Investigating the perceptions of professional engineers that undergraduate engineering students hold?

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Conference Topic: The Attractiveness of Engineering

INTRODUCTION

Graduates in science, technology, engineering and maths are "vital for the UK's future prosperity" [1] The IMechE agree that "Engineering makes a vital contribution to the UK's economy" [2] with the Engineering Graduates for Industry report by the Royal Academy of Engineering confirming that the UK economy needs the best possible engineering graduates to underpin its future [3]. However, despite this very positive consensus, the UK context mirrors the international shortfall of engineering graduates and reveals a real tension between aspiration and reality.

1 THE IMPERATIVE TO RECRUIT AND RETAIN ENGINEERS

There is an international deficit of scientists and engineers; current training rates in the USA suggest a 1,000,000 person shortfall in meeting workforce demands across the next decade [4] and "...forecasts suggest that the UK needs to more than double the number of engineering graduates" to meet predicted demand by 2017 [2]. In the North-East of England specifically, there is deficit in the STEM workforce but also a growing number of great employment opportunities. The North-East of England Process Industry Cluster (NEPIC) estimate that over 235,000 people are directly and indirectly employed in chemical based regional industries and that manufacturing companies generate over 25% of the regional GDP [5]. With an ageing workforce there is need to ensure that the next generation of workers are equipped to exploit the employment opportunities afforded to them.

STEM graduates are in "short supply" and there are numerous challenges in recruiting students onto degree courses in STEM subjects [1]. Engineering, in particular, "suffers from a major perception problem amongst young people ..." [6] with one of the "many barriers affecting the supply of engineering undergraduates" identified by Bowen et al. [7] as a "lack of awareness of what engineering entails." Many teachers, parents and the public in general have "perceptions which do not match the reality" of the multi-skilled, challenging and dynamic profession [6]. Whilst the perceptions of the wider public have been considered, very few investigations "have focused on students' ideas about engineers and engineering" [8].

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Of those who do choose to study STEM subjects at university a high number of graduates go on to "choose to work in non-STEM areas" [9]. Almost a quarter of graduates from the 2010-2011 cohorts from mechanical engineering programmes in the UK did not go into engineering and technology related careers [10].

Gender bias within the UK Engineering profession remains a significant problem, with women comprising just 9% of total workforce [11]. The UK lags behind improvements made in the USA where 11% of Engineers are women [12], Spain, where 18% of Engineers are women and Sweden, where 26% of engineers are women [11]. Chemical engineering leads the way amongst the engineering disciplines in terms of redressing the stark under representation of women within the undergraduate cohort, with "1 in 4 of UK chemical engineering students" being female, civil engineering has 1 in 7, whilst mechanical engineering attracts just 1 in 20 [13].

A lot of resource is, understandably, directed at addressing general barriers to studying engineering at University. However, the data presented also clearly highlights a requirement not only to encourage more students into engineering, to increase training of those who can work within STEM careers, but also demonstrates an imperative to develop better retention strategies, especially for women, who remain underrepresented within many fields of science and engineering.

2 EXPLORING UNIVERSITY STUDENT PERCEPTIONS OF 'THE PROFESSION'/ PROFESSIONAL ENGINEERS

To be able to address students' ideas about engineering, it is important that we understand what ideas they have [8]. One way of discerning perceptions is to use images; studies have used students' drawings to reveal perceptions of scientists and what it is they think scientists do [14]. One of the most well known instruments for exploring students' perceptions in STEM is the 'Draw a Scientist' task [15].

The Draw a Scientist task (DAST) has been modified and the concept developed for use in other subjects such as Mathematics [16], Computing [17] and Engineering – using the Draw an Engineer Task [8]. To support a more rigorous analysis of the data, and improve the consistency of raw interpretation of the drawings obtained from the DAST, a checklist (the DAST-C) was developed [18]. An example of a scoring guide for the 'Draw an Engineer' task can be seen in the work by Lyons and Thompson [14] and the work by Knight and Cunningham [8] describes how images from a DAET were analysed.

