Full Paper

Introduction

Our understanding of what research is changes with societal and cultural advancement, as well as with expanding discipline domains. Due to this constant change, contextualising what research is in a discipline is typically overlooked, particularly in professional disciplines such as engineering. This has serious implications for both researchers and educators alike.

In Australia, the lack of comprehension regarding what engineering research is, has led to unfounded or simplistic decisions being made within engineering curricula, confusion in what and how to teach research methods, and inappropriate simplifications being made in what 'counts' as research throughout undergraduate degrees. This has been precipitated by the shift in engineering courses to AQF level 8, requiring explicit research training in the curricula and for students to undertake a research project.

As there is no clear understanding of what counts as engineering research at an undergraduate level, often academics default to understandings based on their own research, or liken it to PhD research. However, as all engineering students are now graduating with research skills, it is imperative that engineering research be reconceptualised to ensure that these skills are useful in engineering practice, and not just further academic research.

To reconceptualise engineering research, a definition and criteria need to be formulated to assess whether a project constitutes engineering research.

Research has typically been considered the discovery of new knowledge (Boyer 1990). However as discoveries began to be made outside of academia or laboratories, the boundaries of the traditional research understanding were blurred. The Boyer commission redefined research as "the abilities to identify, analyse, and resolve problems": allowing for a much greater scope of what research could be (Boyer Commission 1998). Educational and professional bodies also redefined research, as "an increase in the dimensions of knowledge"(AQF 2012) allowing for variances in context and level of scope, but ensuring that the research covers new ground. Engineers Australia determined research to be a process moving from the initial identification of a problem or a gap in knowledge, through analysis and critical review of current knowledge, resulting in a new conclusion or strategy (EA 2012). The RSD Framework (Willison, Le Lievre et al. 2010) expands on the understanding that research can be completed at different levels of autonomy, requiring different levels of guidance, and therefore being relevant to curriculum design in a university context. In the early stages of researcher development, the framework allows for 'closed enquiry' (Willison, Le Lievre et al. 2010), whereupon the question, method or outcome are predetermined or known by the lecturer, enabling the research to be novel purely to the student researchers. The Oxford Dictionary (Oxford 2015) requires research to be systematic in process as well as finding new conclusions. McLay (2013) believes research to be how we understand and see the world around us and therefore speculate on new possibilities. Stappenbelt 2009 refines the definition of research by requiring that the problem or research question to be "sufficiently complex", and not solvable through existing methods or understandings. Lincoln and Guba 2000 also further refined the criteria of research, requiring peer review, transferability, dependability and confirmability. Unlike the Boyer understanding of scholarship, research and development have typically been divided into separate entities whilst being expected to coexist and be completed by the same person. Research being the traditional acquisition of new knowledge, and development, the application of knowledge to create (Bock and Scheibe 2001). Research by that definition identifies with the scholarship of discovery, and development to that of application and integration. The Frascati Manual, since 1963, has understood research and development to comprise of basic research, applied research and experimental development (Frascati Manual 2002).

Further consideration was needed to determine research context, due to the variance within the definitions. The Australian Qualitative Framework specified “dimensions of knowledge (AQF 2012), the Oxford Dictionary wanted “new conclusions”(Oxford 2015), whilst Engineers Australia suggested that research involves “synthesising … and developing substantiated conclusions”(EA 2012). From these rationales, it can be determined that research context incorporates local and global implications, whereupon a solution could be novel in a certain situation, including novel to the student researcher, or alternatively, novel overall.

This allows for a baseline for what research looks like in any situation or profession: *research is the investigation of a phenomenon in a context*.

Guided by these definitions, we have developed three main criteria to determine if a project can be considered research.

The project should

1. Pose a research question. (Boyer Commission 1998, EA 2012)
2. For which the researcher doesn’t already know the answer[#]. (Bock and Scheibe 2001, AQF 2012, Oxford 2015)
3. Attempt to find the answer through a systematic approach. (Stappenbelt 2009, EA 2012, McLay 2013, Oxford 2015)

[#] though the answer may be known to others, including the research supervisor.

