# Project Design and Scaffolding for Realising Practitioner Learning in a Large First Year Flipped Classroom Course.

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**CONTEXT**
A large first year engineering flipped classroom course involving intensive project work was designed with the aim of providing students with experiences of theory integrated with both practice and professional skills. Integration of these three skillsets can be met by enacting a *situated cogntion* learning framework, which requires a *cognitive apprenticeship* approach to teaching (Collins, Brown, and Newman, 1989; Schoenfeld, 1992, 2014). However, ensuring integration of theory with practice requires careful, crafted design of projects and tasks. Furthermore, in large classes many scaffolds and supports are needed for providing the necessary master-apprenticeship experiences for students.

**PURPOSE**
The aim was to find a set of course design principles that would ensure that (i) the course projects integrated theory, practice and professional skills, and (ii) the quality of master-apprenticeship experiences provided ensured that the students were adequately helped and guided throughout their projects.

**APPROACH**
The principles used to design the project work were: continuous variation in core variables during operation, hands-on experiences, project design decisions requiring professional judgements, and inclusion of project tasks that integrated theory, practice and professional skills. These principles were used to ensure the integration of core theoretical concepts (i.e. Tensile Strength concepts) into the applied project work. Furthermore, extensive *distributed scaffolding* (Puntambekar and Kolodner, 2005) was used to provide students with cognitive apprenticeship experiences using an array of supports, guides, and skill-building activities.

**RESULTS**
The students' final reflections *as* well as their reports were investigated to find evidence that confirmed or critiqued the effectiveness of the course design and course scaffolds. Students provided many comments about the importance of the tensile strength concepts in designing, modelling, testing and building, suggesting that each stage of the project had facilitated learning of theory that was integrated with practice. Inspection of students' final reports revealed that the project work had enhanced the understanding of some teams but not others. Student appraisals of course supports revealed a majority of positive comments regarding cognitive apprentice-type experiences and the supports provided, as well as some negative comments regarding lack of tutor support or knowledge.

**CONCLUSIONS**
Overall, the course design achieved the goals of integrating core discipline concepts into the project work at each stage of the project, as well as providing cognitive apprenticeship experiences for students. These successes were possible due to (i) careful design of projects to ensure that theory was integrated with practice, and (ii) an extensive array of scaffolds for providing students with the necessary guidance and support thought the project work.

**KEYWORDS**
Flipped classroom, situated cognition, project design, theory-practice, practitioner skills

## Introduction

Engineers Australia has outlined three main areas of skills and competencies required for accreditation (Engineers_Australia, 2013). Courses aiming to develop students into engineering practitioners therefore need to develop students' professional and applied skills while ensuring that they still acquire essential discipline knowledge (King, 2008). Rather than addressing content and professional skills in separate courses, a core subset of courses throughout the curriculum should ensure an integration of the knowing, acting, and being dimensions of becoming a professional (Dall'Alba and Barnacle, 2007). The Practitioner Skillset Map is presented below (Figure 1) so as to illustrate these three skillsets and their areas of overlap, along with some common teaching and learning methods which predominantly focus on the different skillsets.

