Addressing inequities in engineering sketching skills

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Abstract: All engineers need to be able to create, read, and sign-off on technical drawings prior to production of designs. From listening to the debate and disappointment amongst colleagues teaching in engineering courses, it seems that it is often assumed that students who enrol in an engineering undergraduate degree program have good technical sketching skills and can move quickly on to computer aided drawing packages. It may also be assumed that they are familiar with CAD packages. This paper presents preliminary research that investigates the familiarity with, and skills in, technical sketching by first and second year students enrolled in engineering at the University of Technology Sydney (UTS). The authors discuss why inadequacies in technical sketching skills can arise in some students as a result of subject progression at school and lack of time spent developing confidence in technical drawing at university. We describe a mini-course in technical sketching that is being trialled through the Engineering Communication subject at UTS.

Keywords: technical sketching, visual communication, engineering communication skills

Introduction

All engineers need to be able to create, read, and sign-off on technical drawings prior to production of designs. It is also well documented that engineers need visual/graphic skills to be able to communicate their ideas (Tufte 1997 and Field 2003) to non-engineers like clients, workshop staff and other professionals as well as to other engineers.

Kardos (1997 p. 1) states that “Engineering drawing ... is the language of the engineer. It is their means of developing and recording their ideas, and conveying them to others. Every engineer will be using and referring to some form of drawings almost daily.” Glegg (as cited in Kardos 1997 p. 1) says “words are not the natural language of engineers. Drawings are their prose, mathematics their grammar and differential equations their poetry.” Figure 1 shows the cover of “Communicating Technology” (Morgan
1983). In this one cartoon she acknowledges the absolute necessity for technologists to be able to communicate visually as well as verbally.

Graham (2004 p. 2), in an article summarising many contributions to one particular newsgroup, points out “while the capability to sketch effectively is not needed by everyone in your organization, it’s essential to have someone. This is a tool, just like CAD – and you would think it is essential to have CAD expertise somewhere.” He discusses the need for dimensions on designs and that while some engineers can draw easily and quickly in CAD, others “generally sketch on the [whiteboard, chalkboard, pad, envelope, napkin – pick one] before even turning the computer on. But ... software encourages attention to detail and working by hand encourages awareness of the big picture.” Petroski (1997) also refers to the engineer’s first sketch as often being on the back of an envelope and regularly forms the basis for final drawings.

A quick tour of engineering labs and offices will soon provide evidence of such technical sketching being used throughout the design process and in any available space (Figure 2).

The particular skill we are concentrating on in this paper is hand sketching or what we have called “technical sketching”.

**What types of technical sketching are used in engineering?**

Graham (2004 p. 3) outlines three major types of hand sketches used by engineers. They are:

- **thinking sketches** – that clarify ideas
- **prescribing sketches** – that add scale, ensure repeatability, eliminate discretion of workshop staff
- **talking sketches** – that guide discussion of ideas, e.g. improvements and ambiguities.

This freehand sketching skill is needed in all engineering fields of practice and at all stages of the design process.

**Throughout the design process** engineers need to use technical drawings to better clarify their ideas to themselves and communicate their ideas to others with whom and for whom they are designing. Sketches and other graphics are generated by hand and/or computer software at various stages through the engineering design process. Students should learn that these graphics are an integral part of designing and should be developed and embedded throughout the process and not seen as an annoying add-on, something to be created in a perfect form just before handing in a project. In fact, many design texts reinforce this latter view that communication and documentation only occurs at the end, for example “Communicating the design to others is the final, vital step in the design process” (italics
added, Shigley and Mischke 1989 p. 8) and “Subsequent to many iterations, the process ends with the vital step of communicating designs to others.” (italics added, Ugural 2004 p. 7)

Figure 3 contrasts two models of communication and documentation during the design process. In the first flow chart, typical of those found in many introductory engineering design texts (Shigley and Mischke 1989, Ugural 2004, Eide et al. 1998, Burghardt 1999), all documentation is shown as occurring at the end of the process. The second, proposed by the authors, shows that documentation and communication is, or should be, more integrated throughout the process.

