

## Reconceptualising studies of engineering professional skills: Moving the field on

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### 1) Introduction

When one looks to the study of engineering professional skills there is a great deal of activity at both an European and at an international level, with the European Commission publishing numerous reports on professional skills and the importance of their development for the labour market [1]. Skills are generally defined as the ability to perform a task and can be nuanced depending on the type of task to be completed, engineering professional skills can be defined as those skills which are valued by an employer [2]. Engineering professional skills are generally studied quantitatively in one of two ways. The first type of study are those regarding *the level* of these skills among students, usually before and after an intervention. The second type are those who wish to know *to what degree* each of a list of skills are important to various stakeholders, for particular engineering disciplines. In this paper, the authors highlight concerns about the methodological approaches to empirical studies in this field and call for a reconceptualization of how one approaches engineering professional skills research; in the hope that this research area can be delineated.

## 2) Methodology

We assert that these skills are measurable as behaviours that are developed through social interaction. These skills are multidimensional constructs that cannot be understood outside of a particular socio-cultural context [3]. The authors reject deterministic views of social reality that do not consider the effects of social, political, educational and economic processes on the development of professional skills and take into consideration the living processes in which the various stakeholders including industry experts, HR professionals, educators and engineering students themselves are situated, these contextual specificities interfere with a researchers' ability to generalise about *what* skills are important without consideration for *who*, *when* and *where* they may play a role. Skills do not exist independently and can be understood in multiple contexts. There is never a definitive or final comprehension of a skill. The authors acknowledge that individuals can attach different meaning to the same word and in doing so acknowledge the complexity of the research conducted in this area [4]

The authors make use of methodological criticism to highlight concerns over the methods used in empirical studies of professional skills and the treatment of skills as objectively real and discreetly measurable. Methodological criticism is most often attributed to the works of Karl Popper, one of the most prolific philosophers of the 20<sup>th</sup> century, in particular this paper relies on his work on the nature of scientific inquiry and the falsifiability of scientific methods [5]. The authors would like to make clear that this is not an anti-positivist position paper. Instead, it presents a case for an interpretive approach and highlights the limitations of the quantitative methods currently employed in the literature. Positivism certainly has its' place in education research, however it is the authors' view that the current over emphasis on quantitative data collection has resulted in stagnation of the research conducted on engineering professional skills. A flurry of literature published by the European Commission in this area in the past decade is evidence that the study of engineering professional skills is an integral part of being successful in the labour market [6]. With this vested interest in professional skills comes the responsibility of being rigorous in the approach to studies which seek to investigate these skills.

## 3) Methods

A systematic literature review was carried out in order to identify articles relating to engineering professional skills. The databases of Wiley, Taylor & Francis, SEFI, IEEE Xplore and ASEE peer were searched with the terms "engineering skills" and "engineering competence" anywhere in the text, this lead to 162,814 papers being identified in the Wiley library alone. The search terms were again implemented to search the article titles. This lead to the identification 1064 journal, conference or magazine publications across the 5 databases. The search criteria were then narrowed to the terms "engineering professional skills", "engineering professional competence", "engineering soft skills", "engineering graduate skills" & "engineering graduate competence" in the title, leading to the identification of 187 papers with overlap.

Search term	Wiley	Taylor & Francis	ASEE	IEEE	SEFI
Engineering professional skills	6	12	36	31	0
Engineering professional competence	1	3	9	11	1
Engineering soft skills	1	1	7	28	1
Engineering graduate competences	0	0	2	2	0
Engineering graduate skills	3	0	21	11	0

**Table 1.** Results of systematic literature review

When overlapping papers were removed 27 journals & 151 conference articles remained. Magazine articles were excluded due to lack of a peer review process. Papers reporting on interpretive studies were excluded. Papers were categorised based on the type of study carried out, whether definitions for competences were provided and contextualised and the type of statistical analysis that was carried out. Papers published before 2000 were also excluded. This resulted in 48 papers being screened for this study. Following screening, 37 papers were analysed; 21 regarding assessment of professional skills [7–28] and 16 regarding their importance to a variety of stakeholders [12,23,37–41,29–36]. The main drawback of this review method was the volume of literature that was initially identified on the topic which falls outside the scope of the search criteria, resulting in seminal research in the area being excluded from the screening process.

