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Framework for enhanced professional practice in engineering programs.

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ABSTRACT

CONTEXT

As indicated in "Engineering Futures 2035: Engineering Education Programs, Priorities & Pedagogies" commissioned by the Australian Council of Engineering Deans (ACED), engineering programs need greater focus on practice to deliver the future expected graduate outcomes. Final-year research projects, capstone courses, and other forms of work-integrated learning (WIL) are particularly useful to expose engineering students to professional practice. In final-year research projects, engineering students work on real-world problems similar to those in professional environments and the workplace, but not in a way similar enough to professional practice. This paper proposes the integration of activity theory and social learning theory as a theoretical framework for final-year research projects in engineering degrees. Activity theory provides a lens to better understand human learning through interactions with people and artifacts, while social learning theory models learning through observing and imitating behaviours. Both theories have been previously used for understanding human behaviours, relationships with technology and interaction design.

PURPOSE OR GOAL

The goal of the paper is to provide a theoretical framework for final-year research projects in engineering programs to recreate professional non formal ways of learning that prepare students for WIL placements. Often in engineering programs, final-year research projects, are supervised and assessed focussing on the problem and the thesis. Problem solving and reporting are valuable skills for WIL, but other additional aspects, such as professional and personal attributes, are as important for successful professional experiences.

APPROACH OR METHODOLOGY/METHODS

The paper analyses how a final-year research project course can be structured and informed through the lens of both activity theory and social learning theory for better preparation for professional practice.

ACTUAL OR ANTICIPATED OUTCOMES

The anticipated outcome is a deeper, theory-informed immersion of engineering students in professional practice, leading to a better preparation for their WIL placement.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The findings will inform the design of activities in final-year engineering research projects to support development of personal and professional skills within engineering programs in order to enhance students' preparation for professional practice.

KEYWORDS

Final-year engineering research projects, work-integrated learning, engineering futures, future engineer, activity theory, social learning theory.

Introduction

Final-year research projects, capstone courses, and other forms of work-integrated learning (WIL) are particularly useful to expose engineering students to professional practice. As indicated in “Engineering Futures 2035: Engineering Education Programs, Priorities & Pedagogies” commissioned by the Australian Council of Engineering Deans (ACED) (Crosthwaite, 2021), engineering programs need greater focus on practice to deliver the future expected graduate outcomes.

Often in engineering programs, final-year research projects are supervised and assessed focussing on the problem and the thesis. Problem solving and reporting are valuable skills for WIL, but other additional aspects, such as professional and personal attributes described in international engineering competency standards, are as important for successful professional experiences.

Students undertaking individual final-year research projects might encounter challenges in WIL placements, which often require professional skills including teamwork, and they could benefit from incorporating a group component in their projects. Moreover, struggling students undertaking individual final-year research projects could potentially benefit from group work by imitating behaviours from their peers and gaining confidence in their abilities through peer support.

The goal of this paper is to provide a theoretical framework for final-year research projects in engineering programs to recreate professional non formal ways of learning that prepare students for WIL placements. This paper argues that it is beneficial to develop professional and personal attributes while undertaking a final-year research project course for better preparation for WIL placement.

The paper describes how a final-year research project course can be analysed and structured through the lens of both activity theory and social learning theory, which are used as a theoretical framework to inform the design of activities in final-year engineering projects with the aim of developing personal and professional competencies that will better equip students for their WIL placement. Both theories have been previously used for understanding human behaviours, relationships with technology and interaction design.

Final-year research projects and WIL

In engineering programs, there are final-year research projects aiming to introducing students to research practice through project planning and management, different research methods, and self-reflection. In final-year research projects, engineering students work on a specific real-world problem similar to problems found in professional environments and the workplace. There are individual and group projects. The latter normally include components to assess individual achievement of learning outcomes.

WIL in engineering programs includes different forms to introduce students to real life practice and hands-on professional experience, such as internships, capstone research projects, or work placements, by which students apply knowledge and skills acquired throughout the engineering program in a comprehensive way. A work placement may provide students with the opportunity to develop professional skills, attributes, and competencies. WIL in a work placement can be assessed using a work log and a WIL report describing and evaluating the engineering experiences and reflecting on the developed competencies for a graduate-level professional engineer.

