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Student Learning Outcomes from Work placement: A Systematic Literature Review

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CONTEXT

Under Engineers Australia (EA) accreditation requirements for engineering education programs, graduate engineers must develop competencies within their chosen discipline at the point of entry to practice. Universities across Australia implement Work Integrated Learning (WIL) as a method to prepare students for the world of work and to give students the chance to develop the elements of competencies required by EA. For this project, we are particularly interested in work placements or vacation employment during undergraduate degrees.

Many universities across Australia have consistently reported the “positive benefits” of work placements. Some benefits included increase in employability, job readiness, and professional identity, and to make the transition from university to work more effective. Despite the growing number of publications that highlight the benefits of work placements in improving competencies that are transferable, employers have consistently suggested that engineering graduates have skill deficits in communication, leadership, and social skills. These are some of the same skills outlined by EA.

PURPOSE OR GOAL

The main question arises as to what competencies engineering students are developing during their work placements. This Systematic Literature Review identifies existing research on generic engineering competencies to determine which one’s undergraduate engineering students develop during their work placements. This review is the first phase of a larger research project focussed on virtual work integrated learning.

APPROACH OR METHODOLOGY/METHODS

The literature search identified the intersection of three concepts (engineering students, work integrated learning, and competency) in selected databases. Databases included A+ Education via Informit, Educational Research Abstracts, Web of Science, Sage Journals and Proquest. Records of 1493 publications, between 2000 and 2020, were found. 35 journal articles meeting the inclusion criteria were included in this review.

ACTUAL OR ANTICIPATED OUTCOMES

This review synthesises the quantitative results and qualitative data to establish a list of generic engineering competencies, refining their definitions and descriptions, and highlighting interrelationships between competencies.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The results of this work will be of interest to researchers in engineering education, university work integrated learning facilitators, curriculum designers in engineering, and those who supervise undergraduate students in their workplace.

KEYWORDS

Generic engineering skills, students learning outcomes, work integrated learning.

Introduction

Work Integrated Learning (WIL) aims to train and prepare students for the world of work. It is *''an umbrella term for a range of approaches and strategies that integrate theory with the practice of work within a purposefully designed curriculum''* (Patrick et al., 2009). WIL is embedded in most engineering programs across Australia, New Zealand, Europe and the United States. The focus of this research will be on physical work placements.

WIL has been shown to provide students with benefits to increase employability, job readiness and professional identity to make the transition from university to work more effective (Ferns et al., 2014; Jackson, 2015). There is a large number of studies focusing on the significance and benefits of WIL experience for the advancement of graduate employability capabilities and skills (Crebert et al., 2004; Peach et al., 2014; Trede, 2012; Jackson, 2015; Reynolds et al. 2016).Despite the growing literatures that highlight the benefits of WIL in improving transferable skills (Patrick et al., 2008; Male, 2010; Jackson, 2014), employers have consistently suggested that engineering graduates have skill deficits in communication, leadership and social skills (Male, 2010). Studies on engineering employability skills mainly included: engagement and teamwork; professionalism and attitudes such as honesty and dedication; ability to learn; business skills; an interdisciplinary approach; leadership; customer focus and knowledge procurement and analysis (Male, 2010). These are consistent with those defined by Engineers Australia (EA) (2015) in the engineering program accreditation requirements and desirable employer-identified skills (Hamilton et al., 2015).

In previous years many projects have been conducted to investigate competencies required for engineering work. A major project that focused on various stakeholders. The SPINE: Successful Strategies of Global Engineering Education Benchmarking Review completed at the Royal Academy of Engineering in the United Kingdom (Spinks et al., 2006), University of Illinois survey (Meier et al., 2006) and an Iowa State University study (Brumm et al., 2006). The SPINE study (Bodmer et al., 2002) identified communication, leadership, and social skill gaps. The largest competency gaps found in many reviews and surveys in Engineering Education are in similar areas (WCEC, 2004; Ashman et al., 2008; Bons & McLay, 2003), yet those are some of the same competencies outlined by EA stage 1 competencies required by graduate engineers. However, the literature remains to show gaps within those skills.

Abdulwahed et al. (2013) conducted a literature review on the general abilities identified in engineering education throughout the world. Aside from the previously mentioned often claimed capabilities, they also acknowledged the significance of a variety of business-related categories such "*decision making abilities*", "*business and management skills*", and "*entrepreneurship skills*". Many researchers in the presented studies have mentioned that generic skills must be integrated within the students' learning activities in engineering education. For example, strengthening student's teamwork abilities could be achieved by allowing the student to experience personal interaction from other backgrounds and fields (Male et al., 2011).

