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Putting Mathematics "Into a Form That a Non-Engineer Will Understand"

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1 INTRODUCTION

Research suggests that while professionals in numerate fields draw upon their mathematics school learning, they do so in a distinctly different manner from the way in which they experienced mathematics in school. It is reported that there is a significant difference between what a mathematician calls "doing mathematics" and what an engineer calls "doing mathematics" [1]. However, in the case of engineering practice, research concerning the type of mathematics used by engineers in their work is sparse [2-5]. While there are a number of studies that investigate engineers' use of mathematical thinking, most of these are conducted in academic workplaces. Difficulties associated with investigating "real" engineers' mathematics usage are that access to engineers is difficult and with many different branches and job profiles within engineering, there is no unique identity as "'the' engineer". Furthermore studies of engineers' use of mathematics have tended to take a qualitative approach that involve a small number of engineering functions and engineers and thus the findings may not represent engineers generally [6].

However the importance of communicating mathematics is evident from the research literature. For example, it is reported that there are three components to doing mathematics, these are: processing, interpreting and communicating mathematical information in ways that are appropriate for a variety of contexts [7]. Similarly mathematics oriented *thinking* skills, which are so important in engineering practice, include: "*the ability to interpret information presented in a mathematical manner and to use mathematics accurately to communicate information and solve problems*" [8]; mathematical literacy reflects the skills needed in business and the communication of mathematically expressed decisions and judgements within businesses [9]; individuals need to be able to understand and use mathematics as a language that will increasingly pervade the workplace [10]; and an important mathematics competency is "*communicating in, with, and about mathematics*" [11].

Practising engineers' requirement to communicate mathematics is also apparent. It is reported that engineers' practice of modelling a problem in "*objective, mathematical terms*" is outmoded and that engineers are now "*immersed in the environment and human relationships from which perception of a problem arises in the first place*" [12]; that modern engineers work in teams and they exchange "*thoughts, ideas, data and drawings, elements and devices*" with other engineers around the world [13]; that engineers spend 60% of their time explicitly interacting with other people [14]; and that a major part of engineers' work is to explain, often at a distance and through intermediaries, how the products of their work need to be designed, built, used and maintained effectively [15]. A study of civil and structural engineers working in a large engineering design consultancy in London, observed that mathematics is used as a "*communication tool*" between the designer and the specialist whereby the "*specialists*" are able to: "*synthesise complex problems down to something very small, which can be expressed mathematically … the specialist can give you a set of equations, which you can adjust … so the maths is used as a communication tool, he's digested a situation into a model which is accessible to the general engineer, with a general mathematical background*" [16]. There is also a view in the research literature that communication and team work contribute significantly to the gap between engineering education and engineering practice [17]. It is further recommended that engineering students should learn how to communicate with "*others who can provide mathematical expertise*" [18].

This paper discusses the finding that practicing engineers are challenged by putting mathematics "into a form that a non-engineer will understand".

2 METHODOLOGY

This study investigates practising engineers' mathematics education and their use of mathematics in their work. The research population of interest in this study is professional engineers who meet the criteria of "Chartered Engineer" determined by Engineers Ireland, the body representing the engineering profession in Ireland. A Chartered Engineer has at least a level 8 engineering degree and a minimum of four years' relevant professional experience.

A sequential explanatory strategy mixed methods design is employed, whereby an initial quantitative survey is followed by explanatory qualitative interviews building on the survey findings. A quantitative approach is considered necessary as the professional engineering population in Ireland comprises a diversity of engineering disciplines, roles and functions working in many different types of organisations. The subsequent qualitative phase offers a new perspective to engineering education research which thus far has generally favoured a quantitative approach. Employing both approaches captures the objective nature (measuring mathematics usage in engineering practice) and subjective nature (exploring individual engineers' feelings about mathematics learning and usage) of an investigation into the role of mathematics in engineering practice and in the formation of engineers.

The sample of 365 survey participants is broadly representative of the professional engineering population in Ireland across industry sector, engineering discipline, gender and geography and the survey sample size is satisfactory for 95% confidence that the findings represent the population of Chartered Engineers in Ireland [19].

Following analysis of the survey data using Minitab statistical software, interviews were conducted with 20 engineers representing low, mid and high *curriculum mathematics*[1] users. These engineers also comprised a diversity of engineering disciplines; roles; sectors, organisations; urban and rural backgrounds and school mathematics levels. 25% of the interviewees were female and 25% were less than 35 years of age. A manual data analysis process was employed [19-23].

