BACK TO BASICS? TECHNICAL DRAWING, SKETCHING AND VISUAL COMMUNICATION IN THE AI ERA

Jeff BARRIE
University of Bristol, United Kingdom

ABSTRACT
This paper focusses on the teaching of technical drawing practice across multiple engineering disciplines, in particular first year teaching where there is a common approach to the delivery of core subjects, such as design. The paper critiques current drawing practice and questions its suitability in providing modern, equitable and inclusive learning for a diverse range of students. The paper also investigates the development of Artificial Intelligence drawing tools which threaten the application of fundamental drawing skills. The conclusion of the paper recommends a more pragmatic approach to teaching fundamental drawing skills to assess students core understanding.

Keywords: Sketching, drawing, inclusivity, equality, Artificial Intelligence, machine learning, automation

1 INTRODUCTION
Technical drawing and communication is a key aspect to engineering education. Many generations of Mechanical Engineering students in the UK have referred to various editions of Engineering Drawing Manuals [1] to support their learning of engineering drawing, such to a point that 'BS8888' and the 3rd angle projection symbol has been ingrained into their psyche. As part of a dedicated module, it is as common as Maths and Mechanics. Students at Imperial College London learn how to "Produce industry standard engineering drawings on CAD" as part of Design & Manufacture 1 and a core part of the module syllabus is 'Design Representation' through drawing and sketching. At Oxford, drawing and design forms part of a first-year engineering science student's practical work. Across the Atlantic Ocean, Junior Mechanical Engineering students at Stanford learn sketching and orthographic projection as part of ME 102: Foundations of Product Realization. For 1st year students studying engineering in the UK, swapping a calculator for a pencil and asking them to draw can be a challenge. Most engineering courses in the UK ask for A-levels in Math's and Physics for entry requirements. In most cases, an A-level in Design & Technology: Product Design is a 'good to have' for most Mechanical, Aerospace and Civil Engineering courses. Unless students have an A-level in Art & Design, or an extracurricular interest in sketching, its unlikely many students would be entering their first year of engineering as confident drawers (unless they make a special effort on graphs or free body diagrams to look nice). Thankfully, technical communication is not an 'art class', nor is it to be associated with the level of representation and sketching ability required for product or industrial design. For an engineering student, a low fidelity level of sketching is sufficient, if it is clear and represents an idea or the design features of the product well. Where more nuanced skill is required is the interpretation & representation of engineering drawings in orthographic projection with the inclusion of key features and dimensions. Such skill is important for producing drawings in both freehand sketches and CAD, providing information to workshop technicians for prototyping, as well as manufacturing drawing. Civil Engineers and Architects also use this visual language, where the elevation, side-elevation and plans of buildings, bridges and other infrastructure can be clearly communicated to clients and stakeholders. Electrical engineers also use 2D drawings to show diagrams and schematics, with standard conventions, rules and symbols. As engineering disciplines become more integrated (for example, there are combined Mechanical and Electrical Engineering courses) such fundamental skills are becoming common across disciplines. For Mechanical Engineering students at Imperial College, much of what they learn is based on what other students in similar courses would learn in an introductory Design and Manufacturing module, for

example, the design of shafts and machine components, parts and assemblies, and technical drawing practice that aligns closely to manufacturing (including variation and tolerancing). At institutions such as Oxford, one may expect a broader approach, given the nature of some courses allows students to specialize in engineering disciplines later in study. Drawing a detailed transmission shaft and learning about geometric and dimensional tolerancing on a lathe may not be the best introduction to technical communication for a Civil Engineering student (some Mechanical Engineering courses can be somewhat obsessed with shafts). As with any general engineering curriculum, there needs to be a balance of nuanced disciplinary practice, and aspects that are broader across all engineering disciplines. Students from across all engineering disciplines benefit from understanding fundamental principles of Engineering Math's, Engineering Science, Experimental and Lab work, as well as the core design and professional practice. This is where a refreshed approach to engineering drawing and technical communication can be utilized.

