Manufacturing Excellent Engineers: Skill development in a Masters programme

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Abstract:
An MPhil programme, delivered by the Engineering Department at the University of Cambridge, claims to be excellent at preparing graduates for manufacturing industry careers. The course uses a combination of different educational experiences including industry based assignments, industrial visits and practical exercises.

This research explores how problem solving skills are developed during the first module, ‘Induction’, which is designed to enable students to undertake their first industrial assignment.

From the literature, four conditions necessary for skill development were identified:

• provision of a skill description, making explicit key components
• a number of different experiences with a range of contextual variables
• a teaching process which includes regular feedback and student reflection
• students motivated to learn

These were used to construct a skill development framework (SDF).

Using a case study research design, multiple types of evidence were collected to test for the above conditions using class room observation and questionnaire methods.

The results confirmed the presence of the SDF conditions at different levels with reflection aspects considered the weakest. Conflicting results were obtained regarding the students’ self awareness of skill levels. A plausible explanation is a change in the students’ frame of reference.

This initial study set out to develop a better understanding of the process of skill development. Whilst the SDF appears reasonable there is a need for further work in three broad areas of defining skills, assessing skills and developing reflection skills.

Introduction

The purpose of this study was to develop a better understanding of skill development in Higher Education (HE) with particular reference to more complex skills used in work related contexts. The aim of this initial work was to construct a skill development framework from literature and then test it by evaluating the development of problem solving skills in a Masters programme. As skill evaluation can be resource intensive, student self assessment was explored as a potential resource efficient option. Further work is identified to continue research related to skills development.

The Industrial Systems, Manufacture and Management (ISMM) MPhil programme at the University of Cambridge (Institute for Manufacturing 2011) claims to be excellent at preparing graduates for careers in industry. The programme, initiated 46 years ago, was designed to prepare engineering graduates for operational roles in industry. A study at the 36 year point (Ridgman and Wiggins 2003) concluded...
the programme was very successful but could not determine whether this was a function of the course or, for example, effective selection of candidates.

Four industrial assignments, accounting for 50% of the programme assessment, are a key component of ISMM. Groups of two students, spend two weeks working on a real life issue of some significance to a company. Students present their problem definition, analysis and proposed solutions on their last day and submit a written report the following week.

The first module of the programme, ‘Induction’, lasts 4 weeks and is followed by the students’ first industrial assignment. During ‘Induction’ there is a focus on developing students to undertake industrial assignments. Problem solving skills are considered fundamental and a method of developing these has been established. This starts with a lecture on problem solving and is then followed by five experience based exercises, with group membership, type of task and group size being varied. Course tutors have found this preparation has enabled the vast majority students to successfully attempt the problem faced during their first industrial assignment.

**Literature Review**

This research considers the broad fields of Employability, Higher Education and Professional Development and how these contribute to skill development. The key bodies of knowledge and how they interrelate is presented below in Figure 1.

![Figure 1: Key bodies of knowledge](image)

**Employability**

Individual skills are a common feature of Employability models (Hillage and Pollard 1998; Knight and Yorke 2002; Dacre Pool and Sewell 2007).

The work of Knight and York has been key to developing a definition and model of employability for HE. Graduate employability is defined as “a set of achievements – skills, understanding and personal attributes – that makes a graduate more likely to gain employment and be successful in their chosen occupations” (Yorke 2006). A key claim (Knight and Yorke 2004) is this is an academic research driven view and not driven by the perceived needs of employers or governments.

The USEM Model (Knight and Yorke 2002) identifies four key components comprising Understanding (U), Skilled Practice (S), Efficacy Beliefs (E) and Metacognition(M). A key feature of the model (see
Figure 2) is that the Efficacy Beliefs provide a foundation to Employability and feed the U, S and M components.

![USEM Model of Employability (Knight and Yorke 2002)](image)

The E component represents a persons’ belief that they can make an impact on a situation. It includes a broad range of theoretical contributions (Knight and Yorke 2004) including Bandura’s work on Self Efficacy and work on Practical Intelligence (Sternberg and Grigorenko 2000) that has a particular resonance as it closely resembles ISMM problem solving. The term Skilled Practice (S) was chosen to capture the view that skills are context specific, not easily transferable, and assessed with difficulty.

