Describing 'generic' graduate engineer skills

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INTRODUCTION

Being able to describe skills effectively is essential for teaching and enabling students to learn skills. A previous study [1], investigating the development of real industrial problem solving skills in a taught Masters course, found inadequate skill descriptions were a significant problem. On further investigation, it was determined that skills could only described at a high level, unless the task and associated context was known. Such high-level descriptions e.g. project management, do not communicate the skills graduates need for work.

Describing tasks has been found to be an effective way of describing graduate work [2] and whilst this does not describe skills, by practising these tasks in relevant contexts, skills are developed. Task frameworks provide a way of organising and communicating tasks in a structured way and provide a holistic view of a particular type of work.

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A high-level task framework (see Fig.1) containing twelve process-stages and five 'generic' domains: **M**anage the **C**lient (**MC**), **M**anage the **P**roject (**MP**), **M**anage **I**nformation (**MI), W**ork **W**ith **O**thers (**WWO**) and **M**anage **S**elf (**MS**) was developed [3]. This was tested, along with individual process-stage tasks, in Short Industrial Placements (SIPs). These involve pairs of students spending two weeks, based at a company, to solve a real industrial problem.

The research question for this study was "What tasks contribute to the five 'generic' domains?" so that relevant, evidence-based frameworks similar to those for the process-stages could be developed.

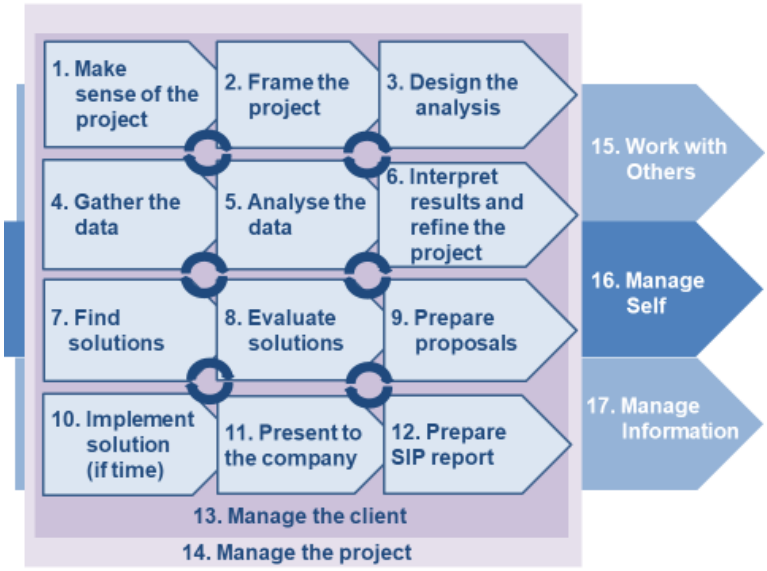

Fig 1. SIP Framework

This work is a summary of part of a PhD Thesis (to be published in September 2018).

1 PROBLEM DIAGNOSIS

The first step was to capture a description for each generic domain, and from multiple perspectives, so that any subsequent literature review could be sufficiently guided.

A student view of WWO, MS and MI was explored after they had completed four SIPs. 26 students recorded challenging tasks for each domain that generated three data sets of 45, 28 and 31 tasks respectively. An analysis of this data determined that; there was an extensive range of tasks per domain, each domain was different in nature, students experienced more challenges with WWO, tasks descriptions were at varying levels of detail and for WWO and MS, behaviours were a key feature. The student view was combined with that of course staff and course documentation to create the following high-level SIP specific descriptions.

Manage the Project (**MP**) Planning and executing the SIP in the two-week timeframe such that the required outputs were delivered on time and at a professional standard.

Manage the Client (**MC**) MC is a subset of MP, but highlighted separately to emphasise its critical nature due to the fixed, short duration of SIPs. The client was the SIP host company, typically with several key stakeholders e.g. problem owner, SIP supervisor, senior manager. MC involves determining who actually represents the voice of the client, getting access to required data, people and resources as early as possible, keeping the client informed of progress, validating assumptions and testing ideas regarding potential solutions.