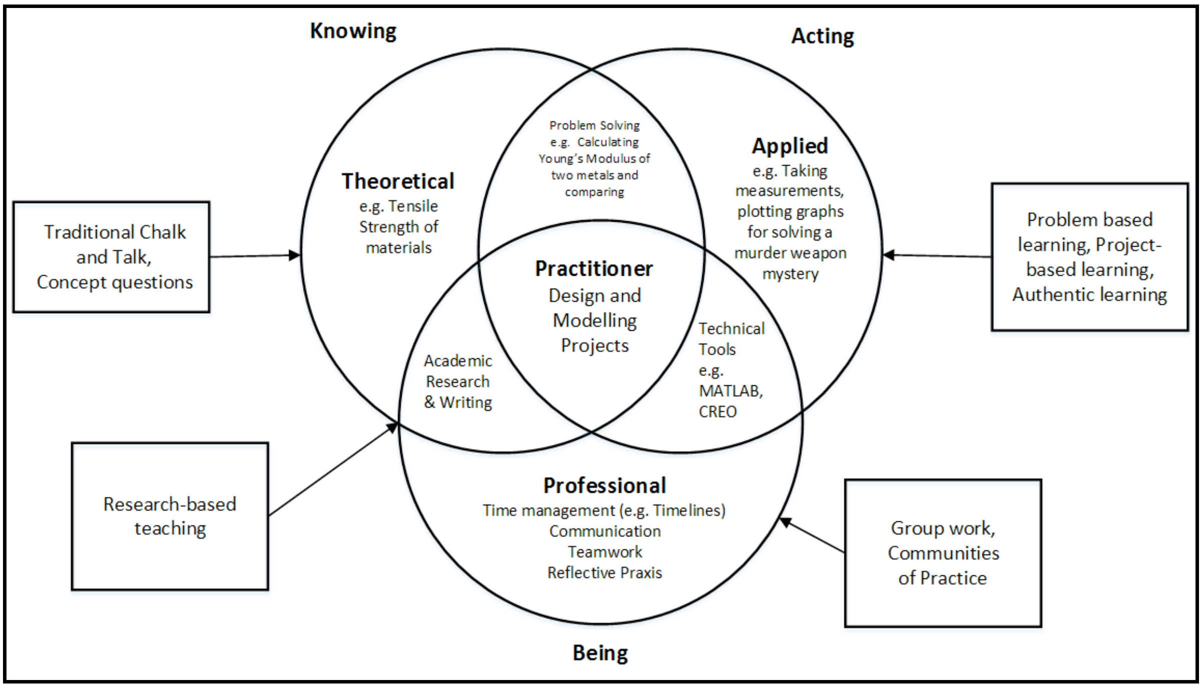



**Figure 1: The Practitioner Skillset Map**

ENGG1200 (Engineering Problem Solving and Modelling) is a large first year course that has been redesigned and expanded from a lecture-based course on materials engineering into a flipped classroom course with a large hands-on team-based component. Its aim is to give students experiences similar to real world engineering practices. Subsequently, the course Learning Objectives have been defined as follows:

- Individual Knowledge: introductory level understanding of engineering materials.
- In-depth (hands-on) experience in the process of engineering design.
- Fundamental understanding of how engineers solve problems using modelling and simulation.
- Graduate competencies: teamwork, project management, and professional communication.

The inclusion of design, modelling, report writing, and teamwork are the aspects of this course that give students experiences that are similar to real engineering practice. As shown in Figure 1, design and modelling projects have the potential to provide learning which integrates all three of the practitioner skillsets.

Due to the focus that the course has on practitioner skills, we call it a ‘Flipped Classroom (Practitioner)’ course, and distinguish it from ‘Flipped Classroom (Academic)’ courses which typically use face-to-face time to deepen theoretical learning. The repurposing of the ENGG1200 course to focus on the integration of all three skillsets has been an intentional part of curriculum redesign at our institution, aimed at developing within our undergraduates all three of the Engineers Australia Stage 1 Competencies for Practicing Engineers (Engineers_Australia, 2013).

The proposed integration of skills can theoretically be achieved by enacting a *situated cogntion* framework for teaching (Brown, Collins, and Duguid, 1989). Situated cognitions occur when a person’s mental schema interacts with the specific learning situation (Elsbach, Barr, and Hargadon, 2005; Lave and Wenger, 1991). The resultant learning includes discipline-based content, practices, tools, and ways of thinking. Situated cognitions are best learned using a *cognitive apprenticeship* method, where the student as apprentice learns from the teacher as master. The teacher-master models, coaches, and scaffolds the students learning, encouraging students to reflect on their own strategies, with this support fading away as the student gains expertise (Collins et al., 1989; Schoenfeld, 1992) .

Fulfilling the above requirements for situated learning presents design challenges for instructors (Kober, 2015). Firstly, projects need to be carefully designed so that core theoretical concepts are integrated into applied activities (e.g., Beichner et al., 2007; McDermont and Schaffer, 2002). Secondly, project work needs to be scaffolded and supported so that students are able to try, to fail, to be given feedback and to try again until successful (Hattie, Biggs, and Purdie, 1996). For team-based project work, the scaffolds and supports need to be able to provide the necessary guidance and feedback to whoever needs it, whenever and wherever it is needed. This presents a major challenge for course design, especially in large classes (Allen and Tanner, 2002).

The aim for ENGG1200 was to design the course components (Herrington and Oliver, 2000) so as to successfully promote a full practitioner learning experience for students. Course projects, activities, and scaffolds were designed to (i) ensure that projects integrated theory, practice and professional skills, and also (ii) to ensure the provision of master-apprenticeship type experiences for students as they worked through their projects. We expected that the course design would promote learning in all three skillset areas (knowing, acting, and being) and more importantly, at the intersection of these three areas. We also expected that the supports and scaffolding provided via a blended online course environment (i.e. the provision of multiple masters rather than a single master) would be able to give students adequate master-apprentice experiences throughout their project work. The focus of this paper is to describe the design principles that were used to achieve these aims, and to investigate whether these aims were met, from the perspective of the students.

# Method

## Integration of theory with practice

ENGG1200 uses a flipped classroom methodology: content is learned out of class time via online modules, and face to face time is used for skill building workshops for the first half of the course, and hands-on project work for the rest of the semester.

The projects were authentic, team-based, and required design, computer modelling and simulations, testing, building, project demonstration and report writing. The projects were specifically designed to ensure that core course concepts underpinned the project work and project solutions. The integration of conceptual understanding with hands-on work was core to the design of activities. As an example, the ways in which two of the main Tensile Strength concepts; i.e., *Young’s Modulus of Elasticity* and *Yield Strength* were integrated in to the project activities are described below. One of the four projects (the drill-rig project) has been used for illustrative purposes.

