Assisting tutors to develop their student's competence when working with complexity.

Keith Willey
The University of Sydney, Sydney, Australia
keith.willey@sydney.edu.au

Tania Machet
The University of Technology Sydney, Sydney, Australia
tania.machet@uts.edu.au

***Abstract**: 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. 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 are complex, requiring trade-offs and combining non-optimum solutions. Dealing with complex problems requires students to use judgement, subjectivity, and reasoning to make decisions instead of relying solely on the scientific evidence and facts. This challenges many students' feeling of competence and inhibits their learning motivation. In this paper, we report introducing student tutors to self-determination theory and a framework to provide a context and vocabulary to understand, reflect on and discuss learning when managing complexity to improve their students' learning and feelings of competence.*

Introduction

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. Brookfield reports that 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).

In previous studies (Willey and Machet 2018, Willey and Gardner 2014a, 2014b) we found that when students were introduced to open-ended, multidiscipline projects, many students welcomed the 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…";*

while others called for change describing the projects 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".*

Viewing the student feedback through the lens of self-determination theory (Ryan and Deci, 2000) we theorised that many students resist dealing with complexity because they do not feel competent nor understand the learning processes (which may be quite different from their previous experience). Dealing with complexity requires students to use judgement, subjectivity, and reasoning to make decisions instead of relying primarily on the scientific evidence and facts. Many engineering students expect their learning to be the simple transition from the 'knowable' to the 'known' (Kurtz and Snowden, 2003), finding it difficult to think contextually and dialectically to find approaches to engineering problems. Reduced feelings of competence, inhibits students' learning motivation and their interest in addressing and benefiting from complex learning activities.

In the flipped classroom, learning can be described as a co-constructed partnership between tutors and students. Hence, for successful learning tutors need to find ways to articulate and scaffold students' learning experiences and their learning expectations. Students need a learning language to engage with the expected learning outcomes and judge their competency in meeting these outcomes.

In Willey and Machet (2018) we introduced a learning framework and language evolved from the Cynefin Framework. It was developed for tutors, to scaffold, articulate and model learning methods and expectations to students, provide students with a language to discuss, evaluate their competence and understand their learning, and to allow tutors and students to co-construct the learning outcomes and expected academic standards when managing complexity.

In flipped classrooms and tutorials it is often only the tutors that have face-to-face contact with the students. Hence. they are often responsible for scaffolding students' understanding and skill development to manage complexity. Thus it is important for tutors to feel comfortable explaining working with complexity and to see their role as facilitating learning rather than simply providing solutions to and or clarifying student's questions. To facilitate this we hold tutor training workshops that include tutors being introduced to self-determination theory and the complexity framework explained later in this paper. Tutors are asked to reflect on their approach to tutoring and are engaged in discussions to provide a context to understand how the students may behave and respond to learning that involves managing complexity.

In this paper, we investigate tutor's reactions to the framework, language and learning theories and how useful they believe they will be in assisting them to improve their understanding of, or interactions with, students in their tutorials and how they might use these tools to improve their student's learning.

Self-determination Theory

Self-Determination Theory links personality and motivation in an effort to describe human behaviour and the choices we make. Built on research about motivation, differentiating between intrinsic motivation (a self-desire to seek out new challenges) and extrinsic motivation (influence from outside forces), Self-Determination Theory describes a continuum from amotivation, "the state of lacking the intention to act", through extrinsically motivated action, to fully intrinsically motivated and self regulated behaviour (Ryan and Deci, 2000a). The theory is built on the belief that humans have an inherent propensity to learn and develop and describes that in order to be motivated to achieve their potential growth, a person's basic cognitive needs of autonomy, competence and relatedness must be met.

Self-determination theory has significant application in the education domain where Ryan and Deci (2000b) identify that supporting these three basic needs in the classroom facilitates students' natural inclination for learning and well being. That is, students need to feel they have some control over their learning and outcomes (autonomy), that they are able to master

the learning content (competence) and to feel a sense of connectedness to others within the context (relatedness), in order to be motivated to learn and grow through the experience. Inhibiting any of these basic needs reduces students' motivation and inhibits learning.

We believe that many students have difficulty with learning tasks that deal with complexity and this lack of competency results in reduced motivation and resistance to learning in these scenarios.

Cynefin Framework

The Cynefin framework was developed to help people make sense of the complexities in knowledge and organisational management (Kurtz and Snowden, 2003 p468). 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.

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 fifth or central domain between the other four domains is called the domain of disorder.