2 A DIFFERENT APPROACH TO TECHNICAL DRAWING

How can a design educator ensure basic competency is met, while providing an engaging series of drawing exercises that will keep beginners and experienced students engaged and challenged? Imagine if students were given a very simple shape or object to communicate using 2D and 3D drawing; what are the basic components that are required? What would the reader of a drawing be looking for? Looking at the type of manuals commonly used for drawing teaching [1], there is a significant amount of information on drawing management, manufacturing, IP and standards (this is before there is any drawing content). Typically, the principles of first and third angle orthographic projection are what needs to be understood first, otherwise anything beyond that is redundant. It is a foundational principle that engineering students need to understand, and one that is quite difficult to explain. Understanding orthographic projection requires good spatial visualization skills and mental rotation. Differentiating between first and third angle projection is also important for a 21st century engineer, as overseas supplier or archived part drawings may be presented in an alternative format. It's important to note that there is no 'correct' way between first vs third angle, much in the way that other nations across the world drive on different sides of the road. It's also important to note that some CAD packages may be installed as either first or third angle projection as default. In the design module, students were introduced to both, and in some exercises were given the opportunity to choose between first or third angle projection, as long as it was clearly indicated in the drawing. Exercises using augmented reality were useful here, to show the rotation of a simple object on paper and limited the reliance of physical artefacts in a large class (although technical hitches and reliance on smartphones/apps limited the inclusivity of this tool.). Tools such as Augment & Vuforia can be used to help students to see how 3D objects are oriented and rotated in orthogonal views, but the accessibility of such software is questionable (Augment is only accessible via a subscription). Understanding the orientation of an object on the page and how views are aligned is a pivotal first step in the technical drawing process. Dimensioning principles are also fundamental, students may have drawn a shape correctly, but there is no information on how big/small the object is. Equally, when specifying a manufacturing or construction drawing, incorrect or missing dimensions would cause confusion and costly mistakes. Using correct notation is also important, to distinguish between diameters and radii, as well as centrelines and centre-marks. If certain features of the object are obscured, for example, a screw hole which can only be seen from a plan view, hidden detail or section views need to be considered. Hidden detail has its merits, but for immediate clarity a section view is superior. Being able to slice through an object and see what is going on inside helps provide immediate clarity for the reader of the drawing. In the world of 3-dimensions, isometric views are very common in engineering (they are the default projection method for most CAD packages) and benefit from being easy to understand when converting from 2D orthographic drawing to 3D and back again. However, there are other projection methods with their own merits. Oblique is another projection method which, apart from isometric, is described in BS and ISO standard manuals [1] but introducing dimetric and trimetric projection provides the context that isometric projection sometimes needs. While isometric projection is useful, for some applications it often provides a skewed perspective which can trick the reader's eyes (anyone who is familiar with the Penrose stairs or stared at a complicated exploded assembly for too long will understand). Dimetric provides a good example of foreshortening to provide proportion and a sense of realism to an object. As such, when students in the module had become familiar with the basics of 2D drawing, the core axonometric views were introduced and explored. From such technical manuals, and bearing in mind the scope and timescales, what is not necessary? This is where any mechanical engineers reading the paper may become upset, but it was deemed that tolerancing, limits and fits and surface finishing would not be covered in the module for two reasons i) it was conceivable that a student who does not understand orthographic projection may be able to understand tolerancing, and ii) none of the students had learned anything about manufacturing yet. Therefore, there had to be a line drawn between visual communication using 2D and 3D projection methods, and additional drawing details for manufacturing drawing. The same can be said for nuts, bolts, screws and washers, as well as keys and keyways (shafts again). To support this argument, there are other, broader manuals to technical drawing, which focus more on Civil Engineering practice [2]. Here, there are references to 'elevations' and 'side elevations' terms that students would use in construction drawing. As such, when describing orthographic projection, these terms were used interchangeably. Such technical manuals also refer to projection methods (but not specifically 1st vs 3rd angle projection) as well as section views (used heavily in construction drawings to show detail and different materials). There is also a broader description of axonometric 3D projection methods. To challenge more experienced students, the module provided a topic on perspective and freehand drawing. This helped students understand the principles behind foreshortening and further develop their 3D sketching skills. Overall, it was to help students naturally draw a freehand sketch without the need for tools.

3 THE FUNDAMENTALS OF TECHNICAL COMMUNICATION

Based on the requirements of a basic approach and the commonality between drawing manuals used in both Mechanical and Civil Engineering practice, one may define the universal fundamental principles of technical drawing as follows:

- Orthographic projection in 1st and 3rd angles.
- Technical annotation and dimensioning (inc section views)
- 3D representation (using isometric and other axonometric views)

From this, a simple assessment rubric can be developed, based on the students understanding of each core topic. Particular focus and weighting should be given on orthographic projection and technical annotation and dimensioning. A core part of any assessment was that there would be an expectation that students would meet all these criteria, using a checkbox rather than grade boundaries. Either the student has understood these principles, or they have not. As such, a series of exercises that are constructively aligned to be at this minimum level of understanding is necessary. As such, gateway assessments such as PASS/FAIL modules are appropriate, as it is irrelevant to provide an exercise where students drawing ability be graded from 'good' to 'exceptional'.