Undergraduate Engineering

Research is therefore crucial in all aspects of work for an engineering graduate, making it imperative that these skills are gained throughout their education whilst at university. However, from course outlines (SUT 2015), competition requirements for activities such as Formula SAE (SAE 2014), and our model of engineering research work practices; it is understood that a lot of projects already incorporated into current subjects, engineering based extracurricular and *work integrated learning* (previously known as Industry Based Learning), currently include research training without specific purpose, intention or understanding. Despite the inclusion of research training, albeit not overly planned, students are not graduating with well-developed or applicable research skills. This could be due to lack of student engagement (O'Donnell, Dobozy et al. 2012) or poor teaching practices. Accordingly, it is important that we make research training an intentional and important component of students’ education, whilst conveying the importance and applicability of research in all careers.

All students are required to complete core subjects and *work integrated learning* to complete their degrees, making these ideal situations to teach all students how to research. Extracurricular activities such as Formula SAE and Unmanned Aerial Systems (UAS) teams although ideal for developing and furthering applied and integrative research abilities, cannot be depended upon due to the optional nature of such pursuits. Additionally, work integrated learning relies on an employer’s willingness, time and other commitments to consider research training as a defined part of the experience. Consequently core subjects must include research training to guarantee a student’s competency.

Different universities have tried integrating research training within certain subjects, or as new teaching frameworks. As developed by the University of Adelaide, the Researcher Skill Development Framework can be implemented beginning at a low level of understanding and autonomy, on the part of the student, whilst retaining the same process and facets throughout the gradual development of the student as a researcher (Willison, Le Lievre et al. 2010). Evidence of the successful integration of this framework across numerous universities, suggests that students’ understanding and awareness of the process leads to a greater appreciation and ability in research (Willison 2014). However no correlation has been found between the levels of success in first year research projects to that of final year research projects (Blicblau and Richards 2012). Rather a suggestion that work integrated learning stimulates a student’s ability to apply research techniques and become independent learners (Blicblau and Richards 2012), prompting a more andragogical approach (Haldenwang, Slatter et al. 2006). The “continuum of students’ intellectual development” (Haldenwang, Slatter et al. 2006) will transform from passive to active, provided that students are given suitable support (Perry 1970, Willison, Le Lievre et al. 2010).

RMIT University offers a subject which teaches TRIZ, the theory of inventive problem solving (Harlim and Belski 2010). The concept is to ensure that information is not missed by creating a procedure for novices, and remove biases by requiring many perspectives to be incorporated (Belski and Belski 2008). It was found that increased confidence impacted upon motivation to face an unknown problem, which was increased by providing students a problem solving method. Without TRIZ, it was believed that greater life experience and time were needed to develop similar strategies. Anderson agrees that being able to define a vague and unknown problem so that it can be solved typically requires ten years of experience, but dedicated teaching can shorten the timeframe (Anderson 2013).

Cape Peninsula University of Technology has integrated research training into their project management skills course (Haldenwang, Slatter et al. 2006), encouraging students to create timelines, and organisational structure, to manage the large undertaking that is a final year research project. Students were deemed to be “not adequately prepared for immersion in the research project” (Haldenwang, Slatter et al. 2006) prompting the necessity of a change to the teaching framework. This has received positive feedback from students who felt more prepared and less stressed due to the organisation and management strategies that were taught. The university considers the material to be lifelong training, for the betterment of their students and society, however states that this type of training should be included earlier in the degree so that students are more prepared and comfortable with demands of a research project. Likewise, research undertaken by the University of Southern Queensland, found that final year students were not prepared especially for literature reviews, and other research skills, within their final year research project. Leading to the agreement that research should be taught throughout the degree to better prepare students (Cochrane, Goh et al. 2009).

The Australian National University combines third year and fourth years within software engineering research project teams who work on industry endeavours. The teams are made up of three to four 3rd year students, and one or two 4th years, who then work with two engineers from industry, who act as “technical advisors”. This provides the students with the “full software development lifecycle” (Johns-Boast and Patch 2010) and the fourth year students with management experience. The Swinburne Design Factory also involves students from at least 3rd year to work with industry on “large scale research project[s]” (SUT 2015). The teams are multidisciplinary to meet the needs of the industry project, being one or two subjects which are typically electives, whilst integrating budget and time constraints, client requirements and applying research methods. Teamwork, and multidisciplinary teams with constraints are frequent in industry, this type of preparation for students allows their research training to be more aligned with what industry will expect, whilst providing a greater understanding of how professionals undertake a project, through supervision, networking and the ability to work under engineers with more experience.

