Graduate engineers as project implementers – implications for engineering education

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Structured abstract

BACKGROUND

Many engineering graduates and junior engineers generally, are employed in roles that are field-based and/or involve first-hand experience on implementation of engineering projects. This applies in a range of branches of engineering for example, civil engineers on construction projects and electrical or communications engineers involved in network field installation. A graduate or junior engineer employed in such a field engineering role will typically be involved in monitoring of field activities to ensure compliance with design specifications. In the conceiving, designing, implementing and operating (CDIO) engineering education framework, employment in such a role enters at the implementation stage, without necessarily first experiencing the conceiving and designing stages.

PURPOSE

This paper explores the questions of what attributes are required as an implementer of engineering projects and what engineering education approaches contribute to preparing a graduate for employment as a project implementer.

METHOD

The educational and training implications of project implementation roles for graduate engineers is investigated by a review of job advertisements describing relevant work roles and the candidate attributes sought. The advertised job roles were classified according to the CDIO framework to identify common characteristics of the candidate requirements.

RESULTS

The review of advertised jobs showed that implementation-type roles were well represented among graduate and junior engineer opportunities. Most candidate requirements were found to be consistent across the CDIO roles. One area of difference observed was the prevalence of attributes related to the ability to work independently in implementing and operating roles. Implementing and operating roles can involve following instructions and procedures with minimal supervision provided. Engineering education, like most education, involves providing instructions and evaluating the results of students work. However, the ability to follow instructions is not generally included as a learning outcome to be assessed. In addition to assessing the ability to follow instructions, learning activities based on the framework of standard operating procedures (SOP) can be used to explicitly train students in skills relevant to implementation of engineering projects.

CONCLUSIONS

Job roles for graduate engineers involving project implementation (e.g. field engineer) require many of the same attributes and skills of engineering design roles. The ability to work independently has been identified as a common requirement of implementation roles that is not as commonly specified in design roles. The CDIO engineering education framework provides a platform to ensure implementation activities are represented in the curriculum. One simple approach is to ensure that the ability to follow instructions is included as an explicit learning objective in existing educational practice. Additionally, educational activities which focus on use, development and evaluation of operating procedures for engineering tasks can be used to develop knowledge and skills relevant to implementation of engineering projects.

KEYWORDS

Civil engineering, CDIO, implementing

Introduction

Many graduate and junior engineers are employed in roles that mainly involve implementation of engineering designs. For example, many civil engineering graduates and junior engineers are employed as field engineers in the heavy construction and mining industries. A graduate or junior engineer employed in such a role will typically be involved in monitoring of earthworks construction to ensure compliance with design specifications. Similar situations exist in other branches of engineering for example, an electrical or communications engineering graduate being involved in communications network installation fieldwork.

Engineering education needs to be understood in the context of engineering work (King 2008). Engineering practice can be modelled as conceiving, designing, implementing and operating activities (Crawley et al. 2007). This CDIO framework provides a practice-based context for engineering education. Based on the CDIO approach an engineering study program should provide: “specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders” (Crawley et al. 2007).

Conceiving and designing activities may be important as the early stages of engineering projects, however, employment for graduate and junior engineers can commence as implementing or operating activities prior to gaining experience in the conceiving and designing stages. This situation leads to the question of whether there is a need for engineering education to prepare graduates for employment as a project implementer or operator. According to Crawley et al. (2011), “implementing includes hardware and software processes, test and verification, as well as design and management of the implementation process. Operating covers a wide range of issues from designing and managing operations, through supporting product lifecycle and improvement, to end-of-life planning”.

This paper gives examples of the types of role where a graduate or junior engineering may be involved directly in project implementation. The skills required for such roles are considered and implications for the engineering curriculum are discussed.

Analysis of Job Advertisements

Job Descriptions

Analysis of job requirements has been used previously as a methodology to assess educational program requirements (Doron and Marco, 1999; Trevelyan and Tilli, 2007). In the current study a sample of 28 job advertisements posted on an on-line employment service were surveyed in August 2013. The general field of engineering, including all sub-disciplines located in any part of Australia, was selected. The advertisements found included civil, mechanical and electrical engineering disciplines. The key words graduate and junior were each used to further refine the sample.

Of the 28 advertisements six were described as graduate programs which were unable to be differentiated according to the CDIO framework. An additional five advertisements were of a sales nature and were not considered further in this study.

The remaining 17 advertisements contained descriptions of a job role which could be classified into the CDIO framework of engineering practice. The classification was conducted based on interpretation of the job requirements as stated in the advertisement (Table 1). Overlapping categories were included to minimise the effect of misclassification. Implementation was found to be a significant category, with 10 (out of 17) of the jobs having a component of implementation in their description (Figure 1).