**The drill-rig project:** This project, similar to a real-world problem occurring within the mining industry, drew on aspects of Mining and Mechanical Engineering, and Information Technology. Figure 2 shows the overall drill rig and control system that was used. (The components that were the responsibility of the teams are shaded in the figure.) Student teams were asked to build a control system and a drill bit that would drill through a piece of simulated rock (aerated concrete). The control system had to measure drilling torque in real time and then use this information to maximise drilling speed while ensuring that the drill assembly was not overstressed. The issue that the project teams needed to address was that the torque required for rotating the drill cutting head varied as the head drilled through layers of concrete of different density.

During operation, the torque from the drill rig was converted to force inside a unit containing the tensile member (Figure 2). An optical strain system sat next to the unit, to measure the extension of the tensile member (proportional to the force on the member). Students were required to design and build the tensile member so that it would be capable of extensions that were measurable (by the optical strain system), yet not be so stressed by the force coming from the drill that it would break during operation.

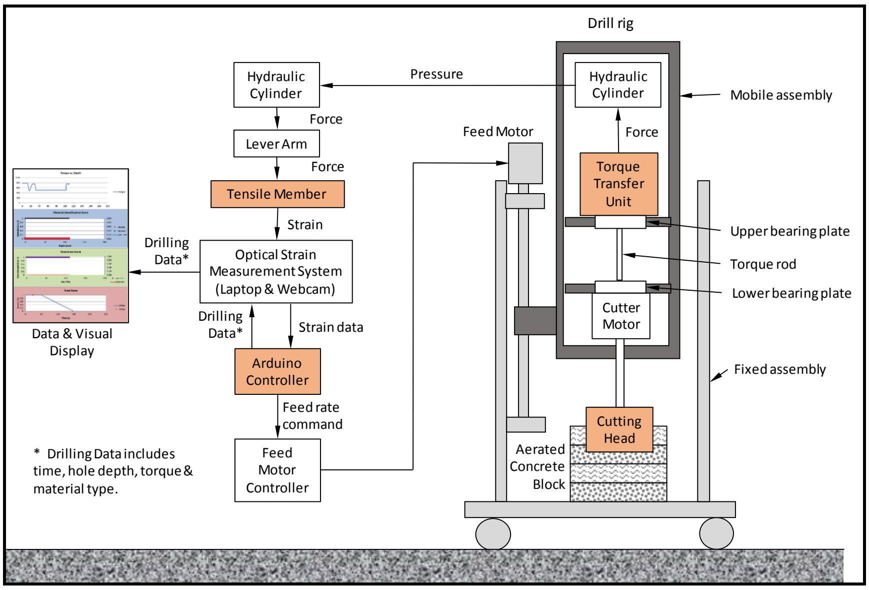



**Figure 2: The virtual, logical and physical model of the drill rig (Cusack and Kavanagh, 2012)**

A prototype for the tensile member (and other drill rig components) needed to be designed, modelled, built, and tested, and the final artefact demonstrated at the end of the 13 week project. In addition, a final report describing all phases of the project needed to be written by teams, as if for a company for which they were working.

## Integration of theory into the project

The project was designed so that the main Tensile Strength concepts, learned via the online modules, were required for the design of the tensile member and integral to all stages of the project. That is, during operation of the artefact within the drill rig, the force on the tensile member changed, resulting in changes to the extension of the member. These extensions were monitored during operation and used to control the system by using known properties of the member's material. The material was chosen by teams during the design phase such that its properties would be suitable for system operation. Thus the design and modelling of the member required the understanding and application of *Young's Modulus*, and *Yield Strength*, including using appropriate equations within the simulations, as well as choosing appropriate estimates for various parameters and adjusting these as a result of testing.