The Known and Knowable domains are those of order, while the Complex and Chaos domains represent un-order.

Engineering Complexity Framework

The Cynefin framework concepts are useful and provide an additional perspective for us to better understand our student's resistance to dealing with complex problems. To assist scaffolding and for both tutors and students to be able to relate the concepts of the Cynefin framework to their experience, we decided to adapt the language, context and visualisation to our engineering context. We developed (through several iterations and discussions with both tutors 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 tutors 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 tutors and students to co-construct their learning environment.

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).

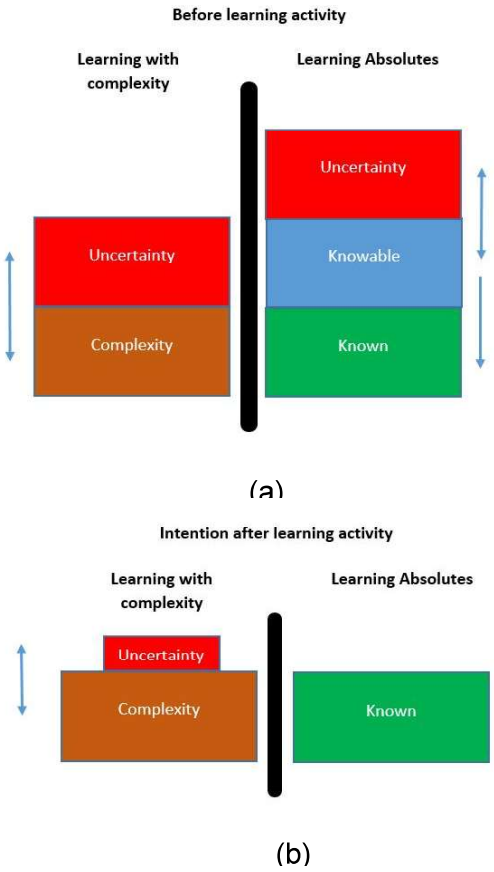

Figure 1: Pre-and post-learning objectives and transition paths when learning absolutes and managing complexity (Willey and Machet, 2018)

The methods and techniques used in the 'known and knowable' domains do not work when managing complexity and you can't move from a truly complex problem to a known solution. Engineering practice involves complex problems and the solutions require the use of judgement, subjectivity, the management of multiple possibilities, competing demands and having to make assumptions to develop considered and reasoned solutions to complex problems (LHS Figure 1a). To resolve uncertainty, theories and assumptions are probed and tested, feedback is evaluated and then a course of action can be chosen. The resulting solution (LHS Figure 1b) will contain residual uncertainty that may only be resolved, if at all, in retrospect after implementation.

Methodology

The Faculty of Engineering and Information Technologies at the University of Sydney, hold a mandatory tutor training workshop for all new tutors. Most of the tutors are undergraduate students, tutoring in a subject they have previously undertaken. A small number are postgraduate students.

In the workshop, tutors are introduced to learning theories such as constructionism, affective processes including self-efficacy and agency, and the different stages of reflection and its role in learning. These concepts provide background to understand and reflect on how their students behave and respond to different learning activities and to assist them in scaffolding these activities to their students.

Within the training workshop, tutors are introduced to self-determination theory (SDT). They are asked to use SDT to evaluate their tutorial learning activities. In particular, to identify how their tutorial activities provided opportunities for students to exercise autonomy, include the social dimensions of learning through group and/or collaborative activities and to consider that resistance or pushback to their tutorial learning activities may result from students not feeling competent to undertake the associated tasks.

The complexity framework and supporting language are then introduced to tutors, including a description of how the framework explicitly describes the way many students have previously experienced and/or approached their learning, expecting it to be a simple transition from the knowable to the known, and how these methods cannot work when dealing with complex open ended problems. Complex problems require students to manage uncertainty through using judgement, subjectivity, and reasoning to make decisions, instead of relying primarily on scientific evidence and facts.

In the workshops, it was explained that the framework and language were introduced for tutors to share with their students in order for the students to understand that it is normal to be uncertain when dealing with a complex problem, and that learning how to manage complexity is an explicit learning outcome of such activities. Tutors are asked to think of examples of when they as a student have experienced, or have observed in another student, resistance to a learning activity or assessment. They were asked to reflect and share with those sitting around them whether they could relate this resistance to not feeling competent and/or with the uncertainty associated with dealing with a complex problem. The subsequent workshop discussions were used to explore a number of scenarios and use self-determination theory and the complexity framework as a lens through which to examine what was occurring.