The University of Arkansas introduced interdisciplinary subjects teaching innovation (Anderson 2013), which for our purposes will be understood as applied research. Utilising intuition development through a hands on approach, with an emphasis on understanding the problem, three courses were developed, initially for engineering students, but then broadened to other disciplines due to demand. The interdisciplinary nature “ensure[d] problems are looked at from more than one perspective”(Anderson 2013). The findings concluded that innovation or applied research training is crucial to the development and future of engineers, especially due to the changing nature of the roles of engineers away from manufacturing. “Mega-capstone courses” involving students across disciplines and applied research training through the curriculum are suggested as necessary for students to gain alternate perspectives and experience.

Education Without Borders projects have been established within engineering subjects in each year level at ANU (Browne, Blackhall et al. 2010). A report on today's engineering graduates, states that they need to have stronger communication and teamwork skills and a broader perspective of the issues that concern their profession, such as social, environmental and economic issues. (Mills and Treagust 2003-04) The importance of service learning, awareness of the wider community and the ability to engage students with project based activities has helped shape the curriculum. Problem based learning increases the probability of engaging all students, regardless of their stage on the “continuum of intellectual development”(Haldenwang, Slatter et al. 2006), through deeper understandings of the material (Biggs 1999). The heightened engagement of students has led to them pushing beyond requirements and expectations to develop creative solutions (Browne, Blackhall et al. 2010).

Similarly, deep learning occurs when students take charge of their education. Action learning, compared to problem based learning, involves greater self-directed learning and less hierarchical structure. Learning action sets were introduced as an alternative to one on one supervision for final year research projects (Stappenbelt 2009), at the University of Western Australia. This supports the industry push for self-directed learning, self-confidence, critical thinking and management skills (Haldenwang, Slatter et al. 2006). The learning action sets also was found to increase motivation, enthusiasm and overall progress due to the students sharing their experiences throughout the project (Stappenbelt 2009). The students involved, preferred the sets to one-on-one supervision, which they had experienced the previous year in their third year research projects. David Kolb developed the Learning Cycle, which facilitates deep learning through experience, reflection, abstraction and testing: reflection being applied to problems with no apparent solutions (Kolb 1984), a key part of the action learning sets.

An Office for Learning and Teaching (OLT) project looked at the requirements to meet AQF8 competencies and guidelines for how best to teach these skills. Recommendations included public presentations of projects to encourage engagement, workshops to strengthen skills during the final year research project, “parallel subjects, preparatory subjects and program curriculum prior to the project subject”(Howard, Kestell et al. 2014). It was also advocated that the final year research project should be an opportunity to improve on skills that have been attained in earlier years, skills such as critical thinking, research, communication and application of knowledge. (Howard, Kestell et al. 2014)

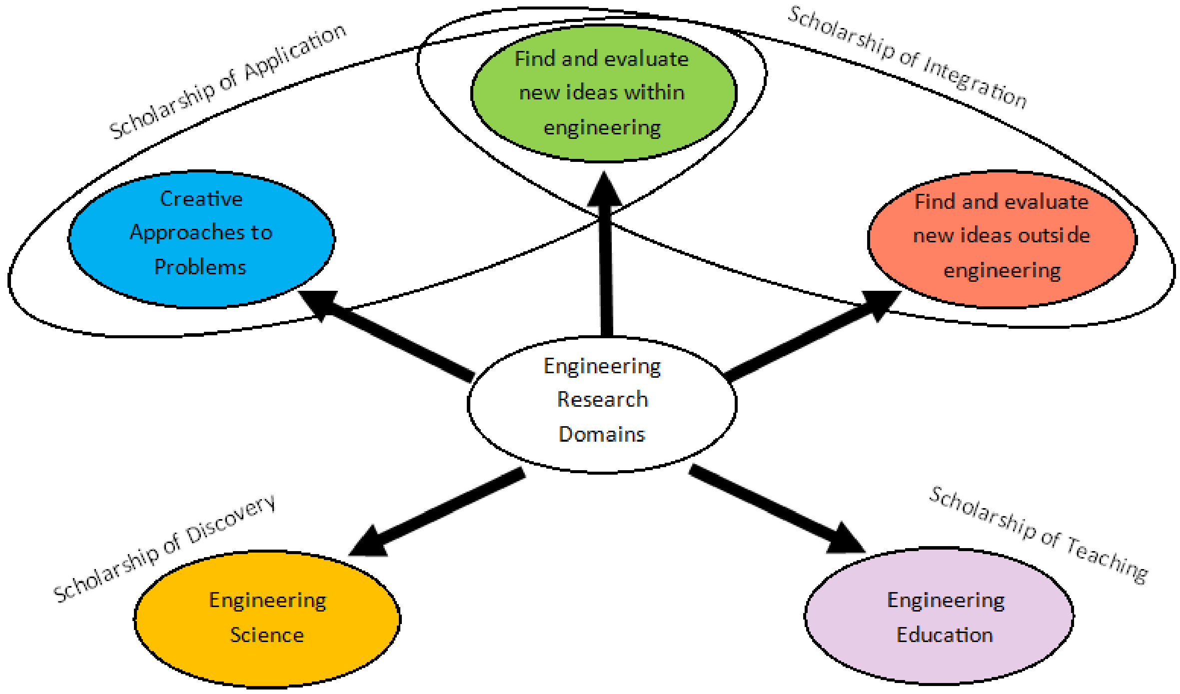
Students have also concluded that more needs to be done. UNSW students started CREATE an organisation which encourages hands on invention, design, and innovation within engineering. Providing tools, facilities, knowledge, resources and the opportunity for collaboration, anyone can “turn their ideas into designs, prototypes and products.”(CREATE NSW 2015) Classes and workshops are run weekly, with entrants into competitions, as well as consulting within and outside UNSW. “We are firm believers in collective knowledge, learning and cooperation as an effective way to expand what is possible for any individual to accomplish in the technical sphere.”(CREATE NSW 2015)

