INCLUSIVE DESIGN PRACTICE - INCREASING ADOPTION BY ENGINEERING STUDENTS

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ABSTRACT
Engineering businesses report diversity, equity and inclusion within design ranks low, in a Royal Academy of Engineering survey of relevance and preparedness. At the University of Southampton, we prepare graduates from engineering UG programmes to have an interest in inclusive design. They are encouraged to empathise with a range of perspectives and issues in pursuing their group design work. To what effect? We do not currently see final year engineering students widely adopting inclusive design principles and practice, so what can we do? We benefit most from seeking to emulate good practice in our taught content derived from standards and expert practice, notably the Cambridge University Inclusive Design Toolkit. A few student groups, in their final year group design project, report an approach that addresses a good range of the eight aspects of inclusive design consolidated here, mainly from EN 17161:2019 Design for All and the Inclusive Design Toolkit. To extend the adoption of good practice we can build on what is delivered to most engineering disciplines in their first and second year, following recommendations here to develop; sensitivity to the need for inclusive design (from wider examples which are likely to resonate), knowledge of good inclusive design practice (from holistic evaluation exercises), design judgement (from user evaluation and empathy tools) and commitment to applying inclusive design (from interim assessment incorporating design risks to aid early prioritisation). We could also benefit from creating manageable opportunities for stakeholder feedback in planning and implementing students' design process, to verify and validate our continuous improvement.

Keywords: Inclusive, engineering, design, education

1 INTRODUCTION
There is a significant challenge in ensuring that inclusive design practice is properly recognised, valued, and prepared for in graduate engineering education, so that engineering organisations can rely on the capabilities of graduate engineers in these increasingly important areas.
The results from a 2023 survey of *ethics in the engineering profession* [1] showed that diversity, equity and inclusion (DEI) ranked highly in terms of relevance to engineering business and professional engineering institutions and such organisations rated their preparedness as 'high'. However, 'diversity, equity and inclusion **within design**' ranked low in survey respondent's judgement of relevance and their preparedness. "While companies were aware of this issue in a general context, many did not see the relevance to their particular product or service" [1]. Good practice is increased by awareness of ethical issues through mandatory training. "A minimum requirement for ethics-related CPD content, and signposting to available resources, would be helpful" [1]. Ahead of the need for CPD, in the University of Southampton's School of Engineering in the UK, we aim to train graduate engineers' capability and preparedness to design inclusively. We aim to address; Physical Needs (aspects including mobility and dexterity), Sensory Needs (aspects including audibility, visual clarity, and the need for tactile feedback), and Cognitive Needs (considering memory, attention spans and an ability to learn new things).
If in our experience final year engineering students are not fully adopting inclusive design principles, we should ask: what more can we do? Perhaps we ourselves are drawing on limited experience, testing how well designs meet a range of psychological and physiological needs appears difficult.
Through our engineering teaching we aim to meet the expectations for inclusive design embedded in professional formation towards achieving professional competence, in the UK expressed in the UK-SPEC [2]. In this paper we examine how effective that provision appears to be, by analysing students' reported practice in their final-year group design projects, identifying gaps and opportunities for improvement.

2 EXPECTATIONS FOR INCLUSIVENESS IN ENGINEERING DESIGN

The UK Equality Act (2010), requires service providers to avoid discrimination based on age and other protected characteristics, emphasising the importance of adopting inclusive design. BS EN 17161:2019 reports that European States have committed to applying Universal Design in the development of new goods, products, facilities, technologies and services to ensure full, equal and unrestricted access for all. This Design for All approach intends that all products and services can be easily accessed (approached & perceived), understood (comprehended and choices decided); and used (acted with or reacted to). [3]

2.1 Engineering – professional practice and the undergraduate formation aim

Accredited engineering degrees prepare students to become registered professionals who are required to demonstrate 'awareness of diversity and inclusion issues [2]. The UK body, the Engineering Council's Statement of Ethical Principles has an expectation that professional engineers will promote equality, diversity and inclusion [4]. However, the standard for professional engineering competence, UK-SPEC, only applies to registered engineers and thus has a limited reach for effecting cultural change [1].