Manage Information (**MI**) Managing a wide range of data and information where identifying data sources, dealing with incomplete and conflicting data are typical challenges. Some aspects e.g. gather and analyse data overlap with the process-stages, see Fig. 1.

Work with others (**WWO**) Building and maintaining a collaborative working relationship with their SIP partner and having an effective transactional working relationship with others. The most significant person is the allocated SIP partner. Others include their company supervisor, University tutor and other company personnel relevant to the problem.

Manage Self (**MS**) Acting in a professional manner – presenting themselves appropriately, being organised, on time, alert, focussed, open minded and engaged whilst demonstrating a 'consultant' rather than 'student' mentality. From the student perspective, this also covered physical health and mental well-being.

2 LITERATURE REVIEW

The descriptions above guided a search to identify academic and evidence-based practice literature that related to an early career work context or reflected 'best practice'/'standards' adopted by professional bodies.

Before considering each domain, the Graduate Capability Framework (GCF) [2] was reviewed as it contributed significantly to thinking behind the SIP Framework [3], met the above criteria and included seven generic domains. The GCF was developed using a task work analysis approach describing the work to be done [4] so the name 'Graduate Capability Framework' is somewhat misleading implying that graduate capabilities are described.

An analysis of the GCF Generic Capabilities at the task level found: overlaps between domains e.g. communication was also a key aspect of both teamwork and project management, variable styles of task descriptions and, the inclusion of non-tasks e.g. works independently. A comparison with the SIP Framework (Fig. 1) found that only two of the GCF generic domains mapped directly onto a single SIP Generic Domain with the rest aligning with multiple domains.

This analysis suggested that categorising and describing tasks was difficult for generic domains. Three reasons are suggested, different interpretations of the domains caused by limited domain descriptions, overlapping domains, and describing tasks appeared more difficult in interpersonal and intrapersonal domains e.g. team-work and self-management.

A typical task description is an action verb followed by a direct object and sometimes followed by a qualifying statement that indicates how, when or why the task is done [4]. Tasks are also expected to have a clear beginning, middle and end and be directed towards a work goal. Whilst this is appropriate for discrete aspects of a job it could be problematic when looking at ongoing aspects of a job. The domains are now considered in turn.

MP - Project Management is a profession and a number of institutions maintain a best practice body of knowledge. The Project Management Body of Knowledge (PMBOK)[5], a global standard from the Project Management Institute, was selected as this best matched the single project SIP context and the literature search criteria. The PMBOK definition and scope aligned well with a SIP and its ten knowledge areas captured 47 processes, seen to be an equivalent of a task, provided a good basis for developing a SIP specific framework.

MC - Four PMBOK knowledge areas were found that covered the practice conception of MC.

MI - In the growing academic field of Personal Knowledge Management, thirteen different models were reviewed [6]. The one judged most relevant, was developed by academics who

conceptualised information skills as a set of problem solving skills that had both logical and practical components required for the "problem solving knowledge work of the twenty-first century" [7]. The framework comprised seven skills: retrieving, evaluating, organising, collaborating around, analysing, presenting and securing information.

WWO - A review of the professional expertise and interpersonal skills literature reinforced the importance of WWO but no rigorous, evidence based, frameworks were found at the right level of detail that provided a good match with the SIP description of WWO.

MS -The academic literature came from many fields including psychology and management. It was typically focussed on single rather than multiple aspects, and related to general work contexts rather than something as specific as a SIP. No suitable evidence-based framework was found that aligned with the MS description.

In summary, domain relevant frameworks were identified for MP, MC and MI but no literature was found that covered WWO and MS with a rigorous evidence base.

3 RESEARCH

To answer the research question "What tasks contribute to the five 'generic' domains?" two different strategies were adopted. For MP, MC and MI, a top-down approach of deriving a framework from theory and validating it empirically applying a variance research design. This approach had been effective when deriving the process-stages[3].