It is notable that whilst the DAST and the DAST-C have seen numerous applications throughout school level children (analysing perceptions of the discipline, stereotypes and representation of gender) there is less evidence of it being used in Higher Education [19]. Stiles [20] investigated why academics are so reluctant to embrace the pictorial form as a methodology and suggested that subjective interpretation, variable drawing ability, technical publishing difficulties and uncertainties about using the medium possible reasons, whilst also claiming that images are considered as a subjective, inferior or even eccentric form of data compared to words and numbers.

Zuboff [21] concluded that drawings can catalyse the representation of feelings that are implicit and hard to define. Meyer [22] explored the use of visual data and argues that drawings are capable of communicating information about multi-dimensional attributes with clarity and precision and the respondents often possess more complex, subtle and useful cognitive maps than they can verbalise [23]. Stiles [20] claims that visual images can be as valuable as words or numbers, may lead to richer understandings and that drawings can capture deep-set, internal visual constructs.

This paper presents pictorial representation as an innovative and challenging technique for exploring how undergraduate engineering students see the engineering profession.

3 METHODOLOGY

This paper describes a study which was conducted to establish knowledge of students' perceptions within STEM degree programmes in the North-East of England. Ethical approval was given for data to be collected from 396 first year (L4) undergraduates studying programmes within the STEM subjects of Mechanical Engineering, Applied Biological Sciences and Forensic Science.

Students from 3 regional HEIs were asked to complete a survey to explore their pre-entry motivations for choosing to study the course, prior study, parental experience of STEM, future post-graduate study/career aspirations and also their understanding of what activities professional scientists/engineers routinely engage with. Students were also asked to complete a 'Draw a Scientist/ Engineer' task; they were asked to spend a few moments thinking of an *'Engineer and the activities they undertake on a day to day basis, where and how they work etc'.* They were asked to draw their vision of that person using labels if they wished and were reminded that their *'artistic skills were not important and that a labelled stickperson is as informative as a work of art!'*

Comparable data from two of the regional HEIs (one Post-92 and one Russell Group) is presented in this paper to explore only the perceptions of students' within Mechanical Engineering (where n = 191 students).

A modified version of the DAST-C was used to analyse the visual images for levels of stereotyping. The checklist enabled consistency in analysis between co-investigators and for the data to be comparable with the significant body of DAST/DAET literature. The modification of the DAST-C for this purpose allowed for the addition of some of the more engineering specific items to be included, as informed by the work of Knight and Cunningham [8] and Lyons and Thompsons [14] such as tools, hard-hats, computers, cars, buildings, images of design and images of products of engineering.

In summary, the checklist (modified DAST-C) used to identify stereotyping within images enabled drawings to be scored to a maximum of 15 points; 7 from an upper checklist and the remaining 8 from an additional list including explicit characteristics which may have significance.

The Upper list looks for: Lab coat/high-visibility jackets; eyeglasses/ goggles/hard-hat/safety shoes; facial hair; symbols of engineering process/research (e.g. CAD or design work; machine or hand tools); symbols of knowledge (books; noticeboards etc.); products of engineering (technology; cars; bridges etc); relevant captions (Mwaa; eureka; formula; etc.)

Whilst the Lower list considers: male gender; Caucasian; signs of danger (explosions; hazard signs etc); mythical stereotypes (crazed; geeky etc); signs of secrecy (keep out); work indoors; middle aged/ old engineer. Other relevant characteristics of images were also recorded as free text entry e.g. 'graduate level' type activity; whether images/ stereotypes were positive, indication of teamwork, etc.

4 RESULTS

4.1 Results of the survey

The data from the 191 engineering undergraduates (Table 1) is presented for each of the survey items. The data from the Post-92 institution was gained during induction week (therefore potentially restricting the sample size as not all students attended the induction sessions) and the data from the Russell Group was gained one-month into Semester 1.

Table 1: Population Data

Gender (%)	Post-92 (n=75)	Russell Group (n=116)
F	7	9
M	93	91

The first question was *"Why did you choose to study this subject at University?"* Students were asked to list the main sources/ reasons/ people that influenced/ inspired them. Multiple responses were possible and the five most frequent responses are presented in Table 2.