## 4) Results

### 4.1 *Issues with definition*

One of the issues with the approach of a great many studies into engineering skills is the use of strict definitions of skills which are seldom contextualised for the purpose of the investigation. Participants attach meaning to these skills based on their own lived experience, the definitions provided are therefore subjective and result in a multiplicity of meanings being attached to each definition. In some instances researchers do not provide any such definition. The issue in both instances is that when a participant is asked to indicate *how important* or *how much they have mastered* a particular skill, they are attributing that to experiences which are qualitatively different from those of another participant. It is the authors' view that the best skills definitions, if they are to be defined at all, are those which can be defined in terms of demonstrable behaviour. In this way, they may be studied in a scientific fashion. Of the 37 papers analysed, 19 did not define the competences they listed. Of the remaining papers, 2 papers defined and contextualised the definitions for the purposes of the study. This lack of definition and of contextualizing the definitions for the purposes of the study raises two issues. If one paper says "Teamwork" is the most important professional skill for an engineer to have and another paper finds the same thing they do not necessarily *mean* the same thing, as the definition of Teamwork is highly contextual and conceptually dense. Teamwork could be stratified into more nuanced skills, such as an ability to negotiate effectively, possessing a positive critical attitude and having the capacity to empathize and listen effectively, for example. These substrata can be further nuanced when one considers the actors which are engaged in these processes. For example, are you negotiating with a client, a teammate or a supervisor? These are the subtleties which are lacking from the body of literature examined in this paper that we would argue makes it difficult to aggregate data collected about skills that are not sufficiently nuanced.

### 4.2 *Issues with statistical analysis*

Another observation about the literature which is currently in circulation is the use of parametric statistics on ordinal data. In theory this practice is acceptable, provided the data can be shown to be normally distributed by Shapiro-Wilk or another equivalent test of normality [42]. Little evidence that this has taken place is presented in the current body of literature. Of 18 papers which utilised statistics, 16 utilised parametric statistics, 0 papers reported a test of normality. It is also important that authors making use of parametric statistics acknowledge the theoretical assumptions of such a decision. The biggest assumption being that a Likert scale is an equal measures scale (the distance between a 1 and a 2 is the same as the distance between a 3 and 4, etc) and that the numbers being collected and interpreted are objectively *real*. It is rare that Likert scale data can follow a normal distribution and those which do usually have skewness values outside of an acceptable range [43]. Two papers utilised a non-parametric approach to the analysis of post intervention self-assessments, which highlights a broader issue around what exactly

## 5) Discussion

It is clear that a more interpretive approach to these studies is required. The authors believe that one starting point for a study of this nature is to define skills in terms of measurable behaviours. This opens the door to scientific measurement through behavioural psychology. Such measurements can be made in a behavioral assessment such as a Situational Judgement Test (SJT) [44]. Situational judgement testing can be attributed to the work of Motowidlo, Dunnette & Carter [45] who discussed the use of what they called a low fidelity simulation of behaviours for predicting job success. The authors used the critical incident technique to collect lived experiences from managers in 7 companies around the topics of problem solving, interpersonal and communication skills resulting in the development of a 58 situation and a 30 situation test. Then, they met with 150 managers and asked them to write a few short sentences about how they would react to those situations, these formed the 4 possible responses to each item. Forty-two managers were then asked to select the relative appropriateness of each response before the pilot study took place. The authors found poor correlation between test scores and the Grade Point Average (GPA) of participants but relatively strong correlation with interpersonal skills, negotiation and communication skills which were evaluated in interviews with test participants. We believe that this methodology is consistent with the authors view that skills are multidimensional constructs which are developed through social interaction. There are of course limitations to this method in that a single test item is construct heterogeneous and repeated observations would be required to build a complete picture of a skill and its' interrelated factors. Responses to such tests can be mediated by culture and experience and can therefore be extremely useful instruments in candidate selection. The second potential means of making a measurement of skill is to use the high fidelity scenario, which is observation of behaviour in a group setting. Such research comes with the limitation that observing group behavior may change alter the groups' *true* behaviour. The benefit is a direct measurement of professional skills. Both methods have proven popular in Human Resources for candidate selection, with both methods providing a greater sense of an individual's skill level than a self-assessment.

## 6) Conclusions

There is a flagrant abuse of statistics occurring in research in this area. The level of abstraction from a self-assessment as measuring skill to interpreting that data as being composed of real numbers is far too great an assumption and so the use of statistics in such studies - should at minimum - come with a section which acknowledges the rather large assumptions made to carry out the analysis and the appropriate statistical tests and their outcomes published to verify that the data are in fact normally distributable and suitable for a parametric approach. More fundamentally the treatment of skills as objectively real and discretely measurable has resulted in the aggregation of rating scale data without due regard for the contextual nature of the definitions of these skills, this pursuit of certainly in the field has resulted in a loss of a sense of meaning in the papers which report such data, what does it *mean* that Problem solving, for example, is rated 1 point higher than teamwork by a stakeholder? And what does it *mean* that students' self-assess their skills after an intervention with higher or lower ratings following an intervention? We believe that there are certainly more interesting questions to be answered in professional skills research that address the context in which these skills are important to a variety of stakeholders that present fresh avenues of inquiry for the engineering education research community to explore.

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