After the workshop, tutors were surveyed to ascertain whether they found the concepts of Self Determination Theory and the complexity framework and language useful and to briefly describe if they thought they would help them to improve their understanding of, or interactions with, students in their tutorial class and how they might use them to improve their student's learning.

Results & Discussion

The responses from the 18 tutors (invited cohort 158) who completed all survey questions were used in the following analysis.

Self-determination theory

In the workshops self-determination theory (identifying competence, autonomy, and relatedness as basic cognitive needs for motivation) was introduced and tutors were asked to use the theory to examine the way they facilitated their tutorials and in particular, think about student resistance as stemming from them not feeling competent to engage with or undertake an activity. The tutors were surveyed on their thoughts as to the usefulness and possible application of the theory to their own classes.

All the responses indicated that tutors believed the theory to be helpful, with some indicating that they were aware of it before the training.

> *"I've encountered this theory before when studying skill acquisition in a previous degree. I think this is a useful framework to remind us how to keep our lessons as valuable to the students and to be alert for how quickly a student can disengage if they feel completely lost. By this framework tutoring is a balance of ensuring the students feel competency without taking over their autonomy, which I think is a fair consideration".*
>
> *"This was a very useful concept to introduce into my perception of teaching, as it encompasses many facets of learning that I had passively understood but not brought*

> *to words. It outlined for me the importance of self-autonomy & compentance [sic] for students, allowing me to reflect on my own teaching methodologies going forward".*

A number of tutors showed that reflecting on the theory had an impact on how they intended to facilitate their tutorials.

> *"I found it extremely intriguing and I can see the benefits of the concept being brought to our attention. Remembering that students may feel a sense of incompetency when I'm tutoring, I will ensure that we cover basic concepts first when addressing an issue a student has encountered."*
>
> *"…students so far have been used to highschool teachers mostly spoonfeeding them on what they need to know and study for. As a result students may expect the same from their lecturers and tutors. I suppose tutors can help smooth students into this transition, such as letting the students solve questions in groups and can make harder questions much less intimidating".*
>
> *"I think this concept is fairly intuitive, from my experience I find that tutors often miss-use their knowledge of this concept and don't use effective methods to enable their students to be competent, autonomous or to understand the relevance of what they are learning. For example, there is a difference between stearing a student towards the resources available to them, or explaining that you want them to learn how to find and research answers, and instead saying "you can work it out, or google is your friend" both responses can be incredibly frustrating to hear as a student. … I aim to make sure that I don't [do this]".*

However, a deeper analysis of the responses shows that many tutor's interpretation of the theory and how it should be used was often constrained by misinterpretations, misunderstanding or their beliefs. For instance, despite the workshop focusing on moving students from being passive to active learners one tutor commented that to them self-determination theory;

> *"…illustrated the need for classrooms to integrate both passive and active teaching styles that direct students towards self-learning".*

We cannot be certain what this tutor meant, for example, passive teaching could mean letting students work things out for themselves. However, language used to scaffold learning activities that can be misinterpreted is likely to be problematic for students.

Many of the comments focussed on the concept of competence (some using "confidence" as an incorrect synonym)

> *"Competence ~ confidence, it is hard to become competent if you lack confidence that you can do something."*
>
> *"Yes, it made me realise that confidence is important. And how providing needed support is more fundamental than I thought at first. "*
>
> *"Self determination theory is extremely useful ….. Believing in yourself and being confident is one of the first steps to succeeding at anything"*

The frequent use of "confidence" may be obfuscating a lack of understanding of the meaning of competence in self-determination theory and again be problematic when used to scaffold activities and assist students. For example, students can be confident in undertake a task even if they are not competent. Future research is required to examine the level of understanding developed in the tutor training. In any case, these misconceptions suggest as a first step the need for mid semester follow-up workshops (after they have some tutoring experience) that include dialogue to socially construct the meaning of these terms and our intentions.

Complexity framework

Tutors were asked if they found the complexity framework and associated language useful and how they might use it in their class to improve student learning.

In analysing the tutor responses to the survey, it was found that while some reservations were expressed, overall tutors were supportive of the framework and the language. Tutors reported increased understanding and appreciation of what is required to manage complexity and an increased capacity to articulate this to their students.