4 21ST CENTURY APPROACHES IN DRAWING TEACHING

One of the first issues that an educator needs to consider is the redundancy of the drawing boards. A2 drawing boards are cumbersome and take a significantly long time to collect, set up and put away in a class. Drawing boards are also not the most portable of devices, which raises the issue of students wishing to continue drawing work outside of class, or practice at home.

A3 college boards, which were lightweight and transportable, can be considered. However, they can be costly compared to the other drawing equipment (pencils, rules, set squares) students are provided with, and deemed unnecessary for the short time students could be using them. Instead, students can be provided with an A3 booklet, which contains all the necessary drawing exercises and information students needed, as well as grid and iso paper for 2D and 3D drawing respectively. Students can also protect their exercises and keep them safe, rather than use loose sheets of A3 paper. (See Fig 1.)

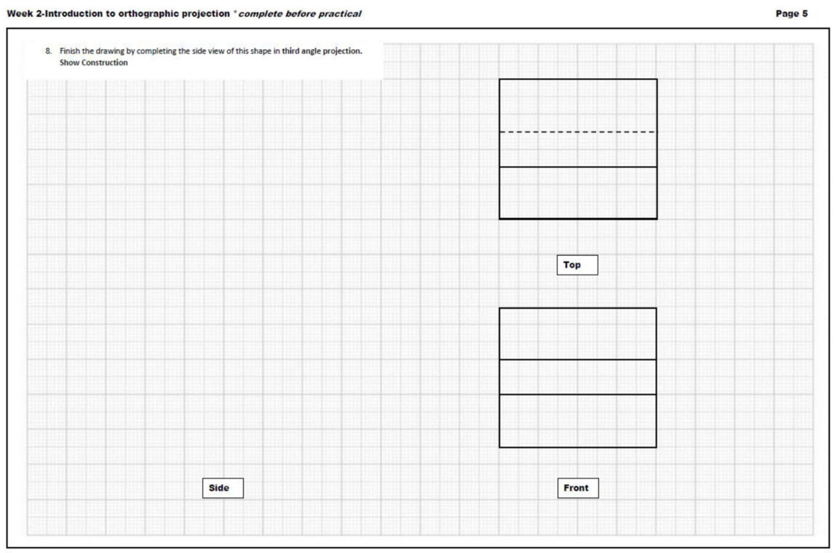

Figure 1. Example of drawing exercise from booklet

The first week of a drawing class needs to focus on fun and help students appreciate drawing again, this should mainly focus online work and circles, encouraging students to draw big shapes on paper and with confidence, before moving onto orthographic projection. Students should be given preparatory exercises to help them understand each topic. Educators may consider using a ‘verbally described’ object as a method of exercise that allows students to ‘graphically ideate’ the object in their minds before putting it to paper, as its simple to copy across 2D information to 3D and vice-versa. The verbally described object provides an opportunity for discussion and comment. Another exercise that students can engage with is a peer assessment exercise, where students can submit a 2D drawing of a simple shape or object they have created themselves anonymously to a peer, with the peer then having to interpret the object and draw it in 3D. This form of exercise helps reinforce the true meaning of technical drawing, *communication*. To draw and interpret/read a drawing are part and parcel of this visual engineering language-and one can never understand the effectiveness of clear communication without someone to speak to. Students can be assessed on fundamental principles using a very simple shape (e.g. a cube with a cylinder and some key features). The complexity of the shape should be kept to a minimum to focus on key drawing elements. An important factor of the shape is that it should never be visually shown to the students, it is verbally communicated throughout class to encourage students to imagine the shape (graphic ideation) & draw out a basic sketch, while providing more details and fidelity to allow the students to progress. See Fig 2.