Figure 3 Where does communication and documentation fit in the design process?

| a) the ‘common’ model | b) the integrated model |

In supporting the development of freehand sketching skills throughout the design process Lueptow (2000) states that “sketches often act as stepping stones to refine and detail the original concept or generate new ideas. Many great design ideas are first sketched on the back of an envelope or in a lab notebook.”

While all engineers and engineering academics agree that these skills are important and are not present, this is not accepted by our undergraduate students who cannot see the need or relevance of such skill. Therefore, it was necessary for us to make explicit for each field of practice where these skills were required. To do this we developed the list in Figure 4.

**Advantages of having good technical sketching skills**

Graham (2004 p. 2) summarises three advantages for engineering students of good technical sketching skills:

- drawing by hand can reinforce fundamental skills like the selection of appropriate coordinate systems, understanding of spatial and mass relationships and prediction of inferences,
- hand drawings are cross-cultural, cross-gender and understood by others regardless of educational background,
hand drawings are easily passed around for comment or annotation or to elicit further ideas.

In a study by Alias et al. (2002) it was also found that spatial visualisation was significantly improved in engineering students who were given sketching activities as well as their standard class work.

Because graphic communication often needs to occur during meetings of engineers with a variety of other people when there are limited tools and materials at hand, the ‘technical sketching’ skill that allows this to happen is an important one for our students to develop.

Technical sketching skills of our students

From the results of some of the work in the hand-graphics activities in the Introduction to Mechanical and Mechatronics Engineering subject at the University of Technology Sydney (UTS) it has been found that some students have particularly poor skills in this area. During our Australasian Association for Engineering Education conference in Melbourne 2003 we heard despair from colleagues about lack of ability in these basic skills. Discussions with colleagues within UTS and from other universities and comments from papers and presentations at various engineering conferences also support our hypothesis that many engineering students come with poor hand-graphic skills. Good skills are expected of them throughout the course and little opportunity and guidance is provided for improving these basic skills.

Given that technical sketching is so important to engineers we felt that the apparent lack of confidence and skills observed in our students needed investigation.

Investigating issues that affect technical sketching skills

Time allowed for development of skills and confidence

In Mechanical Engineering the process of producing accurate 2D detail drawings begins with a rough sketch. A CAD solid model is then produced from which the 2D detail drawings can be generated automatically. In Civil Engineering the process may also begin with a sketch.
either on site or in the office and then detail drawings are produced using AutoCAD, for example. Instead of spending hours, days, weeks, months producing detail drawings with perfect line work using T-squares, set squares, compasses ..., engineers now produce these drawing quickly using a variety of CAD packages.

As a result, university courses in engineering drawing often quickly gloss over hand-sketching and drawing skills and move onto computer-aided drawing skills. Because the requirement for engineers to be able to produce accurate 2D detail drawings by hand is no longer as necessary as it was in the past, we no longer need to devote an entire subject to technical drawing by hand as we once did.

Thus students are not given the extended experience or practice of drawing by hand that equips them with skills and confidence to produce the less formal types of hand sketching and drawing required later in their courses and careers.

Given that we do not spend as much time on technical drawing as in the past can we assume that the students have mastered technical sketching skills prior to entering university?

**Assumptions of prior knowledge**

To answer this question it is important to understand the path of subjects students may have taken to enter university engineering programs.

In NSW, secondary students in Years 7/8 do **Visual Art** in which there is much experimentation with materials and styles of art. It is not like the drawing classes of a century ago. They may touch on perspective, they may be taught various techniques of wrist, elbow and shoulder movement, they may even be given opportunities to draw from still life. However, these experiences will be short and without the rigour required for ‘technical drawing’.

All students in Years 7/8 complete the **Mandatory Design and Technology** subject in which they may encounter some technical drawing experiences. However, this will depend entirely on the design projects they are required to complete and the competency of their teachers in technical drawing. Some design areas of food, textiles and computer-based projects provide little opportunity for engineering-style technical drawing skills.

