in which they had solved a complex problem. As examples, student identified a complex problems as:

- *Group members not showing up or attending group meeting late.*
- *In a group project, half of the group agreed with one idea whereas the other half agreed with another. Neither side of the group was ready to reconsider the idea for the assignment.*

The students identifying group work as a complex problem, did not support this with reasoning that would show they understand complexity. These students did not identify the uncertain nature of outcomes, uncertain cause and effect relationship or lack of a known solution in describing why the situation was complex, rather that they saw it as challenging. For example, one student identified the following complex problem:

> *I had to deal with a subject that was group-based where the members of my team were not on the same page*.

However, they reasoned that it was complex because:

> *As the members of my group did not attend tutorials, I had to complete the work for them by myself. I was unable to get their opinion and therefore had to go with the idea that I had come up with …*

Again, problem solving strategies selected were better suited to complicated environments. It is worth noting that even without a language to explain the complexity inherent in group work or strategies to deal with it, these students have made the link between professionals dealing with uncertainty (as framed in the question) and their own group work.

Reflecting on this we have concluded that group work can contribute to complexity in problem solving situating decision making in the Complex domain. Study teams, where members have their own motivations and approaches, are in different disciplines with differing study schedules, have a variety of anticipated work outcomes, all create uncertainty and an absence of predictable outcomes – all features characterising the Complex domain. As well, the cause and effect of group successes and failures can only be known - if at all - in retrospect.

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This awareness gap indicates an opportunity emerging from this research. Group work is a professional practice skill we look to develop in our subjects and often assessments requiring students to work in the complex domain are group work-based projects by design. How to manage group work in terms of equity of contributions, sharing ideas and credit and aligning motivations is always a concern. The complexities of group work are a familiar experience for students, and we believe they will readily understand the relevance and value of developing strategies to solve group work problems. By introducing the concepts of decision making in complexity in the context of managing the uncertainty in group work, may provide the opportunity to improve students' skills and feelings of competence in dealing with complexity.

Referring to the research reporting on the development of the complexity framework for engineering students, the identified aims of the framework are (amongst others) 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. …
- 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". (Willey and Machet, 2018)

We propose that complexity frameworks can be introduced to students within a discussion of group work to achieve these aims. Most students have experience working with others, making group work a familiar context for managing complexity. This means that not everything will be new, allowing students to reflect on previous contexts to construct new learning. This may be most useful where groups are required to solve a problem in the Complex domain.

Group work is more than students working in a group to create something that individuals could not create alone. It is a context, and an opportunity to leverage learning by including strategies, methods, techniques, and through reflection on managing complexity. We can take advantage of existing group work to help students identify and appreciate how managing problems in complexity helps them. Introducing the complexity framework and its language along with suitable reflection and self and peer review will allow students to evaluate their learning, identifying what worked and what didn't. This enables the skill of managing complexity to be developed and transposed to other contexts.

Using group work explicitly as a vehicle to introduce students to complexity and develop their skills to manage and work with complexity allows this learning to be integrated with any group work learning not simply design based projects. This will also give instructors a context and relevant experience to pass on to students helping them to scaffold, provide feedback, insights and challenge and prompt students to promote learning.

Well scaffolded learning designs that include examples of how students can use strategies to manage complexity in group work are an anticipated outcome of future research. With some guidance such designs can be transposed to different contexts, such that group work can become a vital way of introducing students to both the *need* to develop and the *process* of developing skills for managing complexity, particularly in first-year subjects.

Recommendations / Conclusions

This study indicates that students' lack both the ability to identify problems in the complex domain, and suitable strategies to address them. Academics have a responsibility to address such gaps. As Ramsden (2003) noted, assessment drives learning. Engineering programs that expand their repertoire to include experiences relevant to learning how to address complexity through use of appropriate learning and assessment activities will enable students to accept the importance of engaging with and managing complexity.

A key step in developing students' capacities to work with complexity involves ensuring they understand the difference between complex and complicated problems and contexts. Next is

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devising tasks of appropriate quality and difficulty for engaging students with complexity in their engineering studies. Third is helping individuals and groups build personal capabilities to identify contexts clearly enough to ensure they choose and implement appropriate actions.

This requires action by both students and educators. Students must recognise that not all problems have known solutions. Educators must help students understand the difference in problem solving contexts - making the contexts of tasks and problems assigned for learning and assessment explicit. Both must accept that some problems have solutions grounded in known facts and data, while for others, everything known is insufficient for resolving the problem due to the non-repeating complex context. This work identifies group work as a powerful potential context for introducing and integrating the learning of these concepts throughout a degree program.

Our research has provisionally identified how to expand the value of group-based learning activities. These provide opportunities to introduce the task of managing and dealing with complexity. Group work is a familiar context, making it a good starting point. Within this context and with suitable scaffolding and opportunities, students can evaluate their own learning and continue developing these skills throughout their study program.

The findings from this study will guide further investigation of students' understanding of complexity. Future work will investigate whether students' seeming inability to identify complex contexts and suitable strategies for solving problems within them is an issue of insufficient language, not yet having the knowledge to distinguish complex and complicated contexts, lack of experience engaging in authentic complex problems or lies elsewhere.

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