Table 1: Summary of roles in graduate and junior engineering job advertisements classified according to CDIO framework

CDIO	No.	Example statement
Conceive and Design	1	"You will provide conceptual through to detailed design for a range of residential and commercial sub divisions…"
Design	2	"… a rare opening for an Intermediate level Electrical Design Engineer to join their high performing building services group … part of a sizable team of Engineers and Drafters who cover the electrical design on a range of projects"
Design and Implement	2	"… you will help define the systems design. You will also be involved in implementation, integration and testing."
Implement	5	"… your primary responsibilities will include … construction phase inspections of building projects assigned to you"
Implement and Operate	3	"…performing skilled technical services, usually at the well site. Field Specialists carry out a demanding, hands-on role, often working in harsh and challenging environments, making use of all the latest technologies …"
Operate	4	"The Operations Engineer… an exciting opportunity for an Engineer with ideally up to 2 years experience to be an important and integral part of the Field Services Team."

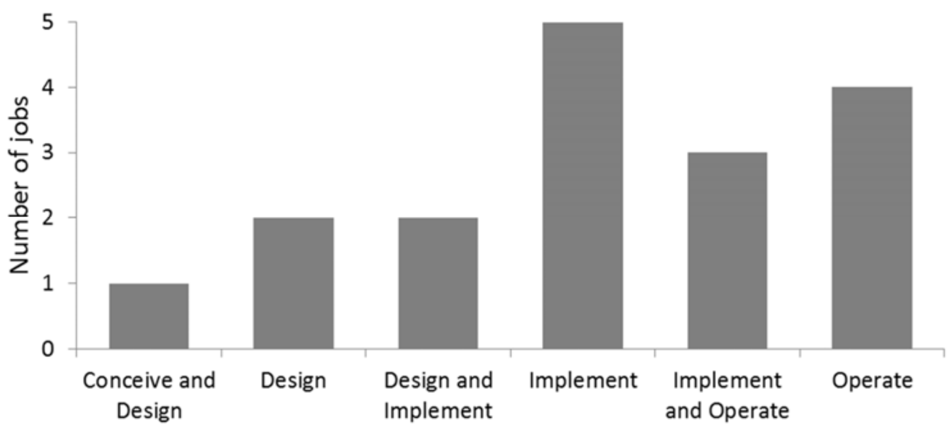

Figure 1: Survey of advertised job roles classified according to CDIO framework

Applicant Requirements

The general requirements of candidates stated in the advertisements were also classified according to the CDIO framework. These requirements were mainly of the type referred to as 'generic skills' (e.g. Male et al., 2011). While the results were variable for the most common requirements, no trends were observed in the sample data (Figure 2). Technical requirements were also collated according to CDIO role type and no significant differences were observed (Table 2).

Other attributes not otherwise captured were also collated for each CDIO role type. These statements typically were words or phrases recognised by Young and Chapman (2010) as 'personal skills'. It was observed that the Implementation and Operation roles contained a large number of statements related to independence and adaptability (Table 2).

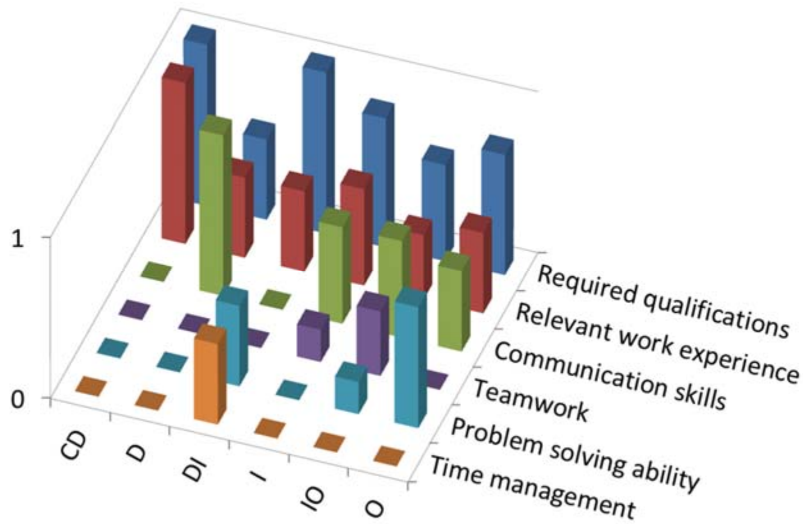

Figure 2: Requirements in job advertisements classified by CDIO roles (normalised to total within each CDIO classification).