For WWO and MS, a bottom-up approach was selected to derive a framework from empirical data because no relevant, evidence-based frameworks were identified to provide a firm theoretical basis. A Grounded Theory, research methodology was selected where an abstract theory of processes, activities or events grounded in the views of the participants is derived [8, 9]. Many researchers use the first part of this methodology as a way to systematically analyse qualitative data [9] rather than go on to develop theory and such analysis would answer the research question and contribute to framework building.

3.1 MP, MC and MI

The frameworks identified required adapting for the SIP context. The PMBOK framework was designed for practising project managers and not novice students. The authors reviewed and adapted it identifying 7 knowledge areas and 33 tasks as an initial framework, of which 4 knowledge areas and 9 tasks were the MC subset. The authors were not in full agreement so all 47 tasks were to be tested with the students.

The MI framework was derived from an analysis of its skill descriptions [7] identifying 15 tasks. Overlaps were found with the process-stages particularly numbers 4, 5, 6 and 11 (See Fig.1). The authors agreed that the adapted framework appeared to be a good fit with a SIP and it highlighted important aspects previously uncaptured such as 'secure information'.

In terms of research design, a three-stage approach was adopted:
Stage 1: test the frameworks to determine if they cover the range of tasks students do.
Stage 2: identify the specific SIP tasks that students undertake in each domain.
Stage 3: test the results with experienced tutors to provide an alternative perspective.

3.1.1 Testing – Stage 1

A variance research design [10] was selected to compare the adapted frameworks with the student view of what they did. During one Masters programme, data was collected after each

of the four SIPs for MI and after the last two SIPs for MP and MC. 304, 181 and 202 statements were collected respectively. The data was analysed for fit and the results, see Table 1, show a lower % fit for MC, caused by students describing behaviours rather than tasks. Once separated, the % match aligned around 90% giving confidence that the domains were interpreted fairly consistently. The three frameworks covered the range of tasks students do as all tasks could be allocated, but overlaps remained with the process-stages.

Table 1. % Fit of responses with domains

Generic Domains	% Fit	% Fit (No behaviour)
MC	77	91
MP	89	0
MI	91	0

3.1.2 Testing – Stage 2

The objective was to identify specific SIP tasks and this testing took place with the subsequent year group to Stage 1. A variance research design [10] was selected to compare the frameworks from Stage 1 to the student view of practice. MI was tested after SIP 1 and MP after SIP 2 and student participation rates were 80% and 66% respectively.

For MI, out of 153 student task descriptions, 13 or 8.5% were considered to be variances with the derived framework. A review by the authors, determined these were part of other domains/process-stages or at a more detailed within the MI framework. So the framework with 15 tasks was confirmed, see Table 2, with refinements noted to extend some task descriptions.

Table 2. MI Domain SIP Framework

MI Task clusters	**MI Tasks**
Retrieve information	Search for information, Gather information from different sources e.g. print, electronic, people
Evaluate information	Evaluate relevance, Determine quality and status of information, Deal with incomplete or inconsistent data
Organise information	Determine an appropriate way to organise information given the context Undertake regular and systematic organisation of information
Collaborate around information	Determine appropriate information/communications systems, Determine procedures for information exchange, retrieval and cataloguing
Analyse information	Determine an appropriate method and tool for data analysis e.g. excel Process the data, Analyse results to extract insights
Present information	Determine an appropriate format to communicate to the audience
Secure information	Protect information, Keep all sensitive data information confidential

For MP, 37 rather than the predicted 33 PMBOK tasks were done by students. On reviewing the variances, 4 tasks and the Quality Management task cluster was reinstated resulting in the framework in Table 3. The need to provide extended task descriptions was identified by both the authors and the students to increase confidence that that the tasks were being interpreted consistently.

The methods successfully identified variances between the frameworks and the student view of what they did but there is no guarantee that all potential variances were uncovered.