3 FINDINGS

This study gives an insight into engineering practice and the type of work engineers do [19-22, 24]. This is important knowledge given that many young people have a "*blurred picture*" of engineering in that they see an engineer as someone who is "*up to his or her neck in equations for forty years*" and "*not the happy, successful engineer contributing to society*". One message about engineering practice that emerges from the study is summed up by one engineer who presents that in a "*typical engineering company, only a few people do maths at quite a high level, there are people below you who need to understand and interpret what you are doing and then others who just need to know the big picture*". The interview analysis gives a first-hand insight into engineering practice and engineers' individual stories illustrating that engineers' work is diverse and that it comprises: degrees of *curriculum mathematics* usage, problem solving; "*bigger picture thinking*"; using computational tools; reusing solutions; analysing data; "*real world practicality*"; integrating units of technology; managing projects; and communicating solutions [19, 20, 24].

In the context of engineers' own education, a major finding is that feelings about mathematics are a major influence on engineering career choice [25]. There is also clear evidence that mathematics teachers have a powerful role in students' motivation to learn mathematics and the ability to communicate mathematics and its relevance is the predominant characteristic of good mathematics teachers; the "*excellent teacher just connected with people through maths*" [19, 21].

[1] *Curriculum mathematics*: Term devised in this study to represent engineers' mathematics education at school and university.

Overall practising engineers' views on communicating mathematics in engineering practice stand out; they maintain that:

1. Communicating mathematics is an important part of engineers' work.
2. Compared to other professions engineers are not good communicators.

1.1. Communicating mathematics is an important part of engineers' work

This study of practising engineers illustrates the importance of communicating mathematics; engineers communicate mathematics when: expressing engineering concepts; expressing conclusions; writing reports; making arguments; "*explaining how you have come to your conclusion*"; "justifying some decisions"; "*rolling out IT solutions*"; reading reports; "*verifying consultants' work*"; "*communicating a concept to a decision-maker*"; "*asking the finance people to provide money"* and selling products. Engineers say they communicate mathematics to a range of people including: other engineers; a variety of technical people on project sites; colleagues in Ireland and abroad; clients; managers; vendors; contractors; consultants; administrators; customers; decision makers; accountants; finance people and human resources people.

Engineers view effective mathematics communication as a means of enabling a number of people to get "*the benefits of the analysis*". Communicating mathematics effectively enables engineers to produce "*rock solid arguments*" and it is a means to "*prevent other people pulling your leg*". Engineers say there is "*skill in communicating maths*"; it is the "*craft of putting the mathematics into a form that a non-engineer will understand*". While many engineers use Microsoft Excel to communicate with other engineers, engineers also need to be able "*to stand up in front of people and explain what is meant by*" the particular mathematics used. Consequences of poor mathematics communication skills are that calculations are "*meaningless*" and the message can be "*biased or abused*".

1.2. Compared to other professions engineers are not good communicators

Compared with other professions engineers who participated in this study view themselves as poor communicators which they say is not good for the engineering profession. One engineer believes that *"engineers lack the emotional intensity that they need to communicate to get a point across to people or to realise the impact of what they do on people's lives".* He says that *"others [non-engineers] seize that opportunity and that is why engineers are so often in the background".* There is a view that mathematics work is "*isolating*" and that when an engineer tries to present mathematics to his work colleagues he notes that his audience is "*nodding off*". There is the difficulty of getting people to "*grapple with an abstract concept*" and there is a view that there is often a disconnection between the engineer who is "*enthusiastic about the mathematical detail*" and the decision maker and that it is not reasonable to expect the manager "*to get up to the level of maths that the engineers are at"*. One engineer notes the challenge of "*converting mathematics into ordinary English*" and that while his documents might be as "*clear as anything*" to himself "*other people*" have difficulty reading them.

The engineers' view, that they are not good communicators, is somewhat supported in a longitudinal study of mathematically gifted adolescents where it was found that "*those with exceptional mathematical abilities relative to verbal abilities tend to gravitate toward mathematics, engineering and the physical sciences, while those with the inverse pattern are more attracted to the humanities, law and social sciences*" [26]. Another study of graduates who didn't come from the pool of mathematically gifted students found that male scientists have "*exceptional quantitative reasoning abilities*" compared to "*verbal reasoning ability*" [27]. Studies also show that engineering graduates lack the communication skills required in engineering practice [28]. A study investigating mathematics graduates' transition to the workforce in terms of their communications skills found that, prior to working, the graduates had not considered the use of mathematics to communicate ideas. Their education did not teach them to use standard computer products such as Excel, Visual Basic or SAS. In the workplace, graduates are often the only ones who can speak the mathematical language and many graduates are unable to release the strength of their mathematics because they do not know how to communicate mathematically [29]. A study of the early work experiences of recent engineering graduates found that the social context of engineering in the workplace is a major driver of engineering work and that interpreting data was a new experience for many engineers. One engineer said he was "*learning more about how to present my data to other people*" [30].