There are few publications citing this model being used in practice. It is suggested that assessment could be factor as broad complex constructs such as employability resist summative assessment (Knight and Yorke 2003).

**Skills**

There is no simple definition for skill (Eraut 1994; Tight 1996; Moon 2004). At a high level there is broad consensus that a skill is the ability to do something e.g. "skill...is the ability to do something that has been learnt" (Moon 2004). Also agreed is that there is a range of skill types including physical, practical and cognitive (Moon 2004).

However below this level, agreement disappears – with overlapping categories and interpretations of skill as in the case of ‘employability' and ‘professional' skills. Each category is typically labelled and defined for a particular community, causing difficulties in direct and consistent translation.

In HE neither ‘employability' or ‘professional’ are used in the specification of programme content. Four categories are used (QAA 2006); knowledge and understanding, intellectual skills, practical skills and transferable skills, with transferable skills appearing to map most closely to employability skills.

There is broad agreement that a skill requires some “knowledge that” combined with some “knowledge how” (Eraut 1994; Moon 2004). In terms of professional skills Eraut states that they “...require unique combinations of propositional knowledge, situational knowledge and professional judgement”. As judgements are made relative to a particular context it is important that skill development is undertaken during context specific activities.

Skills are learned by a combination of methods (Eraut 1994; Moon 2004; Tether, Mina et al. 2005) including education, training and experience.

There a number of models which propose different levels of skill in professional or work context such as the five level Drefus Model (Dreyfus and Dreyfus 1986) and the four level International Project
Management Association (IPMA) to describe project management skills (IPMA 2011). A common thread is the use of multiple experiences to develop higher levels of context specific knowledge and judgement making skills.

It was Kolb (Kolb 1984) who proposed a general model of learning by experience. Whilst all Kolb’s dimensions are likely to contribute to learning, the circular model is perceived as being too simplistic (Coffield, Moseley et al. 2004; Race 2010). However the circle is helpful in reinforcing that a number of related experiences support a person’s learning.

Race (Race 2010) returns to the concerns of Kolb - to identify factors that underpin successful learning. Race accepts that there are relationships between these factors but argues that they will vary between people. A key difference with Kolb’s model is the presence of wanting or needing to learn.

In summary, four key aspects of skill development are identified from the above literature as student motivation, experience, feedback and reflection. These concepts will now be explored further for HE.

**Student motivation**

A common categorisation of student motivation is intrinsic and extrinsic (Harter 1981). Intrinsically motivated students are curious and want to learn, whilst those extrinsically motivated worry about grades and approval by others.

Skill development could be a challenge for extrinsically motivated students given that skill assessment is problematic (Knight and Yorke 2003). However motivation can increase with understanding (Race 2007) and understanding can be developed by experience and interaction. Principles to promote motivation include discussion of importance and utility, provision of clear and accurate feedback and the provision of stimulating and interesting tasks (Pintrich 2003).

**Experience**

Of the experience based teaching methodologies, Problem based learning (PBL) (Barrett and Moore 2011) and Project based learning (PJBL) (Graham and Crawley 2010) would appear to be relevant however, the best match is consultancy projects used in MBA programmes (Jennings 2002).

Exercises or simulations are able to provide a wide range of skill development opportunities (Jennings 2002; Goodhew 2010). It is noted (Goodhew 2010) that they are particularly effective for learning related to complex situations and they tend to be rare in practice due to the time required to develop them.

Experience can also be used to develop a student’s self efficacy - a key component of the USEM model. Ways of influencing efficacy development are identified (Bandura 1995) as mastery and vicarious experiences.

**Feedback**

Feedback can be summative in terms of what was or wasn’t achieved and formative in identifying how performance can be improved in future. Some widely recognised indicators of effective feedback include; being prompt (Race 2010) and being positive and constructive (Landsberg 2003).

Feedback can be relevant to the whole class or to specific individuals or groups so different mechanisms are required (Race 2010) to ensure this crucial aspect of learning is done effectively and efficiently.