Activity theory

Activity theory (AT), also known as cultural-historical activity theory (CHAT), provides a lens to understand human learning through interactions with people and artifacts, and analyse any contradictions.

Activity theory was established by Lev Vygotsky (1978) and has evolved through the works of Alexei Leont'ev and Yrjö Engeström (Engeström, 2001) resulting in three generations.

In the first generation of activity theory, which was based on Vygotsky's work, the idea of mediation was created and analysed using the triangular model of subject, object, and mediating artifact (tools), shown in Figure 1, (Engeström, 2001).

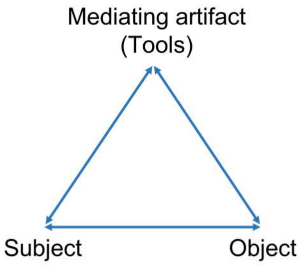

Figure 1: First generation of activity theory. Adapted from (Engeström, 1987)

In the second generation of activity theory, which was based on Leont'ev's work, the triangle was expanded to include the collective part of an activity and the artifacts: rules, community, division of labour, and outcome (Engeström, 2001). The second-generation triangle is shown in Figure 2.

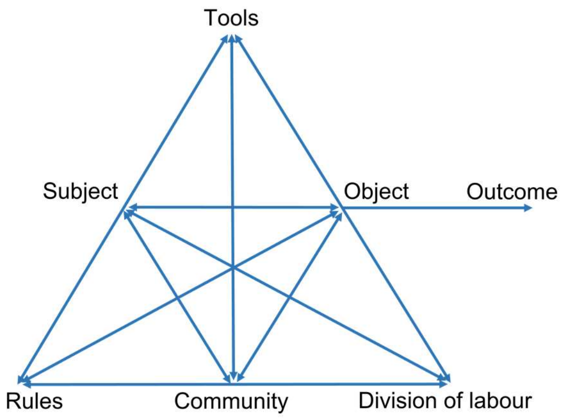

Figure 2: Second generation of activity theory. Adapted from (Engeström, 2001)

In the third generation of activity theory, more conceptual tools were developed to understand multiple perspectives, dialogue, and interacting networks of activity systems with more than one objects, as shown in Figure 3, (Engeström, 2001).

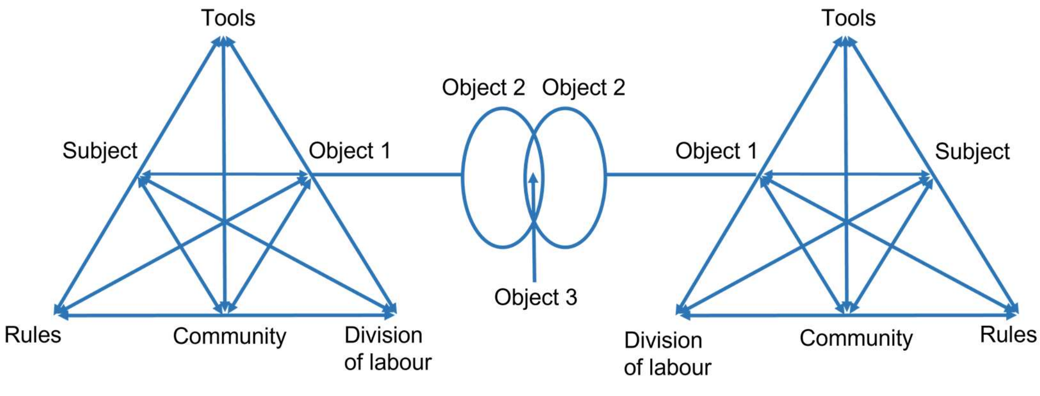

Figure 3: Third generation of activity theory. Adapted from (Engeström, 2001)

Social learning theory

Social learning theory (SLT) was established by Albert Bandura and analyses the foundations of human learning through observing and imitating behaviours (Bandura, 1977). Learning phenomena through direct experience tend to occur on a vicarious basis by observing other people's behaviour and its consequences for them (Bandura, 1977). In particular, learning by observation helps people to acquire integrated patterns of behaviour without having to form them through trial and error (Bandura, 1977).