A significant finding in this study is that communicating mathematics is not only important in engineers' work but that it is critically important for the engineering profession. One engineer asserts that "*if engineers are to survive then they need to somehow harness communication skills"*. There is also a view in the research literature that engineers "*don't do a good job of explaining*" engineering to people outside of engineering and consequently engineering is seen as a "*bunch of technical things they can't grasp … and boring too*". The perceived difficulty of technical aspects of engineering, especially mathematics and science, contributes to difficulties communicating what engineering is [31]. This lack of public understanding of engineering is damaging the image of the profession [32]. It is also presented that society values engineers who can apply their skills across disciplines, that it is important for engineers to communicate effectively with non-technical people and that engineers should have the ability to explain technical problems [33].

One engineer in this study maintains that if one doesn't "*bring the problem and the solution to people in their language*" mathematics becomes "*elitist*". Ernest reinforces this view where he states that the perception of mathematics "*in which an elite cadre of mathematicians determine the unique and indubitably correct answers to mathematical problems and questions using arcane technical methods known only to them*" puts "*mathematics and mathematicians out of reach of common-sense and reason, and into a domain of experts and subject to their authority. Thus mathematics becomes an elitist subject of asserted authority, beyond the challenge of the common citizen*" [34].

4 IMPLICATIONS OF FINDINDS

The engineers' views on communicating mathematics have implications for mathematics teaching. There is strong evidence that mathematics learning requires a social environment whereby students benefit from group discussion and peer assisted learning. In this study good mathematics teachers are identifiable by their ability to communicate mathematics and its relevance. Consequently teachers need to engage with students in mathematics discussions and subjective analysis and they need to help students acquire an appreciation of mathematics. According to Vygotsky's social constructivist mathematics learning theory, teachers' role is to provide scaffolding on which students construct their learning. Scaffolding is a means whereby a more skilled person imparts knowledge to a less skilled person and discussion between teacher and students and amongst students themselves enhance students' mathematical thinking and communication [35]. Furthermore a social mathematics learning environment enables students to enhance their tacit knowledge and this type of knowledge is required in workplace situations [36].

5 CONCLUSION

The greatest reason attributed by engineers in this study to negative experiences using mathematics relates to communicating mathematics and the negative feelings resulting from their colleagues' lack of understanding and consequently engineers' difficulty influencing business decisions. The engineer's feelings about school mathematics and mathematics in engineering practice supports the view that communication and team work contribute significantly to the gap between engineering education and engineering practice [14]. It is interesting to note that engineers give importance to communicating mathematics in both the teaching of school mathematics and the use of mathematics in engineering practice. While engineers maintain that the ability to communicate mathematics is the predominant characteristic of the their own good mathematics teachers, the importance of communication in learning mathematics is also supported by Vygotsky's theory of social constructivism, whereby learning is constructed in a social context and classroom discussion, rather than teachers' transmission of knowledge, is an essential part of mathematics learning [35]. When students are challenged to communicate the results of their thinking to others orally or in writing, they learn to be clear and convincing and they also develop new levels of understanding mathematics. There is a view that communicating mathematics is neglected in mathematics education [37] and in Ireland there is little evidence of group work, and mathematics teachers generally rank lower-order abilities (e.g. remembering formulae and procedures) more highly, and higher-order abilities (e.g. providing reasons to support conclusions, thinking creatively and using mathematics in the real world) less highly than do teachers in many other countries [38].

Furthermore engineers in this study admit that they felt "*alone*" in their enjoyment of school mathematics and that there is an "isolation" associated with using mathematics in engineering practice. A consequence of poor mathematics communications is that engineers are left in the "*background*" and as one engineer asserts if one doesn't "*bring the problem and the solution to people in their language*", mathematics becomes "*elitist*".

The findings in this study suggest that engaging in active or social learning environments that emulate engineering practice would benefit engineering education. This type of learning environment would provide a greater focus on: engineering practice; real world applications of mathematics; working with tacit knowledge; teamwork; communicating mathematics; data analysis and decision making; and interpreting computer solutions. Students would be required to present and defend their mathematical solutions to both their peers and their lecturers. Based on the findings in this study, it is anticipated that this type of learning environment would develop students' mathematics communications skills and would also enhance their mathematics thinking and confidence. It is concluded that learning mathematics in a social context enables students to enhance the tacit knowledge required in the workplace situations and provides a better match to the mathematics required in engineering practice.

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