Table 2: Summary of additional requirements in job advertisements classified according to CDIO. Attributes associated with independence are highlighted in bold

CDIO	**Specified technical knowledge or experience**	**Other attributes**
Conceive and Design	Knowledge of specified software, understanding of project delivery schedules	Enthusiastic
Design	Knowledge of specified software	Desire to progress career
Design and Implement	Knowledge of specified field and software. Experience in most of product life-cycle and experience with technical documentation in a regulated environment	Attention to detail
Implement	Technical area knowledge, technical specifications and standards. Able to undertake structural inspections and present quality reporting', experience and knowledge in specified technical areas (3)	Willingness and enthusiasm to learn all areas of business. Work **independently**
Implement and Operate	Three technical knowledge areas noted. Proven interest in the field, proven skill diagnosing and troubleshooting. Demonstrated technical/practical capability	**Adaptable** (2), **resourceful**. Motivated, **resilient**
Operate	Knowledge of specified commonly used software	Ability to foster positive relationships with various stakeholders, **proactive**, thoroughness. Enthusiasm, determination, and a **'Can Do' attitude**. Commitment to establishing a career in <industry>. Willingness and ability to learn and absorb information, and take **accountability** for tasks

Implementation Role Example

An example of a graduate or junior engineer which was classified as an implementation role is as follows:

> <Company> *offers complete engineering construction and project management services to local, national and internationally based clients working within Australia and is excited to continue its growth within Queensland.*
>
> *As part of our continued growth we are now seeking two Site Engineers to deliver two separate road construction projects, one located in Townsville and the second in Cairns.*
>
> *You will report to a Project Engineer who will offer support and be a mentor to assist in your own development and career within* <Company>*. You will be required to manage and implement quality assurance systems, conduct onsite test and inspections and ensure works are being delivered to the drawings and relevant specifications.*
>
> *You will have a fantastic attitude towards safety and have a passion for delivering high quality projects want to continually drive performance improvement and innovation across your project. Experience working as an onsite engineer on road infrastructure projects will be highly regarded but not essential. Recent graduates will also be considered.*
>
> *The position is full time and will initially be based at one of the above mentioned projects in North Queensland for a period of around six months. Once these works are completed you will transfer to another project that will require you working on a fly-in-fly-out basis on roster arrangement. Generous salary uplift will be given to compensate for working on a roster and living in a camp style accommodation.* (Seek.com.au, 30/5/2013)

In summary, the role requirements are:

1. manage and implement quality assurance systems
    a. conduct onsite test and inspections
    b. ensure works are being delivered to the drawings and relevant specifications
2. fantastic attitude towards safety
3. passion for delivering high quality projects
4. continually drive performance improvement and innovation across your project

It is necessary to consider whether, and how, civil engineering degree programs prepare someone for this employment opportunity.

Requirement 1 involves following a system provided by the company. Requirement 1a involves conducting tests and inspections of the work being done. It is reasonable to expect that the tests to be done will be mostly tests which have been covered in a civil engineering curriculum. It is possible that the company has some new technology, but the candidate will know the physical quantities being measured and be quickly able to adapt to an unfamiliar method. Requirement 1b involves the ability to comprehend and interpret drawings and specifications. Having the spatial skills to transfer information from two-dimensional sections and plans to three-dimensional features, and vice versa will have been developed in a range of courses within the civil engineering degree. Understanding specifications requires a thorough knowledge of material properties and tests, which will have been encountered in a range of courses.

Requirements 2-4 could be considered graduate attributes or competencies that are not restricted to the civil engineering arena. None of these requirements are likely to have been fully developed through lectures, but rather through opportunities to undertake project work. The degree program’s contribution to attitudes to safety would be expected to be high standards of job safety in laboratory and fieldwork coordinated by the university. The “fantastic attitude toward safety” means that safety systems such as job hazard analysis (JHA) are not simply complied with but are used actively and positively.

The candidate is not required to design anything or undertake any complex calculations. The ability to design embankments and cuttings based on appropriate calculations would enhance the candidates understanding of the role and would also be important in the candidate's future prospects in the company. However, for the advertised role, it is most important that the candidate is fully aware of the 'realistic constraints' to the engineering design in its context. To succeed in the role the candidate should have been exposed to numerous examples of the practical issues around implementing a design.

It is important to note that the role is not as project manager. The candidate is likely to report to the project manager, either directly, or in a matrix organisation structure. Fundamentally, the candidate must be able to read the written and drafted plans and to understand the purpose and tolerances of the tests conducted. The candidate also needs to be able to make relevant field measurements and observations.

Engineering Implementation

The process of design has often been the focus of engineering education (e.g. Aparicio and Ruiz-Teran, 2007, Tate et al., 2010). The importance of integrating design and implementation is identified in the field of constructability in which the focus is on whether a design can be efficiently constructed (e.g. Fischer and Tatum 1997). Engineering failures are typically caused by unintended interactions or incompatibilities between design and implementation (Love et al., 2013).