**Reflection**

Reflection is a process that connects the notions of learning and thinking (Moon 2004). As well as being key in the learning process (Kolb 1984), it also plays a significant role in ongoing professional development. The idea of the reflective practitioner was developed by Schön (Schon 1987) who describes an outcome as the ability to handle complex problems with confidence, skill and care.

Moon reports (Moon 2004) a depth dimension to reflection with shallow reflection being less likely to be as effective in supporting learning. Reflective learning can be improved by providing a clear purpose and a list of questions linked to associated learning goals. However students have been found to have limited understanding of reflection, in terms of its value, what it means and how it is undertaken in practice (Moon 2004).
Framework Development

Individual components have been described above and their success in supporting learning could be amplified if they are constructively aligned (Biggs 2003). This suggests that a Skill Development Framework (SDF), integrating the components identified from the literature, would help inform the design and delivery of skill development activities. To that end a SDF must be practical and appropriate for a wide range of skills.

The following conditions for the effective development of complex skill sets are identified;

1. The provision of a description of the skill making explicit key components of knowledge ‘that’ and knowledge ‘how’ and examples of the types of typical judgements associated with the delivery of the skill
2. A number of different experiences with a range of contextual variables and at the level of difficulty to provide mastery and/or vicarious experiences
3. A teaching process which includes student reflection and the provision of feedback after each experience
4. Students motivated to learn of which indicators are engagement in learning activities and learning outcomes linked to summative assessment.

Indicators are identified for each condition. The number has been limited to a maximum of four to present a framework of practical size. This is shown in Table 1 below.

<table>
<thead>
<tr>
<th>A Skill Description</th>
<th>B Experiences</th>
<th>C Teaching Process</th>
<th>D Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate teaching time used to deliver a description of the skill</td>
<td>Number of exercises</td>
<td>Adequate time used to provide feedback on each exercise</td>
<td>Assessment linked to skill development</td>
</tr>
<tr>
<td>Skill description in terms of knowledge ‘that’</td>
<td>Range of different exercises appropriate to the skill</td>
<td>Feedback contains content at a general level i.e. relevant to all</td>
<td>Explanation of why the skill is important</td>
</tr>
<tr>
<td>Skill description in terms of knowledge ‘how’</td>
<td>A sufficient level of challenge to produce mastery level experiences</td>
<td>Time given for student reflection after each exercise</td>
<td>Level of student engagement</td>
</tr>
<tr>
<td>Skill description in terms of ‘common judgements’</td>
<td>Facilitated to provide all with vicarious experience if mastery experience not achieved</td>
<td>Reflection outputs enable learning</td>
<td></td>
</tr>
</tbody>
</table>

The SDF will be tested with regard to problem solving skills so it is important that these are defined. As with many skills, these have been labelled and defined for a particular community – in this case by the Institute for Manufacturing (IfM) - and defined in relation to industrial problems students face.

In the absence of a formal definition, a working definition was compiled by extracting key learning points or learning outcomes from course documentation. This identified three key components; problem solving, managing a project and group work.

The first test of the SDF was to evaluate how it relates to the development of problem solving skills with the objective of determining if the conditions identified are present in practice. In Induction this is carried out in a lecture followed by 5 exercises and from now on is referred to as the Development Method (DM).

Further testing of the SDF will require a mechanism to measure levels of problem solving skills. This has been identified as problematic in terms of resource requirements and ability to provide a reliable scaled measurement. With problem solving being much less complex than employability and a quick method of assessment being very attractive in terms of resource requirements it was decided to investigate whether a self assessment instrument could be used.
Methodology

This exploratory research lends itself to the case study research method set out by Yin (Yin 2009) using ISMM Induction as the case. Measures were taken to ensure that the research had a minimal impact on student or facilitator behaviour to enable results to be unbiased. The overall research design is shown in Figure 3 below.

![Figure 3: Research Design](image)

The research requires multiple sources of evidence to be collected using both qualitative and quantitative approaches. The methods used were observation of the DM and questionnaires, which were applied at the start and the end of the DM.