Table 2: Reasons for Choosing the Subject

Reasons for Choice (%)	Post-92	Russell
General interest/enthusiasm	44	53
Teacher/Family and friends	33	27
Future career options	-	28

Applied nature of subject	19	15
Subject strength or choices at school	19	15

A much lower percentage of students identified with the ‘Broad nature of the discipline’ (Post-92 = 4% and Russell = 3%). The students at the Russell Group University also listed; ‘social/political’ (4%). ‘respected/cool’ (3%), ‘challenging’ (3%), ’sport/F1’ (3%) and ‘money’ (3%). Others responses (≤1%) included previous visits into industry, wanting the qualification, previous work experience, public figure inspiration, course was second choice.

The overall conclusions from Table 2 are positive and show that most students are engaged (through their choice of programme) with a subject that has always interested them, that they enjoy and that they have previously been successful in. Data was very similar between institutes, with one difference related to future career prospects being cited only by respondents from the Russell Group as a significant positive motivation for choice of degree.

Looking at what students had studied prior to University (not including a few students at both institutions who chose not to answer) also revealed a difference between HEIs. There was a more positive bias towards exclusive study of STEM subjects within the cohort attending the Russell Group institution, with more breadth in pre University subjects studied reported in the Post–92 cohort. 49% of students in the Post-92 cohort had studied only STEM subjects prior to starting University and 47% studied a mixture of STEM and other subjects. Of the Russell Group cohort a much larger 66% of students had studied STEM only subjects and 29% studied a mix of subjects.

Students were then asked to confirm whether their mother and/or father had attended University; if they had, students were then asked to indicate [i] what subject/ degree was studied and [ii] to confirm whether they continue to work in STEM occupations (or were in a STEM career up to retirement). This data is summarised in Table 3 and show that at the Post-92 HEI the majority of parents did not study STEM subjects at University and are not involved in STEM occupations. There were a larger number of parents from the Russell group institution who had studied STEM and a very large percentage of them (95%) were still in STEM careers.

Table 3: Parents studying/working in STEM

Of those that went to University: (%)	**Post-92**	**Russell**
Either/ both studied STEM	23	40
Either/ both in STEM occupation	13	38

Students were then asked to list all jobs, or further study they were considering. The majority of respondents gave multiple answers to this question and data is summarised in Table 4, with the most frequent (≥7%) shown. The most significant and positive result is the large majority of respondents who indicate they want to stay within engineering. The prevalence of careers within the Armed forces stems from the well established and current links at both institutions with Armed Forces sponsored programmes.

Table 4: Future Careers Being Considered

Future Career (%)	**Post-92**	**Russell**
Research/ PG study	8	19
General engineering	41	29
Specific Engineering Discipline (Automotive, Aeronautical, Energy, Marine, Mechatronic, Biomedical)	31	41
Design Role	11	14
Armed forces	7	9
Finance	-	7

Less frequent future aspirations (≤3% responses) included Teaching, Management, Business, Research & Development, 'Something which pays well', Police, Pilot, Football Manager, Astronomy, Writing and Medicine.

To shift focus on to establishing what perceptions of engineering students held, they were asked to list up to 3 activities which they thought a professional engineer engaged with routinely and the most frequent tasks indicated are summarised in Table 5 (>10% response from at least one HEI included).

Table 5: Routine Engineering Activities As Perceived By Engineering Students?

Routine Engineering Activities (%)	**Post-92**	**Russell**
Using Science/Maths	11	10
Designing	57	53
Managing/ organising/ planning	19	19
Research	27	11
Testing/ experimentation/ diagnostics/problem solving	56	29
building and manufacturing	20	21
Communication	1	13
Team work	8	12
Maintenance	12	3

Further responses (scoring between 6 and 10%) were Innovation, Drawing, Health & Safety, Analysis, Improving/Ensuring Efficiency and Meetings. Other much lower responses(≤5%) included: Quality, Gathering Data, Modelling, Writing Reports & Admin, Hands-on, Development, Engineering/non-engineering/sleeping, Reading Research, Equipment Calibration, Monitoring, Fixing, Experiments, Using Gaffa-tape, Financial Activities, Site Visits, Teaching, Computing, Hardworking, Travel, Spreadsheets, Pitching & Bidding to Clients, Mechanical Theory, Take Inventory, Decision Making, Deadlines, Evaluation, Technical, Consultation, Environmental Protection.