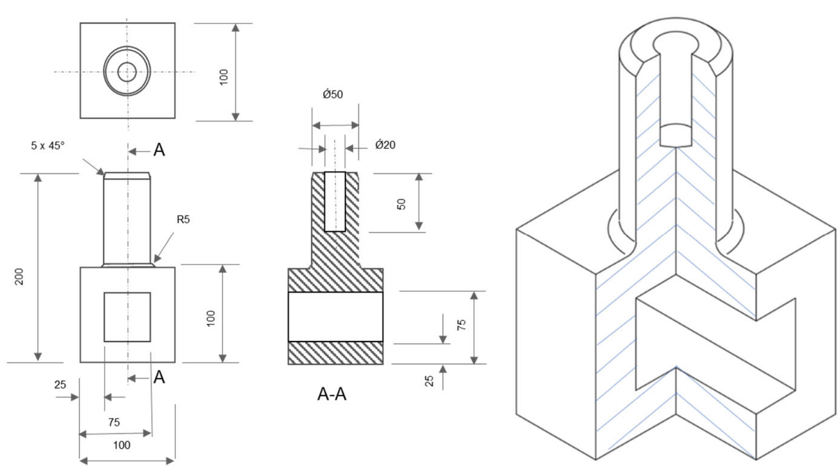

Figure 2. left-orthographic view of shape right-isometric view of shape with half-section

5 FREEHAND DRAWING VS CAD-THE ADVENT OF AI

A debate that goes as far back as 20 years ago [3] is the merit of computer aided drawing against freehand drawing. With CAD packages, students can create accurate technical drawings from their laptops without the need for using drawing boards, printing booklets as well as drawing equipment. However, while students may gain a better appreciation of an object in 3D, technical drawings produced from CAD are 'automated', in that users don't really need to think about the orientation or placement of views as the CAD package achieves this for them. Equally, many CAD packages allow users to import dimensions straight from their 3D model to the 2D drawing. However, there is still some thought and skill required to complete a CAD drawing. One can argue that drawing in CAD does not produce the same level of 'cognitive modelling' that hand drawing achieves. It's also important to develop and improve core 3D visualization skills, which have been identified as fundamental to engineering education since the beginning of the 21st century [4]. Once students achieve sufficient skills in 'spatial visualization', they need to work on their 'mental rotation' and mental transformation' skills which are essential for technical drawing and putting ideas onto paper. As such students were given fun & engaging tests such as PSVT: R (Purdue Spatial Visualisation Test-Rotation) to develop their 3D manipulation/mental rotation skills. Encouraging students to draw a verbally described object allowed students to imagine the object in their heads (rather than copying a 2D or 3D form) which in combination with seeing visual objects & the act of drawings allows all visual imagery to be complete [5].

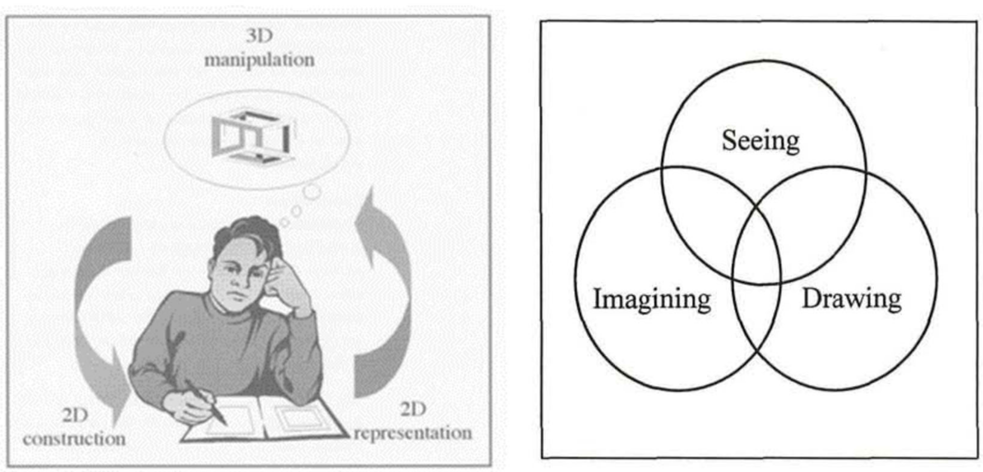

Figure 3. Cognitive modelling of 2D to 3D & back to 2D [3] & McKim's model of visual thinking [5]