**Table 1: The alignment of concepts and skills with project activities and desired cognitions**

| Concepts/Skills | Activities | Desired Cognitions |
|---|---|---|
| Young's Modulus<br>= stress/strain<br>$= \frac{\frac{Force}{Area}}{\Delta L/L}$<br>= slope of stress-strain curve<br>= measure of elasticity, a fixed property for any given material. | **Online learning modules**: Weeks 2 -3. Videos, text, online quizzes, online (MOOCchat) discussions with peers. | Concept of elasticity as being a property of each material. Theoretical equations for calculating elasticity. Recognition of parts of stress / strain curve, including Young's Modulus and Yield Strength. |
| Determine Young's Modulus using graphs and equations; Work backwards with equations for problem solving. | **Materials workshop**: Week 2. Use a laboratory set up to apply a load to a tensile member. Calculate Young's Modulus for different materials. Use results to solve a murder mystery. | Visual, motor and kinaesthetic understanding of stress/ strain. Map changes in length of member to a graph plotted in real time (i.e., map visual to graphical representation) |
| Stress applied must be measurable, yet cannot cause so much strain that member exceeds Yield Strength and breaks.<br>Estimate possible range of forces. Use Torque and Force equations to determine change in length ($\Delta L$) and appropriate cross sectional area.<br>Design cognitions, teamwork management and communication principles. | **Memorandum**: Week 4.<br>Initial design of tensile member using theory applied to set of possible materials.<br>Use results of calculations to design tensile member.<br>Describe design decisions for each component, considering costs/ environmental impact.<br>Describe how components work together to create solution; e.g. how torque on drill converts to force on the tensile member. | Application of theory: Use equations to solve real world problems.<br>Design cognitions: Integrate technical components of artefact into overall design with practical, environmental and budgetary constraints; determine parameters, estimate value ranges.<br>Communicate: text, equations and sketches. Teamwork management. |
| Describe how equation parameters will change as member is stretched under load. Describe relationships using equations:<br>• torque on drill and force on member<br>• $\Delta L$ and force on member.<br>• $\Delta L$ and Yield Stress.<br>• Yield Stress and upper limit to torque on drill | **Simulations**: Weeks 5 to 8. Model physical/ functional properties of tensile component within system. Estimate initial forces from pilot runs. Convert design components into Matlab (Simulink) e.g. integrate optical strain device readings into feedback loop. Integrate torque arm design with member forces and drill torque. Run simulations/ reassess. | Modelling Cognitions: Concept of simulations. Initial estimates for parameters. Design-test-redesign loops. Sketches and descriptions of whole processes. All of these necessary before starting to code. Coding helps to clarify process thinking.<br>Teamwork crucial to modelling, compiling components and testing. |
| Convert relationships between all variables (as described by equations above) to Arduino code. | **Building/ Testing:** Weeks 9 to 10. Use build labs to manufacture tensile member Build other project components. Convert Matlab to Arduino to run controller. Fit member to rig. Setup and test. | Build Cognitions: visual, kinaesthetic, and motor experiences of material elasticity and strength. Requirements for precision. Adhere to OHS, and ethics in labs. Teamwork management. |
| Describe how each component of final artefact affects others in terms of forces. Explain relationship between optical strain device and member extension/ drill torque. Explain theoretical relationship between torque on the drill and porousness of rock. | **Demonstration/ Report:** Week 12. Set up rig with components. Operate/ observe changes in member to predict material being drilled. Ensure drill is not overstressed. Describe how constraints are built into design. Communicate all phases of project, include reflections on teamwork and course supports. | Practitioner Cognitions: Communicate technical concepts/ relationships between components to a lay audience. Use models/ sketches for communication. Reflect on teamwork, time management/ communication. Develop collaborative report writing skills and reflective practice. |

Our experience has been that students typically struggle with the *Young's Modulus* concept when learning it in a theoretical way via the online modules. Students have done poorly on questions in the mid-semester exam given at the end of the online module phase of the course; i.e., the percentage of students who get the *Young's Modulus* question correct is typically around 25% as opposed to 60% for the other material questions (including Yield Strength). The challenge for project design was to utilise the *Young's Modulus* concept within the project work so that it was better understood by the end of the course. The ways in which the theory was integrated with the applied and professional activities along with the particular situated learning that was expected during each project activity is described in Table 1.

Some key organising principles emerged from the above design process. These can be used to inform future projects aimed at integrating theory with practice, as follows:

**Use continuous variation in core variables to achieve deep theory-practice integration**: The use of the theoretical Tensile Strength concepts within the problem was not static. For example, the extension of the tensile member ($\Delta L$) changed in response to differing stresses on the drill, which occurred when the rig was drilling through different types of rock. By requiring that the system be in flux during operation, the problem ensured that students had to attend to how the important variables changed over time, and moreover, when one variable changed, how the other variables changed in response. Monitoring and responding to this constant variation meant that the students had to develop an understanding of how all of the variables related to one another. This principle, of ensuring that the problem includes factors that cause core variables to change in relation to one another, can be used to ensure that theory is integrated into practice at a deep level.

**Provide hands-on experiences**: Requiring students to build their project components by hand gave them physical experiences of the functions of the drill and of the properties of materials. For example, students developed a hands-on feel for the flexibility of their brass member, thus providing them with a sensory-motor representation for a quantity which was previously just a number from a table to them: *Young's Modulus for brass ~ 100-125 GPa*. Such hands-on experiences create richer internal representations for the theoretical variables that students encounter because these concepts are no longer just represented symbolically, but are also linked to sensori-motor experiences (Nathan et al., 2013).