Overall the data set shows a very broad and general awareness of a range of activities that an engineering career might involve. Whilst there were no significant misconceptions the high number of responses which suggest 'building and manufacturing' and 'maintenance' suggest more technician level roles rather than activities which may be assumed as graduate level.

There was generally good agreement with what was written to demonstrate engineering activities and the subsequent drawings which were produced.

4.2 Results: Images of Engineers/Engineering

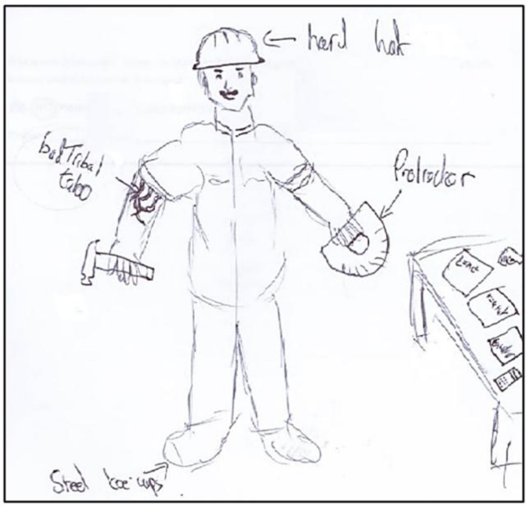
Scores generated from analysis of the images using the modified DAST-C were used to grade the images into three categories; highly-stereotyped, moderately-stereotyped or non-stereotypical (shown in Table 6). Most of the images drawn were not highly stereotyped; the majority showed some stereotyped features (moderate-stereotype category). The Russell Group HEI students generated a greater number of low-stereotyped images; the descriptive statistics for the two data sets show that the Post-92 data had an overall mean score of 4.1 and the Russell Group data had an overall mean score of 3.1.

Table 6: Stereotype within Images

Level of Stereotype (%)	**Post-92**	**Russell**
Non-stereotypical (score 0 – 2)	12	32
Moderately stereotypical (score 3 – 5)	71	57

Highly stereotyped (score 6 – 8)	15	9

A large number of the engineering images produced portrayed individuals undertaking a “technician” type task/ role. Examples (Figs. 1 and 2) are typical and show male (and Caucasian in Fig. 1) engineers wearing PPE including hard hats and holding tools such as spanners or hammers (examples Fig.1 and Fig. 2). Whilst there are occasions where these images may reflect individual/ specific engineering activities they are not the most appropriate/accurate way of depicting the complexity of the discipline. Taken in combination with the very general written responses of routine engineering activities, such images suggest a general misconception about the complexity of the discipline and of the tasks usually associated with graduate level professional engineers.



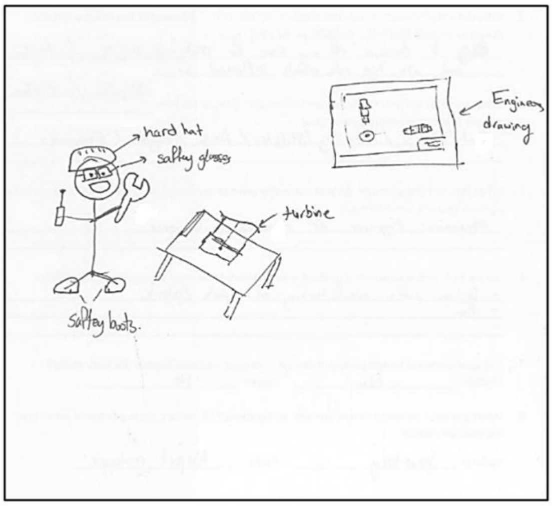


Fig. 1 High Stereotype (Score 6) and *Fig. 2* High Stereotype (Score 6)

Highly stereotyped images weren’t necessarily negatively stereotyped. Many more of the highly stereotyped images indicated positive features of the discipline. For example, figure 3 shows some highly stereotypical elements such as the age and gender of the engineer however in the general context of the use of technology, business wear, PPE nearby (although desk work being undertaken) is realistic. Figure 4, a moderately stereotyped image, shows positive detail of experimental/research work but there were also suggested an area of concern in the noose which potentially indicates the high pressure an engineer may feel.