Chartered Engineers "shall prepare, present and agree design recommendations… taking account of cost, quality, safety, reliability, **accessibility**, appearance, fitness for purpose…" [2]. When forming professional engineering capabilities, the learning aims for undergraduates studying an accredited degree (AHEP 4) include the competence to, "design solutions for complex problems that meet… **diversity, inclusion**…" and to, "…recognise the responsibilities, benefits and importance of supporting equality, diversity and inclusion." To evaluate our teaching of engineering design in UG degree programmes, we can first establish aspects of existing guidance for inclusive design.

2.2 Existing guidance on inclusive engineering design

Established guidance on the scope of inclusive design appears in several standards. However, BS 7000-6:2005 'Guide to managing inclusive design' [5] does not break down specific aspects of inclusive design practice. BS EN 17161:2019 Design for All, is more helpfully prescriptive; "Inclusive design recognises diversity by addressing the ability and preferences, for example, of people who:

- have impaired vision and/or hearing (including colour blindness, etc.);
- are from different cultures (with different languages, values and/or customs);
- have language and/or speech impairments (resulting in difficulties with reading & comprehension);
- have physical limitations (reductions in strength, movement and/or co-ordination, etc.);
- are different ages, have varying cognitive abilities and have different requirements for gender" [3].

These standards both reference the Cambridge University Inclusive Design Toolkit [6] which suggests five categories of user capability should be considered when designing or assessing a product:

- **Vision**; the ability to use the colour and brightness of light to detect objects and discriminate between surfaces and details.
- **Hearing**; the ability to discriminate tones or speech from ambient noise and to tell where sounds are coming from.
- **Thinking**; the ability to process information, hold attention, store & retrieve memories and select appropriate responses and actions.
- **Reach & Dexterity**; the abilities of the arms to reach to different places around the body, perform fine finger manipulation, pick up and carry objects and grasp and squeeze objects.
- **Mobility**; the ability to move around, climb steps and balance.

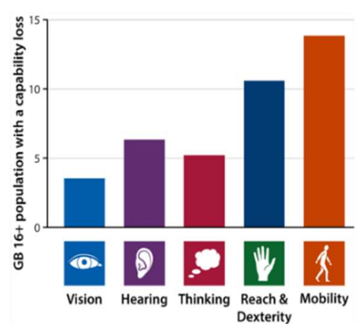

Figure 1. Capability loss in five categories among the Great British adult population [6]

The Cambridge University Engineering Design Centre propose assessing the demand placed on a user by the design in each of the five areas above, to compare with the capability of a sample user [6]. An ideal design should place a demand in each area lower than the lowest capability of a range of users, in the anticipated range of conditions e.g. ambient light/sound levels can compromise a user's ability to read/hear. To extend the range of users whose capability exceeds the lower limit, designers can [5]:

- provide multiple means of information presentation and user interaction;
- provide solutions with fixed or adjustable parameters (personalisation);
- minimise complexity and eliminate unnecessary limits or constraints on user interactions;
- provide compatibility with assistive technologies.

Detailed design process outputs are available in Table C1 in EN 17161:2019 Design for All [3] including results from 'Evaluation from the perspective of the widest range of users. "It is important that inspection is carried out by people with expertise and experience in accessibility and usability… to identify major issues..." [3]. In evaluating designs against user requirements, Useability/Human Factors Engineering methods can enhance consideration of use scenarios with hazards using risk management. This applies for example, in medical devices where ISO EN 62366-1:2015 [7] informs the process, for example to tackle the root cause of use errors, noting, "nearly every evaluation finds use errors…"
Consolidating elements of inclusive design below helps to confirm where we are teaching best practice.

2.3 Engineering Design – consolidated aspects of inclusive design

Drawing mainly on the Inclusive Design Toolkit [6] and Centre for Excellence in Universal Design's 7 Principles of Universal Design [8], we can create a consolidated list of five partially overlapping inclusive design aspects to benchmark our teaching. Physical accessibility is sub-divided into four parts:

1. **Physical Accessibility**: Does the design provide 'dignified access', equivalent utility for users with physical limitations, e.g. multiple forms of interaction, and no segregated 'disabled' provision?
   Does the design demand capability less than the range of anticipated users' capability in terms of,
   a. Vision, considering the size, shape, contrast, colour and placement of form, graphics and text,
   b. Hearing, considering volume, pitch, clarity and location of sounds versus background noise,
   c. Reach and Dexterity, considering forces, movements, precision and types of grips required in use, noting demands increase reaching above the head or below the waist and with repetition,
   d. Mobility, considering whether the product requires the user to move around and provides suitable features to assist with any climbing, with balance and with support for mobility aids?
2. **Cognitive & Neurodiverse Suitability**: Does the design demand less than the range of anticipated users' capabilities in sensory processing; memory, attention, pace and prior experience e.g. through limiting complexity, making layout/form match conventions for function, reducing 'visual noise', simplifying acoustic effects, separating interactions and making them reversible with feedback?
3. **Equitable Use & Safety**: Are functional, privacy, security and safety features equally effective for all body types e.g. male & female, or different heights/reaches/(grip)strengths, also are hazards and errors minimised and do features cater for a range of environmental conditions and use of aids?
4. **Information Inclusion**: Is all interface and safety information available in multiple formats (audio, tactile, high contrast) to suit those with different literacy levels or vision/hearing impairments?
5. **Responsiveness to Diversity**: Is the design responsive to language and cultural differences, speech impairments, age differences, medical conditions, perhaps with multiple forms of interaction or the ability to be personalised to meet individual user needs?

We can then consider how much of this consolidated inclusive design guidance is conveyed in our teaching, and how much capability do engineering students report adopting in final year design projects?

3 TEACHING INCLUSIVE DESIGN – INTENDED LEARNING

At the University of Southampton, aligned with a general EDI Vision, 'To foster a culture of respect, inclusivity & open-mindedness', first year UG engineering students are introduced to,

a) values, including EDI; designing seeking equitable use in terms of age, disability, cultural/socio-economic background, race, pregnancy, religion/belief, gender & sexual orientation, in the context of under-served and changing markets e.g. an ageing demographic with capability loss, Figure 1,
b) performance specification e.g. including anthropometric data informing ergonomic performance.

In groups students apply performance specification in a design project, with an opportunity to reflect and review evidence of their learning in a portfolio. The design brief varies by engineering discipline.
Some briefs e.g. to design a hydro-turbine, do not overtly suit applying aspects of inclusive design.
In the second year most UG engineering students are introduced to systems design in which IDEO Method Cards are referenced, seeking to introduce to them methods which would support inclusive design; anthropometric analysis, error analysis, cross-cultural comparisons, rapid ethnography, extreme user interviews, cultural probes, role playing, behaviour sampling, experience prototyping and use of empathy tools ('to experience processes as though you have the abilities of different users') [9].
An example Design Specification template for second year mechatronic design, build & test projects, prompts consideration of ergonomics and some project groups do add aspects of inclusive design.
Further study of inclusive design in the third year then depends on discipline specific modules. Mechanical Engineering students are introduced to human factors, design following anthropometric

assessment to achieve ergonomic performance, manual handling, further empathy tools e.g. simulation glasses, the inclusive design toolkit [6] and four characteristics of accessible design: Perceptibility Operability, Simplicity and Forgiveness (minimising the occurrence and consequences of errors). Good practice in inclusive design of user interfaces is illustrated with 'Dos and don'ts on designing for accessibility' [10] and examples of perception with colour vision deficiency. An example of co-design with older adults shows how to better understand needs and preferences e.g. for large, easy-to-read fonts, simple interfaces, ramps, wide doorways, grab bars, clear instructions, patience and communication.
Other engineering disciplines may have more or less opportunity for learning before those continuing to a fourth-year group design project can choose to apply aspects of inclusive design in practice.