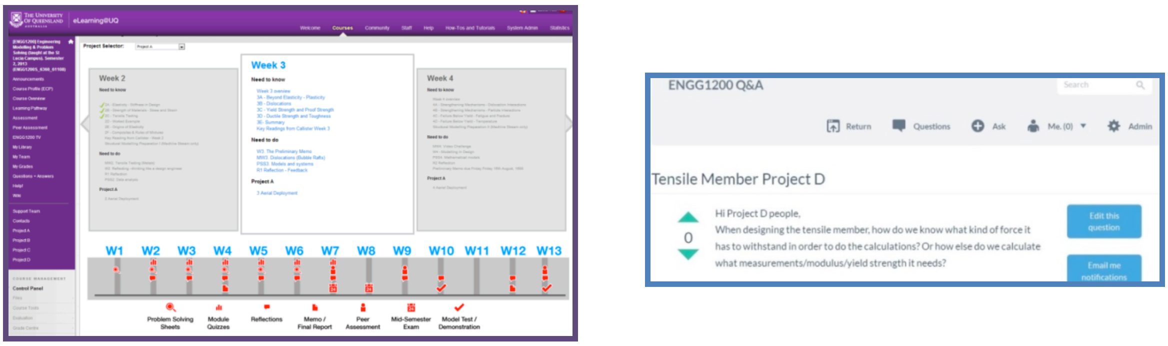
**Integrate authentic, professional judgements into tasks:** The problems within each project were grounded in real world pragmatic considerations. For example, determining which metal to use for the tensile member required interpretation of load-testing graphs from the lab that provided values for Young's Modulus and Yield Stress with a level of uncertainly attached. These properties needed to be combined with other real world system constraints (such as environmental, resource availability and budgetary constraints) to determine which metal was most appropriate for the tensile member. There was not one 'right' answer; rather, students needed to describe how they took all constraints into consideration to justify their final decision. Making these types of judgments allowed students to experience the thinking used by engineers in practice (Dym, Agogino, Eris, Frey, and Leifer, 2005; Walther and Radcliffe, 2006).

**Use tasks that integrate knowledge, applied skills and professions skills**: Many of the project milestones were tasks that required the integration of theoretical, applied, and professional skills. In particular, the initial memorandum, Matlab modelling and simulations, controller coding, artefact demonstration and report all required students to develop a coherent understanding of how the theory related to the design of each component and how the parts of the design related to the whole. The parts may have been subject to mathematical, technical, physical, budgetary or environmental constraints. Such integrative tasks motivated teams to wrestle with these ideas by sketching, discussing with one another, and trying to describe the system in words, diagrams and in code. Such integrative tasks are more likely to develop integrated representations (Nathan et al., 2013) within the mental schema that students develop (Elsbach et al., 2005; Lave and Wenger, 1991) for materials engineering.

### Provision of Master-Apprentice Experiences

Traditional master-apprentice experiences occur face to face. However, this was not possible in a very large class (N>1000). As a substitute, extensive *distributed scaffolding* was used (Herrington and Oliver, 2000; McCredden, Reidsema, and Kavanagh, in press; Puntambekar and Kolodner, 2005). Rather than a single teacher as master, this method uses an array of supports, guides, and skill-building activities to scaffold student understanding and to give them help when needed. Subsequently, many tutors were involved in the course and several in-house tools were developed so as to provide guidance and help online. These supports and scaffolds were:

- **Physical**: Technical laboratories with technicians available for help.
- **Online:** Project briefs, Tutorials for Matlab (Simulink) and CREO, Weekly learning modules, including practice quizzes and online (MOOCchat) discussions.
- **People:** Project leaders, Tutors, Technical support team.
- **Task Scaffolding:** Knowledge and skill building workshops, Materials workshops; Problem solving workshops, Modelling workshops, Narrative workshops (Reidsema, Kavanagh, and Jolly, 2014), Project specific help videos added to online project pages.
- **Self- and team-management**: Narrative workshops to link team processes with project work; The Learning Pathway: what do you need to know, what do you need to do (Reidsema, Kavanagh, Fink, and McGrice, 2015) (Figure 3a).
- **Getting Help**: Online Q&A tool Casper (Herbert, Smith, Reidsema, and Kavanagh, 2013) (Figure 3b), Project specific Facebook pages.




(a) (b)

**Figure 3: Some of the online tools developed for scaffolding and support: (a) The Learning Pathway, (b) Casper Q&A**

# Evaluation

In order to ascertain the successfulness of the situated learning approach, we needed to provide evidence that project activities developed students' integrated practitioner skills, and that course scaffolds provided master-apprentice types of experiences. To collect quantitative data, a pre- and post- course Likert-scale questionnaire: the Knowing Acting Being (KAB) Survey was created (Reidsema, Kavanagh, and McCredden, in preparation). The KAB Survey asked students about their knowledge and skills within the theoretical, applied and professional domains that were addressed in the course, such as knowledge of materials properties, use of Matlab to model a system, carrying out background research to build a prototype, and keeping up constant communication with a team. The results revealed pre- to post-course learning gains in the theoretical and applied areas but no changes in most of the teamwork skills, which were already high at pre-test (except for feeling confident to discuss their own ideas with others, which did improve). To gain more insight into the integrated learning of these skillsets, the students own perceptions of their learning experiences were investigated, using data from the 2015 cohort, described below.

Students were given written reflection exercises at the beginning, middle, and end of the semester. In their initial reflections, students were asked to identify goals for themselves, and in their final reflections, to assess how well they had achieved these goals and what they had learned. We investigated student's final reflections qualitatively, by searching for terms relating to tensile strength concepts, such as *Young's Modulus.*

To assess students' experiences of the course scaffolds, teams were asked to give appraisals of course organisation and supports in their project reports. These appraisals were analysed qualitatively, by looking for comments within specific key themes related to authentic tasks, and distributed scaffolding (e.g. people, getting help, self-management, collaborative learning and teamwork).