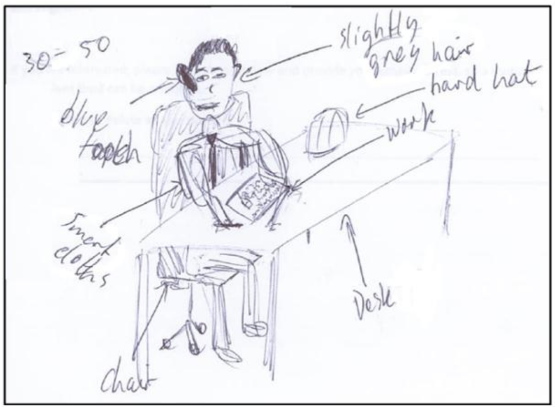
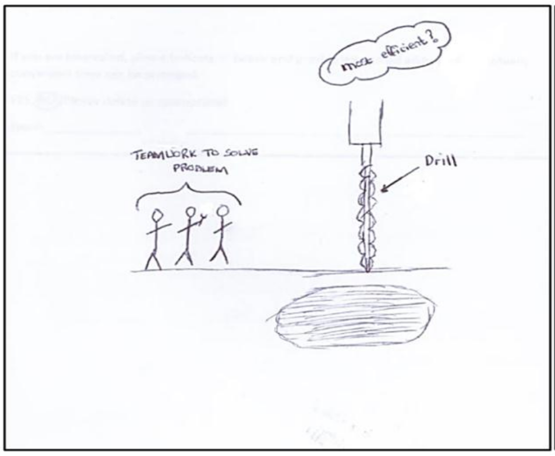


Fig. 3 Positive & High Stereotype (Score 6) & *Fig. 4* Moderate Stereotype (Score 4)

The two images below (Fig. 5 and Fig. 6) are both non stereotypical and positive in their message; they indicate that anyone could become an engineers, teamwork as an essential skill and the key concept of *“efficiency”* is identified (Fig. 5). Other responses used text rather than images to demonstrate an understanding of the discipline;

“An engineer trying to find out why something’s not working.”

“An engineer is a creative person, always looking for new solutions for problem, he doesn’t only work with Numbers he also put people in consideration, therefore an Engineer is a combination of both creativeness, and innovation with a blend of humanity.”



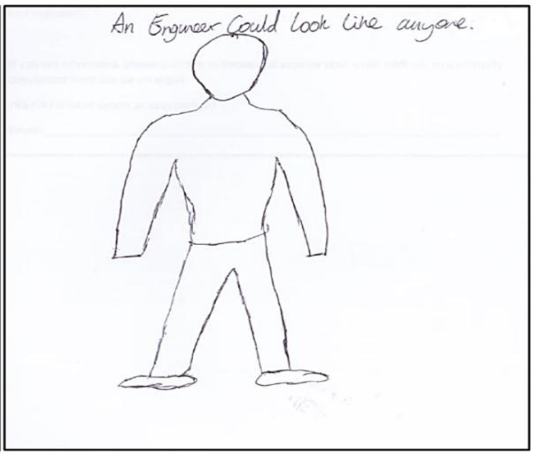


Fig. 5 Non-Stereotyped (Score 2) & *Fig. 6* Non-Stereotyped (Score 1)

Figures 7, 8 and 9 show examples of the images produced by female students. Images 9 and 10 both show low-stereotyped female images working at computers and in offices. Figure 11 is a highly stereotyped engineering image showing a female wearing on-site attire. All images showing females (n=5) were drawn by female students, there we no females drawn by male students. The total number of female students involved in this project was n=15, and of those who draw females images only one of them parent who had studied a STEM subject at University, two had no parental link to STEM and two had fathers within the construction industry.