This research design does not take into account the student perspective on skill development. As this could have a significant impact this will be investigated via the questionnaire at the end of the DM.

The data collection method for each aspect of the SDF is identified in Table 2 below. Each cell has a different coding; I denotes Indicator, M denotes method and R will be used later to denote result.

<table>
<thead>
<tr>
<th></th>
<th>A Skill Description</th>
<th>B Experiences</th>
<th>C Teaching Process</th>
<th>D Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1I</td>
<td>Adequate teaching time</td>
<td>Number of experiences</td>
<td>Adequate time for feedback</td>
<td>Linked Assessment</td>
</tr>
<tr>
<td>1M</td>
<td>Observe DM and record time</td>
<td>Record the number of experiences where students demonstrate the skill</td>
<td>Observe DM and record time</td>
<td>Review course documentation</td>
</tr>
</tbody>
</table>
At the end of each exercise, each group was given time to discuss their performance and identify three aspects that had gone well and three things that could be improved. Results presented to the class were analysed. Four categories were found: problem solving, group working, project management and presentation. These align with the definition of problem solving skills with the addition of presentations.

A consolidated view of the DM was undertaken by making a judgement of the adequacy of each component of the SDF using the four levels of judgements described below in Table 3

<table>
<thead>
<tr>
<th>Table 3: Judgement levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of presence in Induction</strong></td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

To understand the student perspectives of skill development three open questions were asked to identify what aspects of Induction had influenced their learning of skills. All reasons were analysed and answers were sorted by those considered more supportive of skill development e.g. problem solving exercises and those less supportive of skill development e.g. subject specific lectures.

The data collection for self assessment was done via questionnaires. The start questionnaire was designed to capture self assessment of skill levels using a comparative measure with their undergraduate peer group and their confidence in their ability to perform these skills in an ‘industrial company environment’. The end questionnaire was designed to repeat the capture of self assessment of skill levels described above and explore how students related their current level and understanding of skill to their level at the beginning of the module. From a cohort of 49 students, response rates of 94% and 96% were achieved for the start and end questionnaires. This resulted in 88% complete data sets where comparisons could be made between the start and end. With such high response rates the findings from this research will be valid for this course.

Ethical issues in relation to the students were considered (Creswell 2009). All were informed about the research project and reassured that all data would be kept confidential and used only for the purposes of research.

<table>
<thead>
<tr>
<th>2I</th>
<th>In terms of knowledge ‘that’</th>
<th>Range of different experiences</th>
<th>Feedback relevant to all</th>
<th>Explanation of importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2M</td>
<td>Observe DM and record what was presented, how and when it happened</td>
<td>Characterise each experience in terms type and context</td>
<td>Observe DM and record what was presented</td>
<td>Observe DM and record what was presented</td>
</tr>
<tr>
<td>3I</td>
<td>In terms of knowledge ‘how’</td>
<td>A mastery level challenge</td>
<td>Time for student reflection after each exercise</td>
<td>Level of student engagement</td>
</tr>
<tr>
<td>3M</td>
<td>Observe DM and record what was presented, how and when it happened</td>
<td>Observe if any groups were able to achieve a high level outcome</td>
<td>Observe DM and record time</td>
<td>Observe whether students were engaged or not engaged</td>
</tr>
<tr>
<td>4I</td>
<td>In terms of common judgements</td>
<td>Facilitated to provide all with vicarious experience</td>
<td>Reflection outputs enable learning</td>
<td></td>
</tr>
<tr>
<td>4M</td>
<td>Observe DM and record what was presented, how and when it happened</td>
<td>Examples of cohort mastery experiences shared with rest of cohort</td>
<td>Collect outputs of group feedback sessions – see below</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level of presence in Induction</th>
<th>Descriptor – adequacy to support skill development of problem solving in Induction</th>
<th>Descriptor - scope for improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fully adequate</td>
<td>Minor / None</td>
</tr>
<tr>
<td>2</td>
<td>Adequate</td>
<td>Some</td>
</tr>
<tr>
<td>3</td>
<td>Less than adequate</td>
<td>Significant</td>
</tr>
<tr>
<td>4</td>
<td>Inadequate</td>
<td>100%</td>
</tr>
</tbody>
</table>
Results

Comparison of SDF to DM

Each element of the SDF is compared to the DM and the results are summarised in Table 4 below.