# Results

**Student perceptions of the development of situated cognitions**: About 75% of the 2015 cohort (i.e. 725 students) completed the final reflection task. Many gave positive comments regarding achieving their goals and learning specific skills or lessons (e.g. design, modelling, teamwork and time-management). While a more in-depth analysis of the student reflections is presented in (Reidsema et al., in preparation), the following quotes are examples of those that revealed theory-practice integration during project work:

- **Applying Knowledge to Design***: Throughout the course I have gained knowledge (such as material stress/strain) which lay the foundations of engineering design.*
- **Applying theory to Modelling***: The use of Simulink to model the project has developed my skills so that I am beginning to engineer designs using theoretical knowledge, rather than just relying on luck and trial and error when building.*
- **Integrating ethics into engineering decision making***: Not only have I experienced the type of work (e.g. calculations, physical building) that engineers in their respective fields do every day, but I have also learnt of the appropriate ethics and thoroughness that engineers put into their jobs.*

Specific evidence for integrating the core materials concepts into project work (i.e. evidence for situated cognitions) was gained by searching the 2015 cohort's final reflections for the terms *Young's Modulus, Yield Strength, and Tensile Member*. These terms were explicitly mentioned 40 times: just over half of these comments (27) were about how students had managed to understand these concepts, or had struggled with them at first, but then succeeded with integrating them into their final project. Another 13 mentions were made by teams that were still struggling. Of these, a couple were about conceptual struggles, but most were about team time management, expressing the realisation that their team had not put enough effort into ensuring that they understood how the theory informed the design before attempting to model and build project components.

Table 2 gives example quotes revealing how undertaking the engineering practitioner tasks enforced students' accurate and detailed understanding of the Tensile Strength concepts and their project applications. These comments reveal how each stage of the project required correct application of the theory, as well as the importance of engineering practice considerations such as time management and initial estimations. These are all examples of the students describing their developing situated cognitions.

**Objective evidence for the development of situated cognitions:** The question remains as to whether the initial theoretical learning of the Tensile Strength concepts via the online modules and materials workshops was enhanced by the project work; in particular, by modelling and simulating the changes in Tensile Strength during system operation. To assess this objectively, two sets of scores were compared. First, marks for the mid-semester Tensile Strength questions were averaged across each team, to give an overall indication of each team's initial shared understanding of Tensile Strength concepts before the project work began (represented by a team mark out of five). Next, the project reports that were produced by students in the drill-rig project were inspected for evidence of specific applied understanding of Young Modulus and Yield Strength concepts. Marks were awarded for evidence of the separate component ideas of Young's Modulus and Yield Strength in the selection of the appropriate metal for the tensile member. Component ideas had 9 possible marks: explanation (3), stress/strain relationship noted (2), equation correct (2) and calculations correct (2). Further marks were awarded for the integration of these concepts into the entire drill-rig artefact, requiring explanations of how elongation of the tensile member during operation determined the measurements of stress on the drill and the subsequent feedback to the drill via the Arduino controller. Integration ideas were allocated marks out of 11: diagram (2), explanation (3), equations (3) and simulation (3). Altogether, a maximum of 20 marks was possible.

**Table 2: Example quotes revealing integration of tensile strength concepts into project work**

| |
|---|
| **Young's Modulus (n=3): all succeeded** |
| *..the design process for the load arm design along with the creo sessions …to design this I had worked on a presentation for the model test day which involved researching several relevant topics including detailed explanations of how Von Mises stress (calculated using FEA analysis) can be used to calculate is a design can be considered 'safe', along with industry safety factors. During this process I became familiar with researching a materials yield strength and youngs modulus through online resources.* |
| *… I learnt the ability to gather and organise information/ideas to convey and analyse different ideas related to various engineering topics (materials elasticity, youngs modulus, etc.). …* |
| **Yield Strength (n=1): all succeeded** |
| *… about 2-3 important decision we had to make which would lead us to a successful demo day. For example, decision on our tensile member. We need to choose a material that had a large yield strength but also keeping in mind the safety factor and other important criteria.* |
| **Tensile member (n=36)** |
| **Succeeded / struggled then succeeded (n=23)** |
| *The tensile member calculations were an issue to solve as the calculations were either too high or too low. The project is [now] progressing well, with planning and preparation.* |
| *.. in modelling behaviour system and designing the tensile member, initially, I thought it would be an easy job as both only require basic mathematics calculation. As I engag[ed] deeper into the project, I realised that it is important to consider [a] variety of extreme cases, like safety factor[s] in order to handle the worst scenario. The theoretical data calculated does not necessary fit the reality. This really gave me a huge influence to manoeuvre the knowledge learn[ed] in other courses into the problems…* |
| **Still struggling (n=13)** |
| *I personally believe that the group will struggle with the component construction as we currently haven't completed our … tensile member calculations. …* |
| *However, the great trouble at the moment is the team didn't observe the tensile member design .. relative with the crank offset distance. This mistake might result in much higher or lower force applied on the tensile member….Fortunately, the whole model could still work but this issue puzzled us until our Matlab group used the Simulink model to solve it. …the Simulink model can control the feed rate of the cutting head and prevent the force [from being] too large to yield the tensile member. Otherwise, we [would need to] to redo everything about the tensile member, such as selecting the material, gauge width and thickness..* |