The importance of incorporating generic engineering skills into students learning outcomes is evident in the literature. A study conducted by Direito, Pereira, and Duarte (2012) on student's perceptions of generic engineering skills have found that students recognise generic skills as important in engineering professional practice. Similarly, research conducted by Passow (2012) to find out the importance of generic engineering skills as defined by the Accreditation Board for Engineering and Technology (ABET) in the United States have confirmed that graduates from different engineering disciplines regarded problem-solving skills, communication, data-analysis and teamwork as highly important. These results coincide with Male (2011) findings from the Definition and Selection of Competencies (DeSeCo) framework that defines an 11-factor model of generic engineering competencies. Based on a sample of 300 established engineers, 250 senior engineers, and

12 Industry members, it was concluded that generic engineering competencies can be presented by the 11- factor model.

A framework that outlines essential competencies for a particular job or organisation to attain success is regarded a model of competency. A collection of maximum seven to nine skills is typically necessary for a specific job, depending on the work setting and organisation, as illustrated in the competency model (Schippmann et al., 2000). A number of models were developed globally for several professions and organisations (McClelland, 1973; Cheetham et al., 1996).

A comprehensive theoretical framework for conceptual understanding was provided by the DeSeCo project (OECD, 2002). The competencies specified by the DeSeCo projects are only observable and taken by an individual's real actions in specific situations. The complex nature of competencies also encompasses the individual's character or capabilities, setting and external criteria (OECD, 2002). The DeSeCo framework describes performance observations which are an empirical way to assess competence as expressed in actions (Rychen and Salganik, 2003). Previously in the field of engineering education, Besterfield-Sacre et al. (2000) expressed this notion and this was also reported by the Iowa study (Brumm et al., 2006) in which competencies were also observed by actions. Integrity and quality orientation were among the competences identified in the Iowa research, which are human qualities that go beyond knowledge and abilities. Therefore, the DeSeCo framework aligns with other frameworks proposed by previous researchers in engineering education.

This systematic literature review (SLR) is conducted using the DeSeCo framework from the research of Male et al. (2011). In their study, the DeSeCo framework was implemented because its approach was international, interdisciplinary, and acknowledged the complexities of competencies (Male et al., 2011). Four complexities from the DeSeCo framework were particularly essential in their study plan (i) competencies are not distinct from one another, but rather are interrelated; (ii) the importance of competencies is influenced by context; (iii) the stakeholder selection effect competence selection; (iv) Competency selection is influenced by the outcomes for which they are chosen.

This SLR recognises the complexities of competencies and will include papers from all over the world (internationally) and from all engineering disciplines (interdisciplinary). As a result of the aforementioned factors, this study adopted competencies from the study conducted by Male et al. (2011). The exploratory factor analysis was used on competency items to verify that each competency was most closely connected to the variable it represented. Any item having a factor loading of less than 0.4 was eliminated from consideration. The extracted 11 factors explained 50% of the variation in the remaining 49 competency items (Male et al., 2011). The factor was conceptually designated to the items that represented it.

This SLR will focus on studying the generic engineering competencies using the 11- factor model of generic engineering competencies from DeSeCo framework. The generic engineering competency factors are communication, self-management, entrepreneurship, professionalism, ingenuity, management and leadership, teamwork, engineering business, practical engineering, professional responsibilities, apply technical theory. This competency model identifies factors that are more distinct than items currently stipulated for accredited engineering education programs in Australia, in the Stage 1 Competencies (Male, 2011).

Methodology

This systematic literature review aims to review published works related to generic engineering competencies experienced by undergraduate engineering students, and recent graduates. Specifically, it aims to address the following research questions:

RQ1. What generic engineering competencies (knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skilfully) are developed by engineering students' WIL experiences?
RQ2. What are the research methods used to identify those competencies?

Eligibility criteria

Certain inclusion and exclusion criteria were used in this SLR. This SLR focused on journal articles published during the period January 2000 and December 2020. The inclusion criteria were that the research was published in a peer-reviewed journal and presents competencies within practice or training approaches related to undergraduate engineering students and recent graduates. The exclusion criteria were anything other than empirical research published in journals. Non-English research or research where only the abstract in English were also excluded.