Table 3. MP Domain (incorporating MC) SIP Framework

MP Task Clusters	MP Tasks
Integration Management	Develop Project Charter, Develop Project Management Plan, Direct and Manage Project Work, Monitor and Control Project Work, Perform Integrated Change Control, Close Project
Scope Management	Plan Scope Management, Collect Requirements, Define Scope, Create Work Breakdown Structure (WBS), Validate Scope, Control Scope
Time Management	Plan Schedule Management, Define Activities, Sequence Activities, Estimate Activity Resources, Estimate Activity Durations, Develop Schedule, Control Schedule
Team Management	Assess Project Team Capability, Develop Project Team, Manage Project Team
Quality Management	Plan Quality Management, Perform Quality Assurance, Control Quality
Communications Management	Plan Communications Management, Manage Communications, Control Communications
Risk Management	Plan Risk Management, Identify Risks, Perform Qualitative Risk Analysis, Plan Risk Responses, Control Risks
Stakeholder Management	Identify Stakeholders, Plan Stakeholder Management, Manage Stakeholder Engagement, Control Stakeholder Engagement

3.1.3 Testing Stage 3

Both frameworks were tested on six established tutors using semi-structured interviews. There were only a limited number of tasks where tutors could provide an evidence-based view because they only observe, or are involved in, a minority. The MP framework was seen to need more adaptation to the SIP context but there was full agreement with the MI framework.

3.1.4 MP, MC and MI Conclusions

It was shown that: MC did fit fully within the MP framework, there are multiple overlaps between MI, MP and the process-stages which correlates with the findings from the development of the GCF [2] and, the MP and MI frameworks generated, whilst requiring some refinement, do represent the tasks that students do or should do in a SIP.

Reflecting on the SIP Framework (Fig. 1) the seventeen categories are not presented at a consistent level as the process-stages align better with a generic domain task cluster than a generic domain. This results in five high level domains: 'Do the project' comprising the 12 process-stages, 'Manage the Project' comprising MC and MP, plus WWO, MS and MI.

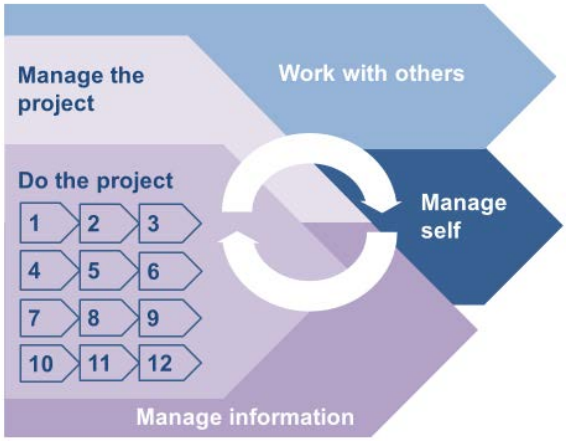

Fig. 2. SIP Framework – new representation

A new representation of the SIP Framework is in Fig. 2. The three purple domains are closely interlinked and are delivery-centric whilst the two blue coloured domains are people-centric and underpin delivery. The large circular arrow depicts the domain interconnectedness.

3.2 WWO and MS

A five-step research method was designed to collect and analyse data.
Step 1 – Collect three descriptions of important tasks from each student for four SIPs.
Step 2 – Analyse the data to test the fit with the domain descriptions in Section 1.
Step 3 – Develop a coding framework using grounded theory principles of letting the categories emerge from the data and applying constant comparison followed by peer review.
Step 4 – Code the data and test fit with the framework using an iterative process until each statement fitted within a single framework category.
Step 5 – Identify tasks by analysing action verbs associated with direct objects [4].

3.2.1 WWO

Step 1: 344 student task descriptions were captured.
Step 2: 37% of descriptions aligned with another domain or process-stage describing tasks that were 'done together' but were not about working with another person. 19% of descriptions referred to behaviours rather than tasks.
Step 3: After a number of iterations, including peer review, two distinct domains were identified as Communication and Partnership and multiple sub-categories emerged in each.
Step 4: Coding the data resulted in framework refinement and the WWO framework that emerged is below in Table 4. 16 behaviours were identified, where 'trust' was the most cited.
Step 5: Further data analysis enabled 81 different tasks to be identified.