A subset of the drill-rig project team reports was chosen for inspection, using 17 teams that received a range of final report marks (from 7.5 to 12 out of 20 possible marks). First, the research investigator conferred with the materials lead tutor using a subset of ten of the reports. Both markers evaluated the levels of component and integrated understanding as described above, with an inter-marker correlation of 0.8. The independent researcher then continued to score an extra seven reports using the same criteria. All scores out of 20 were then scaled to give a team project 'Tensile Strength' rating out of five. These ratings were greater than three out of five for all except two of the teams, revealing a medium to high ability for teams to visibly understand the component concepts and to integrate them into their project tasks. However the markers noted some gaps in some of the reports such a lack of clear justification for why brass was chosen for the tensile member, and lack of a sketch depicting the overall design.

For the projects that were investigated, each team's Tensile Strength project rating (an indication of the team's shared post-project understanding) was then plotted against their average Tensile Strength exam mark (an indication of the team's shared pre-project understanding). There was a significant correlation between the project rating and the exam marks ($r = 0.5$; $p<.05$). Furthermore, most teams had a better project rating than their average exam mark (as evidenced by the fact that most points sit above the dashed line (y=x) in Figure 4; i.e., 11 out of the 17 teams did better, two did the same, and only 4 did worse on their project ratings than on their average exam marks. These findings suggest that theoretical understanding was enriched by the project work for some teams. However, there was an incomplete post-project understanding of both component knowledge and integration of tensile strength concepts for other teams.

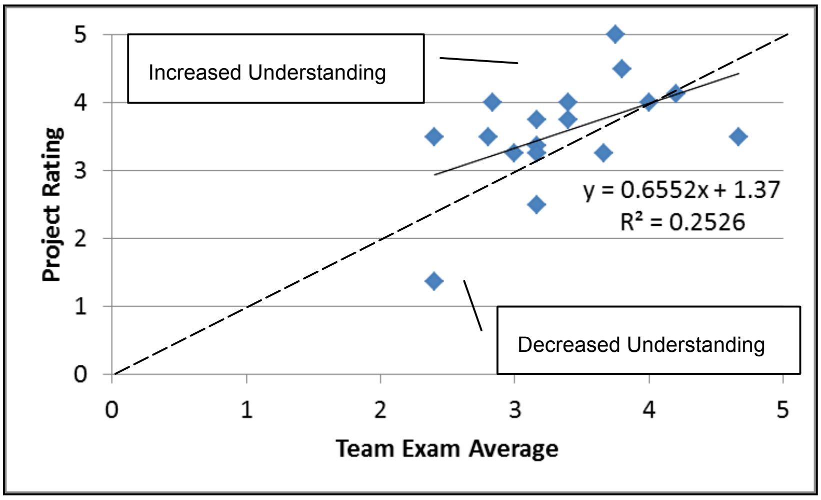



**Figure 4: Team project ratings versus team average exam marks for Tensile Strength concepts**

Together these results suggest that the students' original theoretical learning was somewhat important to the quality of their teams' project work, and was deepened via the applied aspects of the project. These results provide preliminary indications that project work designed to integrate theory with practice is potentially able to develop students' situated cognitions (i.e., mental schema for materials engineering that combine both theoretical and contextual concepts). However, this capability was not realised for all teams. Future versions of the course will endeavour to find ways to investigate more rigorously the enrichment of understanding via project work. In particular, potential improvements will be investigated on an individual rather than on a team basis. (In the above analysis, post-project understanding could only be evidenced by the team project report, which was not able to reveal individual improvements in understanding.)

**Evidence for master-apprentice guidance provided by distributed scaffolds:** Analysis of student appraisals of course supports revealed a majority of positive comments regarding the cognitive apprentice-type experiences provided via the multitude of course scaffolds (e.g. project leaders, technicians, tutors, online videos, discussion tools and help tools):

> *Fortunately, the STC tutors were extremely helpful and knew how to construct each component. During construction stages, they were able to clarify elements of the design that we didn't understand.*

These results are presented more fully in (Reidsema et al., in preparation).

Negative comments concerned lack of tutor support, lack of tutor knowledge of the whole project, and the need for skill-building workshop activities to be further grounded in project learning. Students' negative appraisals of themselves were mostly focused around time-management, revealing students heightened awareness of the importance of this professional skill to their future success.

# Conclusions

The analysis of student reflections revealed that the project design was able to achieve the goals of integrating core discipline concepts into project work, at each stage of the project. Preliminary analysis of student reports suggested that integration created enhanced understanding of core concepts for some teams but not for others. Analysis of team appraisals of course scaffolds revealed that the distributed scaffolding method for providing cognitive apprenticeship experiences for students was positive overall.