<table>
<thead>
<tr>
<th></th>
<th>A Skill Description</th>
<th>B Experiences</th>
<th>C Teaching Process</th>
<th>D Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1I</td>
<td>Adequate teaching time</td>
<td>Number of experiences</td>
<td>Adequate time for feedback</td>
<td>Linked assessment</td>
</tr>
<tr>
<td>1R</td>
<td>A 70 minute lecture was used to deliver a skill description. Feedback time following each exercise covered some aspects, see C1R.</td>
<td>Five</td>
<td>Ex 1 and 2a: &lt;10 minutes was spent presenting a solution. Ex 2b: &lt;10 minutes in short bursts responding to student presentations. Ex 3: None</td>
<td>50% linked to work on real industrial problems</td>
</tr>
<tr>
<td>2I</td>
<td>Knowledge ‘that’ there; Range of different experiences</td>
<td>Feedback relevant to all</td>
<td>Explanation of importance</td>
<td></td>
</tr>
<tr>
<td>2R</td>
<td>is a range of common problems with differing characteristics, are a range of tools and techniques, there is a general process for solving industrial problems. Efficiency improvements for a packing operation. Process flow improvements for food manufacturing. Cost benefit analysis of packaging options. Factory Layout improvements for food manufacturing. Manual assembly improvements</td>
<td>Ex 1 and 2a: A workable solution was presented Ex 2b: All options were discussed. The option most acceptable to the board was identified. Ex 3: Some feedback from other groups that worked on the same problem.</td>
<td>It was made explicit that problem solving skills were vital for Industrial assignments.</td>
<td></td>
</tr>
<tr>
<td>3I</td>
<td>Knowledge ‘how’ A mastery level challenge</td>
<td>Time for student reflection after each exercise</td>
<td>Level of student engagement</td>
<td></td>
</tr>
<tr>
<td>3R</td>
<td>Only the ‘define problems’ aspect was covered in the lecture. Some guidance on identifying the nature of the problem given in the feedback sessions for Ex1, 2a and 2b. Students were referred to other lectures and resources</td>
<td>For exercise 1, 2a, 2b and 2c some groups demonstrated mastery level It is not known how many groups achieved this for Ex 3.</td>
<td>No more than 10 minutes in groups</td>
<td>High levels were observed during the lecture and task part of each exercise. Lower levels were observed in presentation preparation, feedback and reflection aspects.</td>
</tr>
<tr>
<td>4I</td>
<td>Common judgements</td>
<td>Facilitated to provide all with vicarious experience</td>
<td>Reflection outputs enable learning</td>
<td></td>
</tr>
<tr>
<td>4R</td>
<td>Some given e.g. need to judge the validity of information</td>
<td>As some groups demonstrated mastery level this provided vicarious experiences for others.</td>
<td>See reflection output results that follow.</td>
<td></td>
</tr>
</tbody>
</table>
Reflection Output Results

Each output was colour coded to reflect the aspect skill using key below.

<table>
<thead>
<tr>
<th>Key</th>
<th>Practical Problem Solving</th>
<th>Group Working</th>
<th>Project Management</th>
<th>Presentations</th>
</tr>
</thead>
</table>