According to Bandura (1977), personal and environmental factors are not independent determinants. In particular, people produce environmental conditions through their actions and these environmental conditions affect their behaviour in a reciprocal fashion (Bandura, 1977). The experiences through behaviour partly determine what people become and can do, which, in turn, affects their subsequent behaviour (Bandura, 1977). In the social learning view of interactions and behaviour, the personal, behavioural, and environmental factors operate as interlocking determinants of each other, as depicted in Figure 4, (Bandura, 1977).

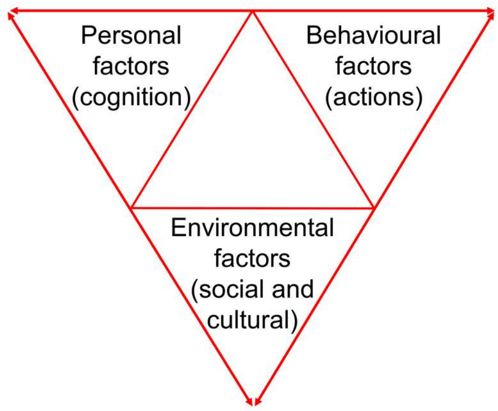

Figure 4: Bandura's triadic reciprocal determinism. Adapted from (Bandura, 1977)

Bandura (1977) also defined and analysed self-efficacy, which is a specific concept in social learning theory. According to Bandura (1977), "an efficacy expectation is the conviction that one can successfully execute the behaviour required to produce outcomes". As shown in Figure 5, outcome and efficacy expectations are different because individuals may believe that particular actions will produce specific outcomes but question their ability to perform those actions (Bandura, 1977). Bandura stated that "efficacy expectations determine how much effort people will expend, and how long they will persist in the face of obstacles and aversive experiences."

Figure 5: Efficacy and outcome expectations. Adapted from (Bandura, 1977)

Bandura (1986) also stated that 'the stronger the perceived self-efficacy, the more likely are persons to select challenging tasks, the longer they persist at them, and the more likely they are to perform them successfully'. Studies have shown that self-efficacy is important because it can determine performance, which operates partially independently of underlying skills (Bandura, 1986).

A great amount of social learning occurs among peers (Bandura, 1986). Peers may assist with some important efficacy functions and those who are most experienced and competent may provide models of efficacious styles of behaviour (Bandura, 1986). In addition, peers may provide information for comparison of efficacy appraisal and verification (Bandura, 1986). This is important because self-efficacy is a critical motivational contributor to success and development of competencies (Bandura, 1986).

Framework for enhanced professional practice

Integration of activity theory and social learning theory

Activity theory has been used as a framework for designing constructivist learning environments (Jonassen & Rohrer-Murphy, 1999) and a framework for project work in learning environments (Hung & Wong, 2000). There has also been research that linked a capstone course with vicarious experience and development of self-efficacy (Dunlap, 2005). Self-efficacy is important for improving the motivation of struggling learners (Margolis & McCabe, 2004).

We propose the integration of activity theory and social learning theory as a theoretical framework for individual final-year research projects in engineering programs to recreate professional non formal ways of learning that prepare students for WIL placements. The motivation for the proposed framework stems from challenges that students may encounter in WIL placements due to lack of personal and professional attributes, teamwork experience, and self-efficacy. The objective of this framework is to inform final-year research project activities in engineering curriculum, reinforce self-efficacy and provide vicarious opportunities for development of personal and professional skills. The integration of activity theory and social learning theory is depicted in Figure 6.