While many flipped classroom courses have used active learning methods to help students to understand concepts more deeply and fully (Velegol, Zappe, and Mahoney, 2015), the flipped classroom practitioner course presented in this paper has used full-scale project work to integrate knowledge, applied skills and professional skills. Such integration is possible in a large class using:

(i) projects which ensure that theory is integral to all project tasks by using the design principles of continuous variation in core variables during operation, hands-on experiences, project design decisions requiring professional judgements, and inclusion of project tasks that integrate theory, practice and professional skills, and

(ii) an extensive array of multiple scaffolds for providing the necessary guidance and support throughout the project work, such as the Learning Pathway for self-organisation, tutor and mentor supported workshops, build labs for guidance through project work, and the Casper Q&A tool for just in time help as issues arise.

Together these activities and supports are able to begin the development of students into practising engineers.

# References


Allen, D., & Tanner, K. (2002). Approaches in cell biology teaching. *Cell Biology Education, 1*(1), 3-5.

Beichner, R. J., Saul, J. M., Abbott, D. S., Morse, J. J., Deardorff, D. L., Allain, R. J., . . . Risley, J. S. (2007). The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) project. In E. F. Redish & P. J. Cooney (Eds.), *Research-Based Reform of University Physics*. College Park, MD.: American Association of Physics Teachers.

Brown, J. S., Collins, A. M., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher, 18*(1), 32-42.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. *Knowing, learning, and instruction: Essays in honor of Robert Glaser, 18*, 32-42.

Cusack, D., & Kavanagh, L. (2012). ENGG1200 Engineering Modelling and Problem Solving Project D (Core Drilling Strata Detection) Project Brief. University of Queensland: Faculty of Engineering Architectrue and Information Technology.

Dall'Alba, G., & Barnacle, R. (2007). An ontological turn for higher education. *Studies in Higher Education, 32*(6), 679-691.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education, 94*(1), 103-120. doi:10.1002/j.2168-9830.2005.tb00832.x

Elsbach, K. D., Barr, P. S., & Hargadon, A. B. (2005). Identifying situated cognition in organizations. *Organization Science, 16*(4), 422-433.

Engineers_Australia. (2013). Stage 1 Competency Standards for the Professional Engineer.

Hattie, J., Biggs, J., & Purdie, N. (1996). Effects of learning skills interventions on student learning: A meta-analysis. *Review of educational research, 66*(2), 99-136.

Herbert, J., Smith, E., Reidsema, C. A., & Kavanagh, L. (2013). *Helping Students find ansers: Algorithmic interpretation of student questions.* Paper presented at the The Australasian Association of Engineering Education, Gold Coast, Australia.
Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational technology research and development, 48*(3), 23-48.
King, R. (2008). Engineers for the Future: addressing the supply and quality of Australian engineering graduates for the 21st century.
Kober, L. (2015). Chapter 4: Designing Instruction *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering*. Washinton DC: The National Academies Press.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*: Cambridge University Press.
McCredden, J. E., Reidsema, C. A., & Kavanagh, L. (in press). Designing an active learning environment architecture within a flipped classroom for developing first year student engineers. In C. Reidsema & L. Kavanagh (Eds.), *Flipping the Classroom – practice and practices*: Springer.
McDermont, L. C., & Schaffer, P. S. (2002). *Tutorials in introductory physics, 1st ed.* . Upper Saddle River, NJ: Prentice Hall.
Nathan, M. J., Srisurichan, R., Walkington, C., Wolfgram, M., Williams, C., & Alibali, M. W. (2013). Building cohesion across representations: A mechanism for STEM integration. *Journal of Engineering Education, 102*(1), 77-116.
Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching, 42*(2), 185-217.
Reidsema, C. A., Kavanagh, L., Fink, E., & McGrice, H. (2015). *Student Learning Pathway Tool*. Paper presented at the Innovate & Educate, Blackboard Teaching and Learning conference, Adelaide, Australia.
Reidsema, C. A., Kavanagh, L., & Jolly, L. (2014). *Flipping the classroom at scale to achieve integration of theory and practice in a first year engineering design and build course.* Paper presented at the 121st ASEE Annual Conference and Exposition: 360 Degrees of Engineering Education.
Reidsema, C. A., Kavanagh, L., & McCredden, J. E. (in preparation). Developing Theoretical, Applied and Professional Skills by Flipping a Large First Year Engineering Course.
Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics. In D. Grouws (Ed.), *Handbook for research on mathematics teaching and learning* (pp. 334-370). New York: Macmillan.
Schoenfeld, A. H. (2014). What makes powerful classrooms and how can we support teachers in creating them? A story of research and practice, productively intertwined. *Educational researcher, 43*(8), 404-412.
Velegol, S. B., Zappe, S. E., & Mahoney, E. (2015). The Evolution of a Flipped Classroom: Evidence-Based Recommendations. *Advances in Engineering Education, 4*(3).
Walther, J., & Radcliffe, D. (2006). *Engineering education: Targeted learning outcomes or accidental competencies?* Paper presented at the 2006 ASEE Annual Conference & Exposition.