Search strategy and study selection

The WIL field and the term 'competencies' traverses disciplines so relevant publications are located across a range of journals, indexed in various databases. To compile a list of suitable databases and keywords, the search strategy was designed to capture all studies that met the eligibility criteria, considering nuances of different databases. Databases included A+ Education via Informit, Educational Research Abstracts, Web of Science, Sage Journals and Proquest. Key search words (Figure 1), informed by the most frequently used competencies terms defined by Passow (2008) and WIL terms identified by Patrick et al. (2009) capture a relatively wide description of WIL. Study selection was guided by several discussions with supervisors (Figure 1). Records identified through database searching (n=1493) and those identified through other sources such as google scholar, bibliography of identified papers, etc... (n=150). Duplicates were removed, abstracts (n = 1443) were screened to determine inclusion or exclusion. Where abstracts met eligibility criteria, full papers (n = 35) were read. Conclusion about inclusion of studies was reached through discussion between supervisors and researcher at this step.

Results

The journal papers that met the inclusion criteria were used to conduct this systematic literature review.

Quantitative results

Answer to research question 1: What generic engineering competencies are developed by engineering students' WIL experiences? To answer this question quantitatively, skills were identified in each paper, and grouped to align with the 11-factor model of generic engineering competencies. After grouping the generic engineering skills, a count was performed to show how many times the skills in each category are mentioned in the selected papers, as shown in Table 1 below. Column "%" indicates the percentage of the selected papers that mention generic engineering skill included in the respective category.

Answer research question 2. Table 2 shows the research methods used in the selected papers. It is unsurprising that surveys dominate the data collection methods and we hope to see more qualitative studies in the future.