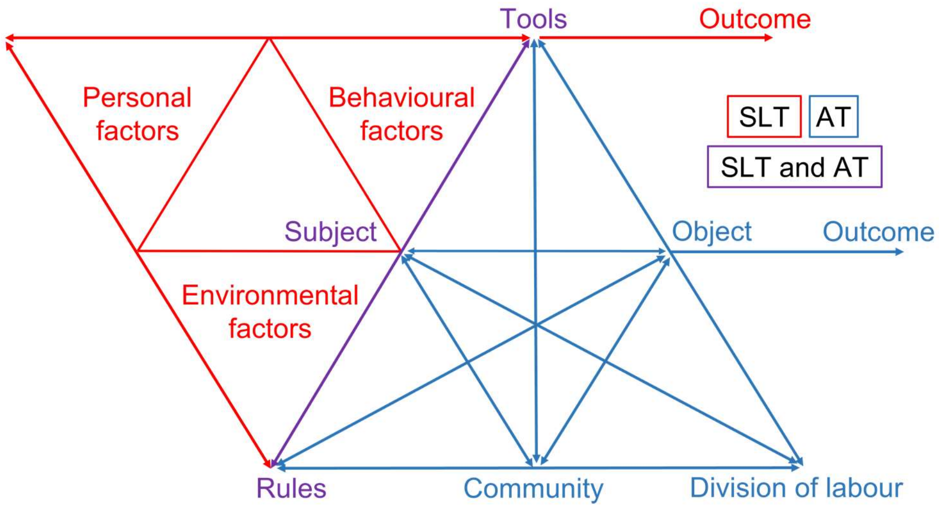

Figure 6: Integration of activity theory and social learning theory.

Case Study

We consider a case study at Queensland University of Technology, where the final-year research project is a 2-semester course and assessment tasks include written reports and oral presentations. There are individual and group projects, which include some components for individual work. The reports normally require a project definition and plan, a literature review, a detailed description of the research work, findings including visualisation tools such as plots, figures, and tables, and a reflection on progress and learning. Students may also be required to present a clear explanation of the research undertaken to an audience of supervisors and peers. Apart from the project requirements, students are also assessed in the quality of the written reports and presentation.

The literature review requires systematic search, relevant references, clear descriptions of the research gaps and explanations on how the selected literature will inform the research project. References and the format of the bibliography are also important. A concept map of the research topic and a Gantt Chart for the project timeline and milestones are normally required.

The presentation slides need to be clear and have a logical flow and the oral presentation will be effective provided that clear and engaging language – including body language – is used. The presenters need to be able to answer questions from the audience in a clear and positive way.

In the proposed framework, we have the following representations for the artifacts and factors in the AT and SLT triangles in Figure 6, respectively.

- **Subject**: student undertaking a final-year research project
- **Community**: peers undertaking similar final-year projects, project supervisors
- **Object**: reports (including thesis) and presentation slides
- **Tools**: learning resources, library, successful completed theses and presentations as samples, Zoom, Microsoft Teams, Slack, software for sharing files, writing software (for example, Microsoft Office, LaTeX, Adobe Acrobat), office software, collaborative applications, computer software, EA Stage 1 competencies (or similar) document
- **Rules**: code of conduct, academic integrity, rules and expectations set by course coordinators, rules and expectations set by project supervisors, rules and expectations set by peers, meeting attendance, internal and external milestones
- **Division of labour**: individual tasks, collective tasks, decided by project supervisors and peers
- **Outcome in AT**: completed thesis, presentation, and work placement
- **Personal factors**: personality characteristics, personal expectations, learning needs and styles, previous learning experiences
- **Environmental factors**: physical and social environment, feedback, previous learning experiences
- **Behavioural factors**: cognition, social stimuli, skills, motivation
- **Outcome in SLT**: development of professional and personal skills, self-efficacy, better preparation for work placement, self-reflection

Students can be influenced by some peers and, in turn, be perceived as models by their peers (Bandura, 1986), (Dunlap, 2005). Through the proposed framework, engineering students undertaking an individual final-year research project will interact with their peers for some project components. Instead of trying to improve the thesis and presentation using trial and error, this can be done collectively by exchanging ideas and feedback with peers.