4 EVIDENCE OF ACTUAL INCLUSIVE DESIGN LEARNING

This study focuses on evidence for the effectiveness of learning in UG engineering degree programmes in the University of Southampton. In the fourth-year final design project, students should be able to apply aspects of inclusive design in a relatively large and challenging group design project (GDP). They respond to a brief proposed by an academic supervisor with some scope to develop performance specifications from researching stakeholder needs. Given the competing priorities within these projects, students' reported choices provide the most reliable available evidence of the extent to which they are incorporating inclusive design in their engineering practice and therefore indicate their likely capability at graduation. Within the group project interim report template, the following prompt question is asked:
"What aspects of equality, diversity and inclusivity have you identified that should be considered with respect to your design and/or project management? This includes the areas/aspects where you will consider inclusive design practices."
62 groups of 5-6 students in the fourth (final) year of their UG engineering degree in 2025-26 responded with free text in their interim report submitted after the first 2 months of their 7-month GDP. This is the stage when their design performance specification should incorporate stakeholder input and their engineering design should be clearly established as a concept. Group membership is aligned with the major technology discipline in the project, predominantly Aeronautical Engineering (32%) and Mechanical Engineering (50%), fewer Civil Engineering projects (13%), Marine or Acoustical Engineering (each 2%). Though the technology focus varies, it would be rare for the scope of the design project to preclude a reasonable expectation for the students to address inclusive design aspects.

The proportion of responses which aligned with each of the eight consolidated aspects of inclusive design (section 2.3) is taken to indicate the student group's collective adoption of these aspects in their design practice. The percentages are suggested here as a reasonable measure of the level of the cohort 's capability and preparedness to apply their learning in engineering design. The level of students' collective adoption of each aspect of inclusive design practice is low, as shown in Figure 2. Within each group the number of aspects adopted is also typically low. While some groups embrace the potential of their design project to incorporate inclusive design, many appear not to do so.

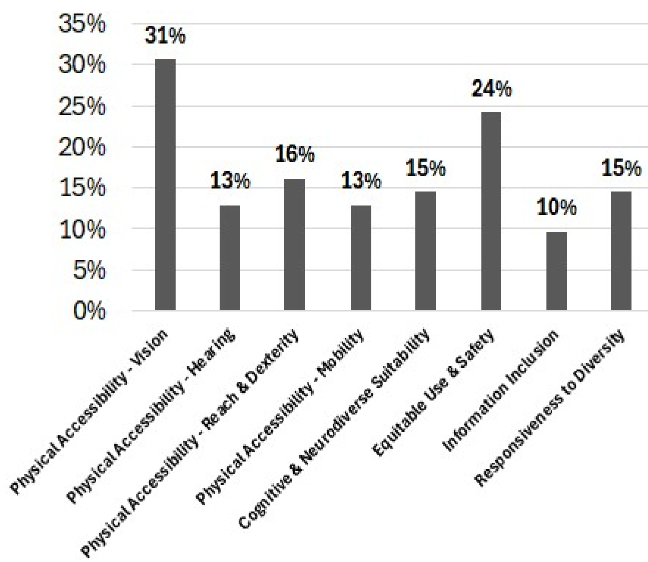

Figure 2. Inclusive design aspects evident in GDP interim reports

35% of groups responded only by noting aspects of equality, diversity and inclusivity that should be considered with respect to project management, with no aspects of inclusive engineering design reported as being included in their design specification and initial embodiment of design concepts.
34% of groups responded identifying only one aspect of inclusive design, typically, as shown in Figure 2, design for impaired vision in their design's user interface, or design for equitable use and safety.

The widest range of aspects, adopted by a Maritime Engineering group, shows that it is possible to reflect most aspects of inclusive design after 2 months work. Their interim report included (extracts):

- Manual tasks (lifting, pushing, pulling) for normal operation must suit a range of strength levels.
- Actions taken to facilitate ease of movement around the vessel should include clear routes with improved visibility, highlighted steps or trip hazards, handrails and clear instructions.
- The operation of the lifeboat and its associated equipment must eliminate any bias towards casualty survivor rate. Recovery and movement of survivors on board the vessel must be accessible to all.
- Signage should be clear... warnings should use audio (siren) and visual (flashing beacon) signals…
- Survivor seating must accommodate 2.5% females to 95% males, inc. children & pregnant women.

An Aeronautical Engineering group also showed that responses to a good range of aspects is possible:

- Wind tunnel operation indicators should use both visual and audible warnings to alert deaf and blind people in any dangerous areas, … issued with sufficient time before tunnel operation to allow physically impaired people in dangerous areas to either vacate or alert tunnel operators.
- All documentation (operation, H&S, software) should be easily translatable with clear instructions. Intense colours and clear symbols must be used to convey the message across relevant languages.
- Modular components must be light or physically undemanding, enabling the widest future usage.

Although only one source of evidence, generally low levels of adoption of practices addressing the eight consolidated aspects of inclusive design (2.3) across the 62 final year group design projects, suggests, with notable exceptions, there is potential to improve this part of learning and teaching for UG students.