One observation that can be found with CAD drawings is the same fundamental mistakes with hand drawing can be made on a CAD drawing, for example, not aligning principal views or using the incorrect project methods (although students arrive at these mistakes much quicker), especially if students are not familiar with the more advanced drawing tools provided with the software. When students gain more competency in CAD, producing engineering drawings from CAD parts and assemblies can seem like an afterthought, an extra set of tasks on top of all the work put into modelling. When one considers a complicated assembly with many subsequent sub-assy and part drawings, it can represent a significant amount of time and work. The advent of AI-generated drawing tools seeks to reduce this semi-automated process. AI is not relatively new in the field of CAD, for example, Autodesk has been using AI tools for generative design, as well as automated markup and similar tools for AutoCAD. There has also been the recent development of AI tools and assistants for technical drawing, such as information retrieval and searches of large databases [6] or in some cases information extraction using machine-based learning approaches [7]. So far, the interpretation of technical drawing could be performed by a machine, but as of Feb 2024, Autodesk announced drawing automation in Fusion 360. Designers can now create assembly and part drawings at the push of a button, and with the placement of 'seed' dimensions, will then populate a drawing with associated dimensions. The designer still can select if dimensions are base dimensions as well as the origin, but fundamentally the AI tool places the views and attaches dimensions itself. While this process is relatively new in the field of mechanical engineering and manufacturing drawings, such tools have been used within Building Information Management (BIM) within the Civil

Engineering and construction sector, such as BricsCAD. The link between architectural drawing and reasoning, with early graphical output produced by AI techniques, can be traced as far back as 1996 [8]. The advent of cloud based computing and industrial demand for faster products to market has accelerated the need for AI tools and assistants with CAD and CAE.

6 RESULTS AND CONCLUSIONS

A more pragmatic approach is required to assess the drawing ability of students. When implementing the techniques described in this paper within a first-year engineering curriculum, a PASS rate of 81% was achieved, and a minority of students failed the assessment despite all solutions being provided in class. A more rigorous approach was adopted the following year, with solutions for preparatory exercises provided but not for those that were assessed. A PASS rate of 75% was achieved, with some concerning observations. Many students did not provide dimensions on drawings despite being explicitly instructed to do so. There were also fundamental misunderstandings of orthographic projection that prevented students gaining a PASS mark. If the ability of technical communication was assessed on CAD alone, students may have passed the module without dealing with these fundamental errors. Feedback from students indicated that some found the drawing elements of the module enjoyable, while others struggled, stating they required more 'examples. There needs to be a focus on helping students understand these core principles from the outset, before they perform more complicated activities (for example, CAD drawings or advanced techniques). In conclusion, the revised approach to technical drawing has provided a unique insight into the way students understand technical drawing. Perhaps other approaches are too complicated, and students may fumble through a Design and Manufacturing module by doing well on other elements. It may be argued that some students 'go through the motions' without really understanding the fundamentals. Nonetheless, educators may find benefit in the findings of this paper by taking a step back and questioning what is important. Such exercises and approaches could be used for introductory or foundational drawing classes to help students understand the core principles of technical drawing. Such an approach is analogous to aspects of mechanics and thermos-fluids. Students are expected to understand the fundamental and core principles, beginning with analytical hand-calcs and free-body diagrams, but one would not argue that using computational methods such as FEA or CFD is 'cheating'. We are at such a paradigm with AI-drawing tools, which present challenges within engineering and design education within this area. Perhaps it is ample time to go back to basics.

REFERENCES

[1] Simmons C. and Maguire D. Manual of Engineering Drawing: Technical Product Specification and Documentation to British and International Standards. *Elsevier Science & Technology*, 2012.

[2] Bielefeld B. Basics: Fundamentals of Presentation, Technical Drawing. *Walter de Gruyter GmbH, Basel/Berlin/Boston*, 2013.

[3] McCardle J. R. Back to the Drawing Board? *The Journal of Design and Technology Education* 2002 (John Wiley & Sons, Chichester).

[4] Sorby S. A Developing 3-D Spatial Visualisation *Skills Engineering Design Graphics Journal* 1999.

[5] McKim R. H. *Experiences in visual thinking.* Boston, MA: PWS Publishers. 1980.

[6] Van Daele D., Decleyre N., Dubois H. and Meert W. An Automated Engineering Assistant: Learning Parsers for Technical Drawings. Proceedings of the AAAI Conference on Artificial Intelligence, 35(17), 15195-15203. https://doi.org/10.1609/aaai.v35i17.17783 2021.

[7] Haar C., Kim H. and Koberg L. AI-Based Engineering and Production Drawing Information Extraction. In: Kim K. Y., Monplaisir L. and Rickli J. (eds) Flexible Automation and Intelligent Manufacturing: The Human-Data-Technology Nexus. FAIM 2022. Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-031-18326-3_36 2023.

[8] Yi-Luen Do E. and Gross M. D. Workshop on Visual Representation, Reasoning and Interaction in Design, *Artificial Intelligence in Design 96,* 1996 Stanford University.