In the proposed framework, engineering students undertaking a final-year research project as a part of a 2-semester course will form small groups (4-6 students, aiming at diversity in culture, gender, and engineering discipline) in the first semester and collaborate in project components that are common in different projects, such as project plan and timeline, Gantt Chart, literature review search and bibliography, report writing and formatting, presentation slides, and practise their oral presentation together. Learning resources, such as sample reports and presentation slides will be provided for reading and discussion. Students will also discuss a reflection of their progress and learning as a group and as individuals and reflect on development of personal and professional skills. In the second semester of the final-year research project course, the number of students in the group will be increased to 10-12 students aiming again at diversity in culture, gender, and engineering discipline. The reason for the increase in the number of students is to enable students to interact with more peers and observe their behaviours. Students will have regular meetings with their peers and with their project supervisors as individuals and as a group. The roles of the project supervisors will interchange between mentor, facilitator and client with different objectives in each role.

The specific choice of peers to form groups will affect the students' learning of professional skills from observations and competencies and will shape their learning outcome. This, in turn, will affect their actions and shape the nature of the peer collaboration in learning in order to develop specific personal and professional skills. These skills include, among others, behavioural and cognitive skills, written and oral communication skills, project management. As an example, we provide a list of professional and personal attributes that may be developed through the proposed framework (Engineers Australia, 2019) in Table 1. This framework is applicable to other equivalent international initiatives, such as CDIO, ABET, etc.

Table 1. EA Stage 1 professional and personal attributes that may be developed through the proposed framework (Engineers Australia, 2019)

Elements of competency	Indicators of attainment
3.2. Effective oral and written communication in professional and lay domains.	a) Is proficient in listening, speaking, reading and writing English, including: - comprehending critically and fairly the viewpoints of others; - expressing information effectively and succinctly, issuing instruction, engaging in discussion, presenting arguments and justification, debating and negotiating - to technical and non-technical audiences and using textual, diagrammatic, pictorial and graphical media best suited to the context; - appreciating the impact of body language, personal behaviour and other non-verbal communication processes, as well as the fundamentals of human social behaviour and their cross-cultural differences. b) Prepares high quality engineering documents such as progress and project reports, reports of investigations and feasibility studies, proposals, specifications, design records, drawings, technical descriptions and presentations pertinent to the engineering discipline.
3.4. Professional use and management of information.	a) Is proficient in locating and utilising information - including accessing, systematically searching, analysing, evaluating and referencing relevant published works and data; is proficient in the use of indexes, bibliographic databases and other search facilities. b) Critically assesses the accuracy, reliability and authenticity of information. c) Is aware of common document identification, tracking and control procedures.
3.5. Orderly management of self, and professional conduct.	a) Demonstrates commitment to critical self-review and performance evaluation against appropriate criteria as a primary means of tracking personal development needs and achievements. b) Understands the importance of being a member of a professional and intellectual community, learning from its knowledge and standards, and contributing to their maintenance and advancement. c) Demonstrates commitment to life-long learning and professional development. d) Manages time and processes effectively, prioritises competing demands to achieve personal, career and organisational goals and objectives. f) Presents a professional image in all circumstances, including relations with clients, stakeholders, as well as with professional and technical colleagues across wide ranging disciplines.
3.6. Effective team membership and team leadership.	a) Understands the fundamentals of team dynamics and leadership. b) Functions as an effective member or leader of diverse engineering teams, including those with multi-level, multi-disciplinary and multi-cultural dimensions. c) Earns the trust and confidence of colleagues through competent and timely completion of tasks. d) Recognises the value of alternative and diverse viewpoints, scholarly advice and the importance of professional networking. f) Takes initiative and fulfils the leadership role whilst respecting the agreed roles of others.

Conclusions and future work

In this paper, we provided a theoretical framework for final-year research projects in engineering programs using activity theory and social learning theory to inform the design and structure of activities in individual final-year engineering research projects with the aim of developing personal and professional competencies that will better equip students for their WIL placement.

The proposed framework has the potential to be applied internationally in similar engineering programs for professional practice. The proposed framework will be the foundation of a study in which the proposed design will be tested with students who have recently completed the engineering final-year research project and the professional placement. Contradictions when using this framework will be also studied. Future analysis will also explore the role of supporting technology to facilitate the implementation of this framework.

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