Table 5: Reflective outputs – Example Results from Exercise 2b

<table>
<thead>
<tr>
<th>Things done well</th>
<th>Team</th>
<th>Things done not so well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assigned tasks well</td>
<td>A</td>
<td>Not well organised but better than last time</td>
</tr>
<tr>
<td>Good at timing – no mad panics</td>
<td></td>
<td>Rushed too much then had to go back and redo</td>
</tr>
<tr>
<td>Communicated well</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assigned tasks &amp; executed well</td>
<td>B</td>
<td>Disorganised</td>
</tr>
<tr>
<td>Good involvement</td>
<td></td>
<td>Wasted time doing the same things</td>
</tr>
<tr>
<td>Took wide perspective of issue</td>
<td></td>
<td>Presentation</td>
</tr>
<tr>
<td>Split tasks up well</td>
<td>C</td>
<td>Time Management</td>
</tr>
<tr>
<td>Communication as one person switched between sub groups</td>
<td></td>
<td>Didn’t check results initially</td>
</tr>
<tr>
<td>Good answer – only missed out one calculation</td>
<td></td>
<td>Made one slide for presentation 4 times</td>
</tr>
<tr>
<td>Split into groups to analyse main options in detail</td>
<td>D</td>
<td>Made calculation error</td>
</tr>
<tr>
<td>Good teamwork and communication</td>
<td></td>
<td>Not enough checking of others work</td>
</tr>
<tr>
<td>Good professional power-point presentation</td>
<td></td>
<td>Organisation</td>
</tr>
</tbody>
</table>

Adequacy of the DM

Given the above results the levels of judgements described in Table 3 were applied and the results are shown in Table 6 below.

Table 6: Skill Development Framework – Level of Presence Results

<table>
<thead>
<tr>
<th>A Skill Description</th>
<th>B Experiences</th>
<th>C Teaching Process</th>
<th>D Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Adequate teaching time</td>
<td>1 - Number of</td>
<td>2 - Adequate time for feedback</td>
<td>1 - Linked Assessment</td>
</tr>
<tr>
<td>1 - knowledge ‘that’</td>
<td>1 - Range of different experiences</td>
<td>2 - Feedback relevant to all</td>
<td>1 - Explanation of importance</td>
</tr>
<tr>
<td>2 - Knowledge ‘how’</td>
<td>1 - Mastery level of challenge</td>
<td>3 - Time for student reflection after each exercise</td>
<td>2 - Level of student engagement</td>
</tr>
<tr>
<td>2 - Common judgements</td>
<td>1 - Facilitated to provide all with vicarious experience</td>
<td>3 - Reflection outputs enable learning</td>
<td></td>
</tr>
</tbody>
</table>
Student Self Assessment

Table 7: Student Self Assessment Results

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness of skill level</td>
<td>-0.3%</td>
<td>-2%</td>
<td>-2%</td>
<td>-22% to 36%</td>
</tr>
<tr>
<td>in comparison with their</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>undergraduate peers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence that they could</td>
<td>-2.3%</td>
<td>-2%</td>
<td>-1%</td>
<td>-21% to 19%</td>
</tr>
<tr>
<td>perform specific tasks</td>
<td></td>
<td></td>
<td>-9%</td>
<td></td>
</tr>
<tr>
<td>in an industrial company</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For student self assessment relative to the module start, the majority of students failed to answer the set of questions as intended. However it was possible to determine that 57% thought their skill levels had increased and 47% felt that problem solving skills were more complex than they had thought at the beginning of the module.

Student perception of skill development

The percentage of correct answers per question was 75%, 88% and 51% indicating that understanding of skill development is variable.

Discussion

Comparison of the SDF to the DM

Reflection aspects were considered the weakest. The exercise was problematic as it did not encourage individual, focussed or in depth reflection and students were required to reflect quickly immediately following an exercise. However it did provided an effective way to identify issues and prompt discussion on aspects of skill development.

The outputs were judged superficial due to their general nature e.g. Time Management and containing contradicting statements e.g. ‘good at timing’ and ‘rushed too much then had to go back and redo’.

Reflective outputs remained superficial throughout the exercises as students demonstrated poor levels of reflective skills and instruction on reflective skills was not provided. The issues identified were mostly project management or team working aspects and as the students had only had limited descriptions of these elements there was little basis for reflection.

Some elements of feedback provision reflected good practice such as prompt feedback of a workable solution and supporting handouts. However the workable solution was presented quickly and, as the reflection activity followed immediately, there was little time for digestion.

Student levels of engagement fell during feedback activities. Although this could be tiredness on completion of the activity, it would be useful to test understanding of feedback given other aspects of skill development have been found to be poorly understood.