To ensure engineering graduates are adequately equipped with research competencies, it can be derived from current practice that universities believe there to be complementary skills that are needed to be an effective researcher. These include management, organisation, teamwork, communication, leadership and many more. To properly prepare our students for their futures, all of these skills must be suitably conveyed and taught, to allow for consolidation of skills, and the transition from passive to active learners. Engineering degrees need to evolve from the technical focus, and embrace where engineering as a profession is headed, and not just within final year research projects.

Boyer’s four scholarships

From this interpretation of research, we can then analyse engineering research, to gain a more discipline specific comprehension. Engineers Australia have formulated stage level competencies to recognise the respective stages of engineer development, including the overarching research understanding, that engineers are *"responsible for bringing knowledge to bear from multiple sources to develop solutions to complex problems and issues"* (EA 2012).

It can therefore be argued that research is not purely the Scholarship of Discovery (Boyer 1990), but rather the combination of different approaches and way of creating new content. This can be aligned to all four of Boyer's scholarships in conjunction with the Engineers Australia competencies.



1. The Scholarship of Discovery (Boyer 1990) is reflected within **engineering science**, ie. the discovery of entirely new materials, processes or components. Engineers Australia Stage 2 competencies demonstrate this through the option for engineers to "conduct research concerned with advancing the science of engineering and with developing new principles and technologies within a broad engineering discipline"(EA 2012).
2. Problem solving (Al-Abdeli and Bullen 2006) or **creative approaches to problems** aligns with both Boyer's Scholarship of Application (Boyer 1990) and the Stage 1 competency: *"Applies creative approaches to identify and develop alternative concepts, solutions and procedures, appropriately challenges engineering practices from technical and non-technical viewpoints: identifies new technological opportunities"* (EA 2012).
3. The Scholarships of Application and Integration (Boyer 1990) both apply to the research domain of **finding and evaluating new ideas from within engineering**. Graduate engineers (or stage 1 engineers) must *"Interprets [sic] and appl[y] selected research literature to inform engineering application in at least one specialist domain of the engineering discipline"* (EA 2012). This requires graduates to not only be aware of new discovery within engineering, but know how to apply it to new situations and integrate with existing processes.
4. Similarly, **finding and evaluating new ideas from outside engineering** identifies with Boyer's Scholarship of Integration (Boyer 1990), whereupon a graduate engineer *"identifies and critically appraises current developments, advanced technologies, emerging issues and interdisciplinary linkages in at least one specialist practice domain of the engineering discipline*."(EA 2012) Thereby engaging in *"work*

that seeks to interpret, draw together, and bring new insight to bear on original research" (Boyer 1990).

5. These domains of research are brought together by the discipline of **engineering education**; the pursuit to improve the teaching methodologies and approaches to develop all engineers. Otherwise understood as the Scholarship of Teaching, whereupon *"pedagogical procedures must be carefully planned, continuously examines [sic], and relate directly to the subject taught"* (Boyer 1990). Engineers Australia supports this, stating that educators must lead a *"progressive pedagogical framework, adoption of best practice" and demonstrate "interlinked research and teaching programs"* (EA 2012).