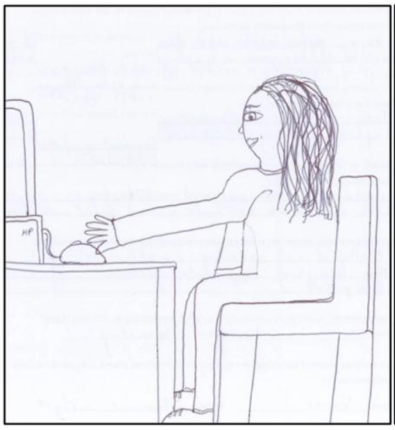


Fig. 7, Fig. 8 and Fig. 9 Representation of Female Engineers

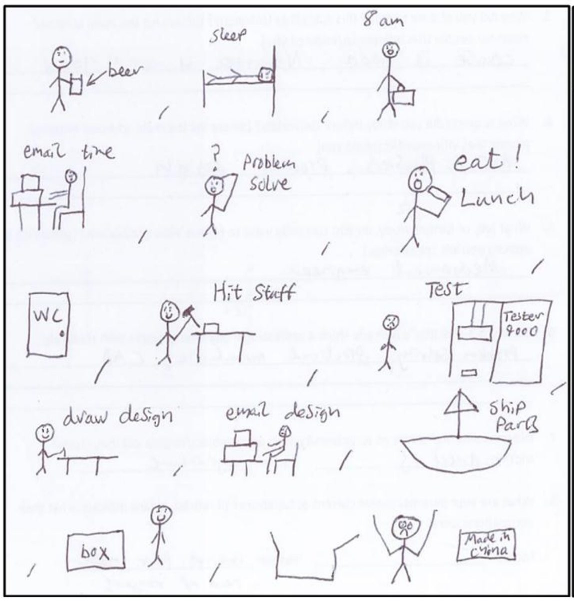
Description/annotation was used on a number of images to provide a very specific description of gender, ethnicity, age, personality and status.

On one image a stickman was shown with the caption: *“A white middle aged 30-50 working with ‘expensive machinery’ of some sort.”*

On another a stickman was shown with captions of: *“stubble because he’s a manly man”, “big brain”* and *“make money”* alongside the image of an Aston Martin car badge.

Another showed “Bob” an engineer who is: *“clever”,* has a *“dry sense of humour”,* is *“logical”* and *“thinks before he does”,* he’s *“good at maths*” and *“enjoys sudoku”.*

Several of the responses suggested the varied and busy nature of an engineering career through use of multiple images; the images in Figs. 10 and 11 demonstrate varied activities during a working day. These images were 2 out of 3 submitted which showed the engineers drinking alcohol; “beer” and “whiskey” and six of the images submitted showed the engineers drinking tea/coffee.



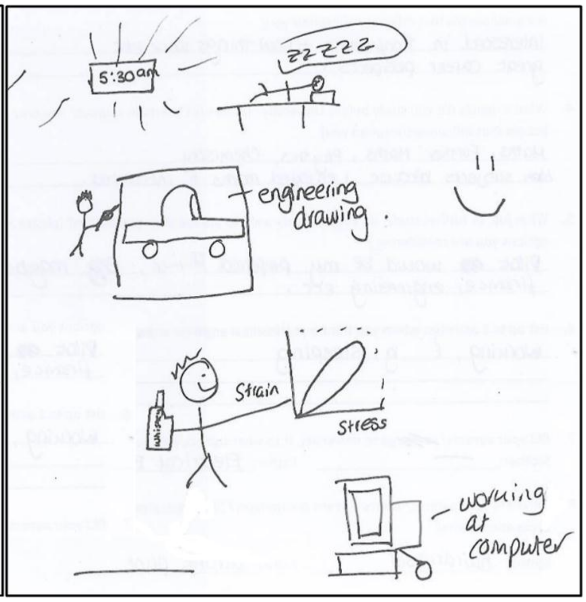


Fig. 10 and *Fig. 11* Varied Engineering Activities

5 DISCUSSION

As a means of exploring the personal constructs of engineers and the engineering profession held by engineering students themselves, pictorial representation (as an innovative technique) was utilised in our research. Based on the literature previously presented, the assumption was that drawing pictures would allow emotional and unconscious aspects to surface and would help respondents represent concepts that are difficult to articulate in written format. The images drawn provided a means of exploring the various factors that may influence, limit or inhibit their perceptions.