The nature and degree of support and level of autonomy have been identified as significant factors influencing the development of core work skills (Ithaca Group, 2013). Engineering roles for graduate and junior engineers are likely to involve working independently (or with minimal supervision) and completing tasks which are thoroughly defined and supported by prior training. In most organisations such tasks will be defined by standard operating procedures.

Learning Implementation Skills

A fundamental skill for proficiency in implementing engineering projects is the ability to follow instructions. The ability to follow instructions forms part of most educational activities and is typically considered as a component of the comprehension or understanding stages of learning (e.g Bloom, 1956; Anderson et al., 2000; Raths and Wittrock, 2001). However, the ability to apply instructions appropriately and to critically evaluate instructions in the context of project objectives can also represent higher levels of learning activities. This form of knowledge is sometimes called procedural knowledge in contrast to declarative knowledge (e.g. Carew and Mitchell, 2002). Procedural knowledge is an important aspect of information literacy (Pinto 2010).

The ability of students to interpret instructions accurately and appropriately is not typically included as a specific learning objective. Including explicit evaluation of students ability to follow instructions is a simple change to enhance preparation for engineering implementation roles.

In engineering projects, the most common method of planning and managing field activities is with the use of the standard operating procedure (SOP). The SOP for each activity provides a guide to follow. An employer will have SOPs for the activities employees are expected to conduct. Engineering education can include training in how to use SOPs in general and with relevant industrial examples. The following summary of the purpose of SOPs and aspects to consider in their preparation provides a framework around which to design SOP-related learning activities for engineering students. Appropriate learning activities include preparing an SOP for a well understood activity, following an SOP for an unfamiliar practical activity or critiquing an existing SOP.

SOPs can achieve the following (DEC WA, 2013):

- Provide step by step instructions on a specific procedure

- Ensure that procedures are performed consistently and in compliance with standards or regulations
- Protect the health and safety of personnel by enabling jobs to be carried out in the safest possible way
- Ensure that all of the environmental and operational information is available to perform specific procedures with minimal impact
- Facilitate training in procedures, for both new personnel and for those that need re-training. Having step by step instructions aids trainers to ensure that nothing is missed
- Serve as a historical record for use when modifications are made to that procedure and when the SOP is revised
- Promote quality though consistent practice, even if there are changes to personnel
- Encourage improvements and work evaluation by ensuring that the procedures are completed, and can be used in incident investigations to improve operations and safety practices

Written instructions, such as an SOP, should include reference to (DEC WA, 2013):

- What is needed before starting the task, including materials and tools and using drawings or graphics
- Health and safety considerations, specified at the appropriate steps
- Whether there may activities which must be done at the same time. This needs to be clearly stated so that there is no confusion
- Alternative steps if there is a possibility that a step may not work (i.e. under specific circumstances)
- An estimate of the time that the task may or should take, or how long it should be performed for should be clearly stated
- A critical review of an SOP involves identifying gaps, overlaps or contradictions in the procedures as well as assessing its role in achieving the objectives of the engineering project

Future Developments

Many large construction projects are using augmented reality to assist field-based construction tasks (e.g. Wang and Dunstan, 2006; Sampaio et al., 2010). Augmented reality is used in construction to allow personnel to consult 3D models with apparent real-spatial positioning during construction activities. Demonstrations of such methods are highly relevant to the skills needed for implementation roles in engineering and indicate that implementation is a highly valued engineering role. Wang and Dunstan (2006) have conducted laboratory trials of the effectiveness of augmented reality in the speed and accuracy of personnel completing practical construction tasks. Such a measurable validation process could also be applied to following SOPs or other instructions in an engineering student laboratory, with or without enhanced technology.

Conclusions

A review of advertised jobs for graduate and junior engineers indicates many roles mainly involve implementation activities. A distinctive feature of the advertised statements of required candidate attributes for implementation (and operation) roles was the ability to work independently. This is inferred to be because the engineer in such a position plays an intermediary role between the engineering design team and the construction crews. While the field engineer may not have a management role, in terms of supervising or directing crews, the testing, monitoring and reporting done by the field engineer will directly impact on the day-to-day activities of the construction crews.

Program syllabuses which have incorporated the CDIO engineering framework may have focussed on the transition of taking a design into the implementation stages. This paper highlights that it is also important to recognise that implementation of an existing design is a complementary skill which also requires development.

In order to ensure that skills related to implementation are included in an engineering syllabus it is recommended that:

1. The skill of “following instructions” should be elevated to an explicit learning objective. This can be readily achieved as most educational activities involve presenting instructions to students and evaluating their response.
2. Formalised instructions such as standard operating procedures (SOP) should be incorporated into learning activities with students required to understand and apply the SOP and also to analyse, evaluate and improve the SOP in the context of the engineering project objectives.

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