All students in Years 7-10 must do **Maths** in which some geometry is studied and diagrams are generated. In compulsory **Science**, diagrams to accompany project work or ‘experiments’ are required. However, in both these subjects, although diagrams are required, the results are either good or poor and little instruction is given about the ‘how to’ of technical drawing. This experience then carries through to the Maths and Sciences in Years 11/12.

These experiences and opportunities for development of technical drawing skills is all we can assume from our students when they enter engineering courses at university. In NSW, universities no longer have ‘prerequisite subjects’ but ‘assumed knowledge’ and these are Maths, Physics and English at HSC level.

However, some of our students will come to us with much more than the vague and basic skills developed through the compulsory subjects discussed above.
Elective subjects in Years 9-12 allow students, who so choose, to study Technical Drawing through specific subjects. These subjects include Technical Drawing (Technology – Graphics) (9/10), Technology – Industrial (wood and metal options) (9/10), Technology & Design (9/10), Design & Technology, Industrial Technology, and Engineering Studies. These students should be quite advanced in their hand technical drawing skills and also familiar to a beginners level with at least one CAD software package.

**Analysing technical sketching skills**

To test our assumptions about prior knowledge and skills of technical sketching we presented students in our 2nd Year Engineering Communication class with a relatively simple technical drawing exercise (Figure 5 Part 1.), and a more complex drawing exercise (Figure 5 Part 2). Results of the sketching exercise were submitted in hard copy to the authors for assessment and formative comment.

We also presented students in our 1st Year Introduction to Mechanical and Mechatronics Engineering subject with an online non-assessable questionnaire about their prior experiences in technical drawing. The pre-test was run via our UTSONline web-based learning platform. The UTSONline software tracks who has accessed the material and their results.

In both the pre-test and the questionnaire the initial return was quite small. Nevertheless, the results (see below) give credibility to our assumptions of prior learning.

**Results of Pre-Test**

The pre-test shows that most of the students tested required some development of their technical sketching skills. They are from 30 students from the entire range of engineering majors. A range of these submissions is included in Figure 6. It is interesting to note that many students did not know what an ‘orthographic drawing’ was. There was even one English-speaking student who did not know the term ‘freehand sketch’.

Some excellent drawings were submitted for this task demonstrating excellent to adequate technical sketching skills. Some examples are included in Figure 6a.

Other submissions demonstrated a lack of 3D thinking, use of boxing and guidelines and even line drawing skills. Some of these sketches needed to be enhanced so that they could be scanned adequately for this paper. Some examples are included in Figure 6b.
It is also worth noting that it was very difficult to get submissions from students who thought they ‘could not draw’ and most of the drawings received from these people were only received under pressure. For a more comprehensive range of evidence of the skills of our students it would be necessary to make the pre-test both compulsory and assessable. This is to be trialled in Spring semester 2004.

Figure 6a. Results of the pre-test – some better examples.

Figure 6b. Results of the pre-test – some poorer examples from students who may need support to develop their technical sketching skills and spatial relationship skills.
**Results of questionnaire**

It is important to note that this was also a non-compulsory and non-assessable task. The number of students who attempted the questionnaire was 67 (out of 120), an excellent return. There were no unanswered questions from these students.

From the results shown in Figure 7 it is obvious that our assumption of prior knowledge and skills in technical sketching and even hand drawing is correct. More than half of the respondents feel that they have had a very small amount of training in technical sketching.

It would be easy to assume that school students are moving on too quickly to CAD programs at the cost of sufficient technical sketching skill development, but from the results of questions 2 and 3 this does not seem to be the case.

This deficiency in technical sketching skills needs to be addressed early in the university courses of engineering undergraduates.