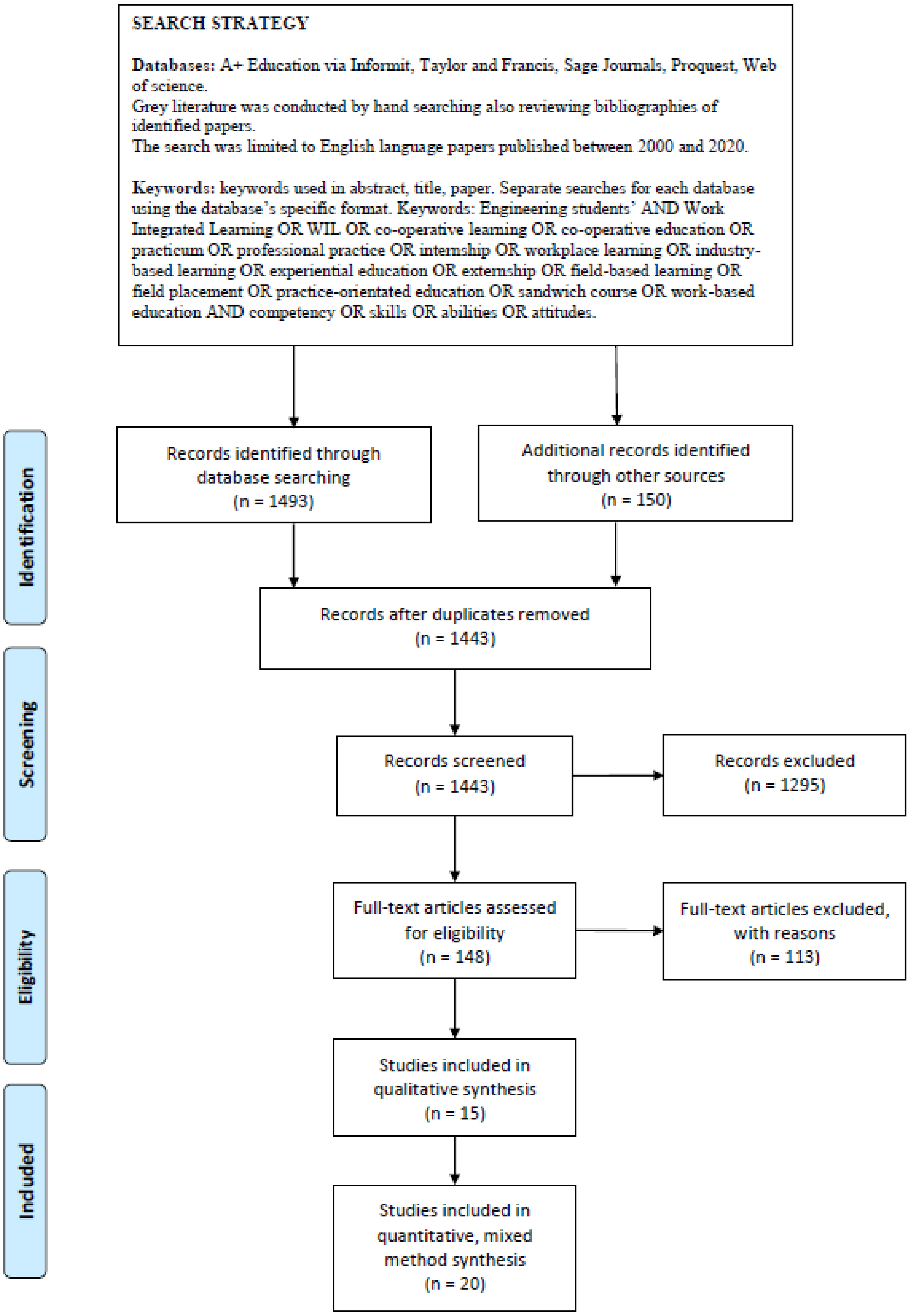

Figure 1: PRISMA flow diagram of search strategy

Table 1: Eleven factor model of generic engineering skills and how many times they appear in the selected papers

Generic engineering skill	Frequency	Percentage %
Communication	34	97
Creativity/Problem-solving	28	80
Working in diverse teams	28	80
Management and leadership	27	77
Professionalism	27	77
Self-management	24	69
Apply technical theory	23	66
Contextual responsibilities	20	57
Engineering business	9	26
Innovation	9	26
Practical engineering	9	26

Table 2: Data collection methods in selected papers.

Data collection method	Studies
Survey	28
Interviews	13
Focus groups	7
Observation	5

Qualitative Thematic Analysis

Qualitative studies have explored interrelationships between generic engineering competencies. Six common findings/themes were found however, only 4 themes will be reported in this paper due to space limitations.

Theme 1: The eleven empirically defined competency factors can be used to develop and assess student learning outcomes.

The results of this study have found that the eleven competency factors rated as highly significant regardless of individual competency ranking that fluctuated among the various engineering disciplines. Compiling the competency results that are essential for engineering work from the papers, they can all be grouped under the eleven competency factors presented (Crebert et al 2004, Le & Tam 2008). Those generic engineering competencies were defined as the core of the engineer's skill set and were essential for the development and advancement of engineers (Lenihan et al 2020). Work placements provided a platform that supported student's transition and development to the workplace.

Teamwork was frequently defined as working as an individual within a team with members from various social and cultural backgrounds (Sankaran & Mohanty). This aligns with the 11-factor generic competency "working in diverse teams". Entrepreneurship was found to be an important competency factor by various studies yet it is not mentioned in EA competencies for accrediting engineering programs in Australia - yet (Male et al 2011)].

Participants have consistently reported that universities can better prepare and develop some of the generic engineering skills before students undertake work placement (Crebert et al 2004). They suggested that program coordinators should set goals and provide a vision in collaboration with industry supervisors to make the most of the workplace learning opportunity. It was also suggested that a greater emphasis should be placed on individual/team project work at university. Student's knowledge, competency and individual abilities could be best enriched and developed through university project work. Thus, selecting appropriate projects that utilise these set of skills along with providing informative feedback will in return have positive results for engineering students. Working in diverse teams, problem solving, designing and making decisions can be greatly enhanced using this approach (Sankaran & Mohanty, 2018).

Theme 2: Teamwork

Engineers are continuously required to complete projects within a team and in the quantitative results of this SLR "working in diverse teams" ranked equally as the second most important competency. The significance of teamwork was a focus of the literature (Scott and Yates, 2002; Holcombe, 2003; Sageev and Romanowski, 2001) and re-emphasised by the results as highlighted by the participants in the presented studies (Martin et al 2005). Freudenberg et al. (2011) results show that students and employers ranked teamwork, communication and initiative skills as most important. Fleming et al. (2009) argued that teamwork, cooperation and building relationships in effect help develop other skills such as communication skills. Particularly for students, understanding that cooperative social relationships are equally as important as providing technical information is an important realisation (Trevelyan 2010).

Interactive group learning and working in diverse teams were highlighted as work place learning outcomes in survey responses by students. Employers and students further highlighted the importance of this generic engineering skill in the curriculum. Scott and Yates (2002) confirmed that teamwork is essential as it helps in the development of other skills such as problem solving, critical thinking and ethical awareness. While acknowledging the significance and relevance of teamwork skills, not all graduates felt confident in their abilities to operate as part of a team at the onset of employment. This lack in confidence in transferring this skill to employment is reported as mainly due to the lack of emphasis given by university to develop these skills (Crebert et al 2004).

Theme 3: Communication

In Australia, engineers value communication as an important skill required for their work (Male et al 2011). In the UK, study results from the largest part of each cohort population considered communication skills to be most important skill (Spinks et al 2006). These were consistent with study results conducted in the US (Male et al 2011).