Table 4. WWO Domain SIP Framework

Communication		**Partnership**	
Sub-category 1	Sub-category 2	Sub-category 1	Sub-category 2
Mechanism	communication plan	Way of working	pace
	meetings		approach / style
	interviews		review of partner's work
	format		pattern
	discussions		resolve disputes
	questions	Team	goals / objectives
Content	ideas		performance
	information		leadership
	issues / problems	Tasks	allocation / split
	opinions		capability requirements
	findings	Capabilities	strengths and weaknesses
	recommendations		skills
	expectations		confidence
	feedback	Relationship	empathy
Verbal	terms and phrases		understanding of partner
	structure / logic		agreed positions
	fluency		partnership attitude
Non-verbal	body language		

3.2.2 MS

Step 1: 311 student task descriptions were captured.
Step 2: Preliminary data analysis found strong alignment with the MS practice description but thinking tasks were missing. The only domain overlap was with WWO, accounting for 8% of responses, which was attributed mainly to the task context.
Step 3: After a number of iterations, five main categories emerged centred on health, thinking, self, 'being professional' and 'managing my work' with sub-categories at two levels. Following peer review a few minor revisions were made.
Step 4: Coding enabled some new sub-categories to emerge from the data and the final framework is shown in Table 5. There was a clear link between 'Managing my work' and the MP time management tasks. 19% of all MS task descriptions referred to behaviours. Sixteen behaviours were identified, with 'being focused' and 'open-minded' the most important.
Step 5: Further analysis of the data enabled 77 tasks to be identified.

Table 5. MS Domain SIP Framework

Sub-category 1	% split of total	Sub-category 2	
Health	12%	physical	Mental
Thinking	11%	objectivity	logic and structure
		decision making	Reflect
		creativity	
Self	23%	knowing me	being me
		learning about me	motivating me
		learning new things	managing my emotions
Being professional	7%	Etiquette / cultural norms	
Managing my work	47%	Goals/objectives	Organisation
		Plan/ schedule	Delivery (tasks)

3.2.3 WWO and MS Discussion and conclusions

The research question was answered from a student perspective since they do these tasks and some are not-observable by others e.g. thinking tasks. The task lists may be incomplete because only a limited number of tasks per student were asked for and the domains remain to be explored fully in literature.

37% of WWO responses, aligned with tasks that were 'done together' but belonged to another domain or process-stage because WWO tasks often happened in combination with others. The name WWO was insufficiently specific and a split into 'communication' and 'working in a partnership' should be better. The narrower definition of 'working in a partnership' at a host company explains the lack of fit with the literature reviewed which was predominantly employee focussed.

The analysis has identified task clusters for review in the literature to contribute to the ongoing development of both frameworks. The through-SIP nature of these domains was confirmed and behaviours were identified as an important component of a description.

4 OVERALL CONCLUSIONS

Describing ‘generic’ skills is more challenging than describing ‘process-stage’ skills. The work analysis concepts applied may be better suited to discrete process tasks than tasks repeated throughout a process, and behaviours are an additional component of describing people-centric tasks. The relative size of the people-centric domains was larger than previously reported [2]. This adds to the limited, but growing, evidence that engineering practice is an intellectually challenging socio-technical activity [11].

5 IMPACT AND IMPLICATIONS

Adequately describing the generic aspects of what Engineering graduates do in practice has the potential to significantly improve Engineering Education because it will enable these aspects to be communicated in ways that multiple stakeholders can understand and interpret consistently. As a result, there will be a better understanding of engineering practice, the most important people-centric skills can be identified and taught, and students will be better prepared for practice.

The SIP Frameworks developed would require some adjustments to apply to other real problem solving projects or placements used in HE as SIPs are not common. However, it is likely that only some of the domains would require adjustments and the main categories and the relationships between them would remain the same.

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