**Addressing inequities of technical sketching skills – the mini-course**

At UTS students in their first year do many subjects in common but also encounter the first of the specialist subjects in their particular major. Students in Computer Systems, Mechanical, Mechanical & Mechatronics, and Electrical Engineering must complete a subject called Introduction to Mechanical and Mechatronics Engineering. Students in other majors can also choose this subject as an elective in their course. In this subject only one week (6 hours) is spent on instruction in hand graphics before moving on quickly to computer-generated graphics through a CAD software package. However, students are required to submit several hand sketched assessable items, mostly integrated into a design project. Civil Engineering students and Telecommunications Engineering students are not given this opportunity to develop their technical sketching skills.

At UTS, all students (usually in their second year) complete a subject called Engineering Communication that focuses on their communication skills in an engineering setting (Jacobs & Griffiths 2004).
In the earlier design of our Engineering Communication core subject a decision was made by the development team that ‘Engineering Communication should concentrate on developing generic visual communication capabilities’ and that it was ‘inappropriate ... to teach sketching and drawing skills’ that were specific to any one field of practice (McGregor, Mack & Jarman 2002 p. 249). In other words, students should learn about visual literacy rather than how to do specific technical sketching tasks.

While the authors appreciate this decision, we have found that minimum levels of graphic communication skills are assumed and students do not necessarily have these skills. However, the development of this skill in our students suffers from the ‘Whose job is it? – everybody, somebody, anybody, nobody’ syndrome and thus ‘falls through the cracks’.

This year the authors have begun to address this technical sketching issue and skills of visual communication, not only through visuals in presentations and reports but also by offering an opportunity for students to improve their hand technical sketching skills. This is achieved via a mini-course run in parallel with other activities in Engineering Communication for students who do poorly on the graphics pre-test discussed earlier. Currently it is a completely voluntary program but from Spring 2004 students with poor skills will be able to gain bonus marks for the subject by submitting their Portfolio of Technical Sketching that is the outcome of this mini-course. At the time of writing this paper, these students were progressing through the exercises with some success. For this mini-course, students work at their own pace through a series of 12 basic sketching exercises that develop skills in drawing straight lines and boxes, curves and circles, lettering, boxing and guidelines, thumbnails, dimensioning then progresses to exercises in orthographic projections and perspective views. Figure 8 includes some pages from the mini-course booklet developed.

The pre-test and mini-course have been developed by the authors, in conjunction with an undergraduate mechanical engineer working in an engineering drafting office. This student has worked on this project as part of an elective subject run through the Faculty of Engineering called Professional Service Project. This subject gives students the opportunity to
find a ‘community’ project that requires their engineering expertise and has a communication outcome (Jacobs et al. 1999).

**Where to from here?**

As this semester progresses results of the pre-test and mini-course will allow us to modify our strategies for developing competent technical sketching skills in our students who need help.

It is obvious that universities must come to terms with the discrepancies between assumed and actual prior knowledge of our students. It is not appropriate to assume that the skills of the best students are the skills of the whole cohort, or that those without the skills have been lazy or stupid in their schooling. We must realise that many students who enter engineering courses have not had the opportunity to acquire the skills we assume they have.

Perhaps we need to be more explicit in describing to our First Year students the skills that we assume they have, the benchmark from which we will begin their education as engineers, and provide them with pathways to develop these skills if they do not have them. This issue has been addressed in many engineering maths and physics courses with the provision of bridging courses and slower-paced foundation courses for those in need. Our solution this year for technical sketching has been to provide a mini-course. This is just a beginning. Is there opportunity to recommend a course from another faculty or TAFE that can be used as an elective subject for our students? Should the Engineering Communication subject extend its already full curriculum to include technical sketching as well as visual and textual literacy? Is there a need for a ‘standards document’ outlining standards for ‘technical sketching’?

The authors look forward to opening and continuing the debate about these issues and to finding solutions to the problem of technical sketching for our students.

**References**


Acknowledgements

The authors wish to thank staff at UTS, especially Rob Jarman, Alan Brady, Kumbesan Sandrasegaran and Michel de la Villefromoy for giving their time to explain the importance of technical sketching in their particular fields of practice. We would also like to thank the students who were willing to demonstrate their technical sketching skills, especially those who knew their skills were not adequate. Special thanks must go to James Samuel who developed the mini-course we are now using with our students.