Two components of skill description where some weakness was identified was the description of knowledge ‘how’ and ‘judgement’. These aspects lend themselves to further explanation following an exercise as they are often context specific. Thus the implication is how to incorporate additional teaching time or resources to support this activity.

Strengths and Limitations of SDF

The SDF describes skill development as a multi-dimensional construct in which all components should be present and ideally at an adequate or fully adequate level.

As with any framework trying to capture complex constructs there is a danger of oversimplification. It is argued that the ‘Teaching Process’ condition should be split into separate feedback and reflection conditions. There would then be five conditions which would map closely with the core components of Races’ learning model (Race 2010). Another issue to that many components are interrelated, a feature poorly represented in the current presentation.

As an indicator, student engagement appears to offer a useful lens with the ability to highlight whether components are working effectively or not. This correlates with the literature on student motivation which identifies links to many aspects of the learning process.
This framework is very much at the initial stages of development having been developed as an evaluative tool in one context and only in relation to problem solving skills. A more reliable method of evaluation is required to support further testing. It should also be possible to revise the SDF for use as a design tool at a later stage.

**Student self-assessment of skill levels**

The importance of student self-assessment lies not only in its contribution to their ability to reflect but also from the practical view point of the resources required to run and provide external assessment for these forms of experiential exercises.

Any self assessment of skill is made in comparison to a reference point, such as a peers or a defined level of competency. Plausible explanations for the conflicting results point to issues of reference point selection and recalibration.

One reference point was a students' undergraduate peer group. Valid results rely on this reference point remaining fixed for the duration of Induction. It is suggested that for many their reference point changed to be more in line with the current cohort – typically top level undergraduates.

A second reference point was an ‘industrial company environment’. Given this was where careers were sought it was plausible that they had a perception of this. In practice many students had little exposure to industrial company environments as determined from work experience data in the start questionnaire.

The final reference point tested was them-selves at the beginning of the module. Again this is problematic as it relies on their ability to keep this point fixed during the module. It was possible to ask more qualitative questions e.g. is the skill more complex than they thought? Do they know how to improve? This might form the basis of a reflective exercise towards the end of the module that could help students consolidate their skills learning and identify where they need to improve. These conclusions are similar to those of Knight and Yorke (Yorke and Knight 2007).

**Conclusions and Further Work**

Using the SDF to analyse the DM gave the following insights;

- All conditions of the SDF were found to be present in the DM but with different degrees of judged adequacy. Eight of the fifteen SDF components were considered fully adequate, 5 adequate and 2 less than adequate. Reflection aspects were weakest and exercise aspects the strongest.
- The exercises were judged fully adequate, providing a range problem types and contexts, as well as the level of challenge to produce mastery experiences.
- The knowledge ‘that’ aspect of the skill description was good but there was limited provision of knowledge ‘how’ and judgment aspects. These are often context specific, so lend themselves to further explanation following an exercise.
- There was a lack of formal definition of problem solving skills.
- There was limited provision of formative feedback and opportunities for general feedback were limited by the class time allocated.
- A combination of poor student reflection skills, the use of a general reflective exercise and its timing resulted in superficial reflective outputs.

Since the DM was previously considered to be well developed this suggests that the SDF, even in its current early stage of development, could be a useful evaluation tool.

Student self assessment proved problematic as they were not able to reliably identify changes to their levels of problem solving skills during Induction as conflicting ratings resulted. Problems arose with identifying appropriate reference points that remain fixed for the duration of Induction.

Whilst the SDF appears reasonable there is a need for further work to enable future testing and refinement. This involves defining problem solving, developing effective assessment methods as well as addressing the two further problems discovered that students had a poor understanding of skill development and poor reflective skills.

Three phases of investigation are proposed, defined by the research questions below and shown diagrammatically overleaf in Figure 4.
Phase 1
- What is the Problem Solving Skill set?
- How can performance levels be defined and measured?
- How can students understanding of skills be developed?

Phase 2
- How can students assess their skill levels?
- How can reflective learning skills be developed?
- What reflective learning tools support skill development?

Phase 3
- How can the DM be improved?
- What implications are there from Phase 1 and 2 for the SDF?

Figure 4: Phases of further work

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