Communication in engineer's daily work involves speaking, listening, reading and writing. In literature on WIL international placements, students reported that they strengthened their foreign- language communication skills as well as gained insights and knowledge of cultural differences (Spinks et al., 2006). Communication in engineering practice involves more than just providing technical information to others. Shaping the perceptions of others and cooperative social relationships are equally significant (Trevelyan, 2010).

In Australian surveys, communication is the competency most frequently featured in deficiency results (Male et al., 2010). Graduate engineer's competency gaps reported by employers in Australia, the USA and UK most often featured communication and teamwork (Nair et al., 2009; Le et al 2008). However, an Australian study reported an improved oral communication but deficiencies in written communication remained (King, 2008).

Trevelyan (2010) explains the gaps in communication reflect the dominant focus on analytical techniques and engineering sciences and that is predominantly due to the educators misunderstanding of engineering practice as a socio-technical practice that necessitates both technical and social capabilities (Le et al., 2008). Educators can play a major role in developing student's communication skills by integrating communication skills learning session activities in the foundations of the learning process. More communication-related activities in the classroom, open discussions on problems, and projects that match technical concepts in spoken, written and visual formats can all help students acquire these important abilities. It's important to remember that strong communication skills can only be developed through consistent practice (Spinks et al 2006).

Theme 4: Reflection and feedback on workplace activities and university learning is crucial in the development of skills and students learning outcomes.

Critical reflection on workplace activities and university learning was a common theme highlighted in the presented studies. According to Harvey (2002), *"systematic reflection"* is required for students' learning to progress through work placement. Students definitely noticed the usefulness of systematic debriefing and reflection sessions and have commented about the importance of reflection in addressing competency outcomes following work placement.

Consistent with the literature on best practice, oral presentations; professional portfolios and reports summing up the WIL experience and developmental strategies such as reflection diaries and journals (Martin et al., 2011; Yorke, 2011) were viewed as significant. Industry evaluations of student performance were considered vital (Patrick et al., 2008) with supervisors/mentors instrumental in ongoing observation, review and feedback.

As well as incorporating critical reflection into the curriculum, feedback is sought to be vital for student's skill development. Students should be encouraged to seek out and negotiate chances for skill improvement while on placement, and students should formalize the process performance feedback from their industry supervisor throughout their placement. To enable effective skill development during work placement and as an established model of good practice Drummond et al., (1998) emphasizes practicing those skills with guidance and support which informs and encourages constructive reflection and improvement strategies. Key component of facilitating these opportunities include feedback from peer groups, work placement supervisors and self-assessment.

The successful transfer of skills largely depends on continuously practicing the skill in different context. Students have emphasized that integrating skill development from university to the work place involves few steps. These include, learning the basic theory at university, given the opportunity during work placement to refine skill performance; shadowed by self-reflection and review of performance upon classroom return to cement understanding and learning of established professional practice. These steps support the effective integration across the two settings (Coll et al., 2009; Billet, 2011; Jackson, 2015).

Limitations

A number of limitations were presented in this SLR. Some relating to the studies presented while others are directly related to the process of conducting SLR. Just as with any other SLR, the inclusion criteria presented in the methodology restricts searching the literature to the terms used, type of publication, review process and data used in methodology. This was used to eliminate studies that did not include empirical research data. Moreover, when screening for papers there were informative studies discussing generic engineering competencies but had no empirical research data and were therefore excluded. Although this study searched databases along with grey literature and in paper references it could possibly have missed papers that may meet the inclusion criteria.

While this study initially intended to capture undergraduate engineering students' learning outcomes following their physical work placement, it was difficult to only pick undergraduates while so many studies included recent graduates. As a result, studies that included recently graduated engineers, senior engineers and industry supervisors that discussed students learning outcomes from work placements or generic engineering competencies were also included.

Conclusion & Future work

This systematic literature review assessed generic engineering competencies using the 11-factor model as a framework. It searched, collated and appraised available and relevant empirical evidence to provide an interpretation of search results. This systematic literature review can be used as a guide for engineering educators and stakeholders to inform decisions and descriptions of the generic competencies.

Future work following this review will extend to identify student learning outcomes in terms of generic engineering competencies following their virtual work placement. Future research in evaluating engineering virtual work placement is essential especially since the COVID-19 pandemic outbreak where many engineering work placements were experienced virtually. The next phase of this research will determine student learning outcomes in engineering physical work placements and investigate if virtual work placement students were able to experience similar/equivalent learning outcomes.

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