5 RECOMMENDATIONS FOR POTENTIAL IMPROVEMENTS

For the University of Southampton to realise greater potential in inclusive design practice there appear to be five opportunities to address the gaps in UG students' apparent capabilities (Section 4), through developing learning content and learning methods. Adapting Davis and Feinerman's learning aims which can be applied to engineering ethics [11], the learning content and method should first seek to improve students' **sensitivity** (the awareness and recognition of inclusive design challenges) and increase their **knowledge** (resources such as codes, standards, theories, and/or decision-making tools). Then the method should enhance students' **judgement** (the analysis and reasoning required to make and justify choices) and finally reinforce students' **commitment** (the motivation to act based on learning).

5.1 Recommendations for Developments in Learning Content and Methods

1. Ensure knowledge, particularly of the less widely adopted aspects of inclusive design (Figure 2) is suitably enhanced with illustrations of good design practice in response to hearing impairment, limited reach & dexterity, limited mobility, limited cognitive ability, neurodivergent conditions, information exclusion and characteristics of diversity – so the realisation that design responses are needed for all 8 aspects is relatable to technological solutions resonating with students' interests.
2. Include in workshop-style activity, students performing an evaluation of an example design for its demand versus different user groups' capability in the eight aspects, by plotting assessment of demand vs. capability, as illustrated in the Inclusive Design Toolkit [6]. A group of students can be given different user profiles in terms of age, physical or mental impairment and compare their evaluation results, thereby practicing recognition and empathy for others' ease of use. Empathy tools such as the Cambridge Inclusive Design Toolkit's Simulation Gloves and Simulation Glasses and Impairment Simulator Software (demonstrating the effects of vision and hearing impairments on image and sound files) could be explored, or the effects reproduced by other means.
3. Include in processes for establishing performance specifications, prompts to consider the eight aspects of inclusive design for relevant user groups, validated with available (proxy) users (e.g. academics). Include inclusive design aspects in reviews of design performance vs. specification.
4. In design risk assessments, prompt for including potential failures to suitably address the 8 aspects of inclusive design. Seek to show how designers can identify potential failures to design inclusively alongside all other aspects of design performance, and prioritise responses to severe or likely detrimental consequences, even in the case of novel designs with unprecedented use scenarios.
5. Include in formal assessment of designs, expert/stakeholder and peer evaluation of inclusive design performance at an interim stage when improvements can still be implemented within the current design process. Evaluation at a final assessment stage, should consolidate the recognition of the priority of addressing inclusive design and integrating it as a relevant capability to commit to.

Through conferring on such recommendations with stakeholders in the development of engineering education, we aim to develop inclusive design practices in our teaching methods and monitor the results, including how well future students' practice aligns with the consolidated aspects of inclusive design.

6 CONCLUSIONS

Though engineering businesses report diversity, equity and inclusion within design ranks low in relevance and their preparedness, we can at the University of Southampton prepare graduates from engineering UG programmes to have a real interest in inclusive design. Students are already encouraged to empathise with a range of perspectives and issues in pursuing their group design work from their first year. However, we do not currently see final year engineering students, deeply or widely adopting inclusive design principles. We can further emulate good practice in our taught content by revisiting standards and expert practice, notably that in the Cambridge University Inclusive Design Toolkit [6].

A few student groups, in their final year group design interim project report, note an approach that addresses most of the eight aspects of inclusive design consolidated in section 2.3. To extend that limited adoption of good practice, we can build on what is delivered to most engineering disciplines in their first and second year, following the recommendations in section 5.1 to develop; **sensitivity to the need for inclusive design** (from wider examples likely to resonate with students), **knowledge of good inclusive design practice** (from evaluation exercises for the eight aspects), **design judgement** (from proxy user evaluation and empathy tools) and **commitment to applying inclusive design** (from interim assessment incorporating design risks at stages in design where improvements can be realised).

Through implementing such recommendations, we, amongst others teaching engineering design and tutoring related projects, can make our modelling of desirable behaviours more evident. We can then seek feedback from stakeholders in our education process to evaluate the effects of this approach, seeking to continuously improve our influence on student learning and subsequent professional practice.

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