Accordingly, it can be ascertained that engineering research is comprised of five domains, each applying the same research skills in different manners.

Framing engineering research therefore requires a multifaceted approach. It will look different in the lab to industry, and even between industries. However the commonality between them all is that research requires systematic investigation into a phenomenon to determine something novel.

How can we teach this?

"I feel like I am on the verge of much academic pain. I have spoken to previous students during their suffering." - USQ student (Cochrane, Goh et al. 2009)

The recent introduction of the Australian Qualifications Framework (AQF 2012) has led to engineering degrees shifting to honours level qualifications around the country. This has required the explicit teaching of research principles and methods, as well as a research project in the final honours year. Up until now, the implementation of this has been largely modelled from research training in science degrees, where the approach to research is aligned to Boyer's Scholarship of Discovery (Boyer 1990). However from our new conception of research, specifically engineering research, this dedication to engineering science is inappropriate for the majority of students who will enter straight into industry (King 2008, Blicblau and Richards 2012, EA 2014). Unfortunately, students are not prepared or equipped with necessary skills regardless of the research domain.

The prevailing technique of universities is to teach students the required competencies during their final year research project. Proficiencies ranging from written communication skills (Blicblau and Dini 2012) to project management (Haldenwang, Slatter et al. 2006). Online videos (Mann 2014), and workshops are used to communicate the requirements to students, but supervisors can be left with expectations from the students to support this learning (Cochrane, Goh et al. 2009), without suitable workload allocations. Thereby resulting in learning opportunities being lost in an effort to complete projects that students are not prepared to finish, or manage (Haldenwang, Slatter et al. 2006).

Currently FYRPs include a combination of staff, and industry led projects. Despite industry led projects not typically following a traditional discovery research approach, the benefits to the university: sponsorship and connections, and students: industry contacts, typically leads to the science-based definition of research in a final year project to be stretched without educational justification. Curiously, Swinburne University of Technology presents more awards to students who complete industry based FYRPs (Blicblau and Richards 2012), possibly due to greater student interest and motivation in the type and content of projects (Gorka, Miller et al. 2007)

From the integration of Boyer's four scholarships (Boyer 1990), industry-led final year research projects typically fall under either one of, or a combination of the scholarship of application and that of integration. Whilst industry led projects are typically limited to engineering projects of smaller scales, the University of Calgary has demonstrated the ability to form larger research project teams to enable civil engineering students the ability to engage with industry projects (Ruwanpura and Brown 2006), encouraging more ambitious project types, affiliations and sizes. Especially in integrative projects, teams comprised of people from varied disciplines and/or backgrounds allows for the creation of more diverse ideas (Smith 2010), which is utilised in industry, but not capitalised within university led projects. As university led FYRPs encompass application and integration type projects, as well as the existing discovery research, diversity within teams should be embraced, including across faculties.

Similarly, by expanding the domains of engineering research, engineering education research projects can be included as justifiable final year research project topics. The scholarship of teaching should be demonstrated by academic staff throughout an undergraduate course, to support the understanding that teaching is not just a hindrance to research discovery (Boyer 1990).

The consolidation of a definition for engineering research allows projects to be undertaken that would previously have been questioned under the scholarship of discovery model, and encourages students to pursue research topics relevant to their interests and ambitions.

Final year research projects (FYRPs) should reflect the AQF guidelines which allow the research to be “applied research or professionally-oriented research” (AQF 2012), whilst supporting the future direction of graduates and the research skills they are likely to require.

Conclusion

Universities struggle to adapt to the broad Engineering Australia competencies, as current teaching practises are forced by funding models to focus on esoteric research or industry sponsored projects, without comprehension of the reasoning or benefits to the students. The Australian engineering industry will continue to decline as the demand for graduates with pertinent skills is not met by university offerings. We must embrace the multiple domains of engineering research within our bachelor degree course structures to develop engineers for all career paths, not just that of research and further study.

Next steps will be to test the findings from the literature review, by interviewing participants from industry who employ engineering graduates. This should be undertaken across a range of engineering disciplines, larger companies and SME’s, genders, ethnicity, experience and area type (e.g. R&D, construction, etc.) to ensure diversity within the responses.

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