Engineering education can be considered as part of the process that supports students in being acculturated “into the world of professional engineering practice” and in developing “their professional identities” [24]. The data for level 4 engineering undergraduates at the two HEIs included in this research was broadly comparable, with difference between the two groups of students noted in terms of motivations for choice of University course, the pre-university subjects studied, parental experience of STEM and finally in terms of the level of stereotype within the images they produced. Images from the Russell group students were slightly less stereotyped; there may therefore be some relationship to explore between the higher levels of parental experience of STEM from students at the Russell group institution with the less stereotyped nature of the images produced by these students.

The majority of the descriptions provided about engineering activities and the images drawn show items/activities which are generally appropriate to the discipline. However, we have identified an issue with the graduate ‘levelness’ and lack of professional nature of some of the activities. A large number of the sample portrayed misconceptions about the difference in the role of an engineer versus a technician. As noted in the PROGRESS project report [25] the image of engineering in Britain is such that it should be of no surprise that students' expectations of their courses often differ from reality. The disconnect between reality and perception shows scope for enhancement approaches with engineering programmes to promote and support the development of professional identity.

Data obtained during this project supports research which has shown that students in their first-year of an engineering degree often possess only superficial knowledge about their chosen field, this can make it difficult for them to really appreciate why learning the fundamental theory of the subject is required [26]. The data shows that the students in the Post-92 Institution had a more varied experience of subjects formally studied before coming to University whilst the Russell group HEI group was more focused with the STEM stream; and it is logical that this experience contributes to the perceptions students develop of STEM disciplines.

There were noticeable difference in parental educational and occupational status between HEIs, but no straightforward association between STEM background and reported level of influence on motivation to study STEM. The prospective future career options offer positive motivation for many and the data is very positive in terms of L4 year students aspirations to remain in STEM. The data showing future career aspirations is in sharp contrasts with the literature presented earlier that showed the high rate of attrition of graduates from STEM discipline. The motivations for studying Engineering are shown to be highly biased towards students selecting the subject because they were interested in it but some interesting alternative answers were given such as Engineering being a respected career, it being a highly paid job and that it offers the opportunity to support social change.

Previous research has shown that when “asked to draw a scientist in has been found that both male and female students are more likely to draw men” [8] the same has been true in this research with all males drawing male images and the majority (60%) of all females in this work also clearly drawing males or stickmen type images.

Overall some very imaginative/ thought provoking images have been produced. There are many positive outcomes to this work; some students understand that engineering includes fundamental activities such as problem solving, improving efficiency, producing/working with engineering drawings and the need often to move away from desk work. Some of the areas which suggest concern are the “white, middle-aged, male” stereotypes (e.g. Figure 12) and the possible negative indication of stressful careers in which people are mentally pushed as in Figure 4, or those in which alcohol featured as a prop as in Figures 15 and 16.

6 CONCLUSION

The technique of pictorial representation was successful and generated rich data about multi dimensional constructs that would be difficult to articulate in a traditional written format.

The majority of students do not draw highly stereotyped images and stereotyped images are often positive. The data does highlight areas for concern, including bias in gender and representation of negative stereotypes and negative aspects of the profession such as stress/busy work schedules.

The majority of students have chosen Engineering as they are interested in it, they have previously shown strengths in the subjects required for course admission and have been influenced or recommended to the course by family or friends. Most see themselves moving into an Engineering related career, although a large number are still vague about what exactly that might mean for them and didn’t identify specific engineering fields or job roles.

It is positive to note that students have a general/ broad awareness of a range of activities that an Engineering career might involved however there is definitely scope to develop this further. A successful induction week can support students in “establishing goals and mitigating the challenging transition to higher education” [27]. It is suggested that induction week would be an ideal time to begin addressing stereotypes within the subject and also better informing undergraduates of the range of engineering roles which exist and the skills/knowledge required for them.

As identity construction is a developing and iterative process [28] it is assumed that the views the students hold of themselves and of engineering as a career may change as their time at University progresses. As a follow-up work from this project there is now data being gathered from a final year cohort to analyse any progression in the way students perceive engineering.

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