They comment on the nature of student learning and how they feel they can use the framework and language to support their students:

> *"somewhat useful for giving me the vocabulary to explain these ideas [of complex problems] to students"*
>
> *"These frameworks were particularly useful, as they illustrated the movement of students from knowledge consumers to knowledge generators. It illustrated the need to avoid the typical student mentality towards rote learning content, within a teaching environment. This was particularly useful, as a measure to encourage meaningful and useful learning processes for students"*

Tutors believe the framework will assist them in scaffolding their learning activities for students, including being better able to explain the learning opportunities provided within open-ended, ill-defined projects. Comments specifically identified the link between the framework and the students understanding of the expected outcome of the learning activity:

> *"Its indeed helpful to explain to students why their learning activities are designed in a certain way and what they are meant to gain from them"*
>
> *"Yes. I had thought in the past that the mindset of: "I don't know, but i can find out!" is important for people to have, but this supports that idea and defines it more explicitly, making it easier to adapt to learning tasks."*

There were comments that indicated some reservations on the part of tutors. Many of these were based on tutors' beliefs and the traditional curriculum design used to teach many engineering topics that allows students to simply transitional from the knowable to the known:

> *"Personally, I think it depends on the course structure and content"*
>
> *"To some extent. I believe this can be useful, however I think there is an extent to which this works and it comes down to using one's discretion to best determine what will work."*
>
> *"Depending on the topics.."*
>
> *"…I think uni needs to be better at setting problems that incorporate these "complex" less easy to answer problems. Its all well and good to explain to students that questions aren't as easy in the real world but we need more examples of it in the teaching outcomes and questions that are set."*

Interestingly, some tutors expressed a belief in the usefulness of the framework but their belief in repetition and moving from the knowable to the known (the transition depicted on the right-hand side of Figure 1) meant it was unlikely to inspire impetus for change.

> *"I think this is a useful framework to a degree. It is true that complex engineering problems cannot merely be solved through repeating past problems but I do think that the repetition will solidify some concepts into the minds of the students meaning that when they are presented with a complex question, their goal is to reduce it to a simplified problem that they can solve through known knowledge."*

Findings

While overall the response to the training, which included discussions introducing and using self determination theory and the complexity framework and language was positive, the tutors responses included:

- incorrect use of language discussing learning theory;
- reservations expressed in terms of the wide application of the complexity framework and language;
- personal resistance (often because of strongly held beliefs as to how knowledge and skills are exchanged in an educational context) to adopting the framework in classes where it may be applicable.

It is probable that in some cases this resistance is also due to the tutor's own perception of competence, with several expressing the opinion that it was their job to provide students with answers and meet their needs. These factors suggest that there is a need to improve the training for tutors. A single session of tutor training describing the concepts is unlikely to be sufficient to overcome the tutor's own misconceptions, misunderstandings and/or resistance, especially since some participants had limited and/or no previous tutoring experience. Interestingly, many tutors stated the main reason they believe they were selected as a tutor was their previous achievement of a high grade in the subject.

We suggest that the tutor training would be more effective if it included a process described by Rust (Rust et al, 2003) in reference to learning academic standards, of socialisation involving observation, imitation, dialogue and practice with highly skilled tutors. This would allow a cycle of application (practice), assessment, feedback, dialogue and reflection to ensure both the concepts and associated language are well understood and can be clearly articulated. However, even if the required funding was available for such activities our recent experience of initiating a paid professional development teaching and learning program suggests it may be difficult to attract committed participants, with many potential candidates declining the opportunity as they did not see the value and/or benefit to their future professional engineering career.

Future research will look at whether tutors chose to apply the language and framework in their teaching, and whether the use allowed the co-construction of knowledge with their students, providing both tutors and students a language to understand, discuss and evaluate the associated learning outcomes.

Conclusions

The motivational need to feel competence is often inhibited when learners do not have a language and understanding of the expectations and processes involved. This is particularly visible when engineering students are asked to engage in learning activities that involve managing complexity as the required processes are often quite different from their previous learning experience and approaches. We investigated tutor's perceptions of the usefulness of tools to understand, scaffold and facilitate student learning that involves managing complexity. We found that introducing tutors to self-determination theory and a complexity framework and supporting language generally increased tutor's feelings of competence. Despite some reservations, they expect the use of the framework and language will allow them to more competently scaffold their learning activities to students, being better able to explain the learning opportunities provided within open-ended, authentic engineering projects.

We also find, not surprisingly, that tutor training workshops are a beginning and not an end to helping tutors develop the skills required to successfully facilitate their student's learning. We suggest outcomes would be vastly improved if tutors were involved in temporally spaced observation, imitation, dialogue and practice with highly skilled counterparts. This would

allow a cycle of application, assessment, feedback, dialogue and reflection to ensure both the concepts and associated language are well understood and can be clearly articulated.

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