Innovative approaches to teaching engineering drawing at tertiary institutions

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ABSTRACT This paper arises from our concern for the level of teaching of engineering drawing at tertiary institutions in Australia. Little attention is paid to teaching hand drawing and tolerancing. Teaching of engineering drawing is usually limited to Computer-Aided Design (CAD) using AutoCAD or one of the solid modelling packages. As a result, many engineering graduates have difficulties in understanding how views are produced in different projection angles, are unable to produce engineering drawings of professional quality or read engineering drawings and unable to select fits and limits or surface roughness. In the Faculty of Built Environment and Engineering (BEE) at QUT new approaches to teaching engineering drawing have been introduced. In this paper results of these innovative approaches are examined through surveys and other research methods.

Keywords: engineering graphics, solid modelling, teaching at universities

1. Introduction

Engineering drawing is an essential part of Engineering Design and crucial in the graphical communication skills of engineering graduates. Ability to produce, read and correctly interpret engineering documentation (including drawings) is critical for the successful work of professional engineers. Authors of this paper have come across cases when, due to a lack of knowledge on engineering drawing, engineers have misinterpreted information about a piece of equipment, and developed a Finite Element Model (FEM) that has misrepresented a real machine. The consequence was a highly embarrassing situation for the company because conclusions drawn from the modelling failed to explain causes of machinery failure.

Despite the importance of teaching engineering drawing, there is a variety of approaches at different educational institutions in different countries. For example, in Republics of former USSR, India and Sri Lanka, hand drawing is taught to engineering students for three to four semesters accompanied by Computer-Aided Design (CAD) and a theoretical unit on Descriptive Geometry. In addition, a stand-alone unit is taught on tolerancing and metrology, which includes a term project. This approach ensures that engineering graduates acquire strong knowledge, hands-on experience and ability to produce engineering drawings of professional quality.

In Australia, engineering drawing is taught at schools (more as general drawing than engineering drawing), at Institutes of TAFE (both hand drawing and CAD) and at universities. Most universities teach CAD as a stand-alone unit. Usually AutoCAD or solid modelling software is used (e.g. SolidWorks, SolidEdge, and Pro-engineer). It is more the exception than the rule that hand drawing is taught at tertiary level. Only a few universities teach tolerancing. It is quite common when young engineers do not understand the concept and struggle to select fits and limits. A common approach is to copy fits from other drawings with identical parts and joints. A typical excuse is that the curriculum is already overloaded with other important units and there is no room in it for teaching hand drawing. The Bologna process [1] adds additional pressure, because an undergraduate engineering degree has to be squeezed into three years. How Australia is going to align with the Bologna process remains an open question – the Government just takes the first steps [2]. Engineers Australia has agreements with some countries regarding mutual recognition of engineering degrees, such as the Washington Accord as well as bilateral agreements.

Extensive literature reviews have shown that very few research publications are devoted to teaching engineering drawing at educational institutions. Raine [3] discussed the importance of teaching engineering students the use of parametric design software packages, such as Pro-engineer and SolidWorks. Radcliffe [4] highlights the problem that engineering design has traditionally been taught at universities by a small number of individuals in each Department, in some cases complemented by part-time industry practitioners. Design lecturers have always had a difficult time competing in a university environment that has traditionally rewarded research (narrowly defined). The practical experience of lecturers has lost its favour as “new” universities promote research culture.

The national Review of Engineering Education [5] outlined attributes for future engineering graduates. Most of these attributes can be developed through studying engineering design, and this puts additional pressure on design lecturers in the sense of developing teaching approaches and methodologies.

In 1998 the Boeing Corporation conducted summer fellowship of a group of academics. Results of this fellowship are discussed in [6] in the form of recommendations. One of the recommendations was the use of advanced CAD programs. Another recommendation was the use in teaching of design projects with open-ended problems that encourage communication between team members. McKenna & Agogino [7] describe an instructional module for teaching integrative design using six simple machine elements. The work with an on-line module is combined with hands-on activities using a LEGO™ set.

Impelluso & Metoyer-Guidry [8] admit that often, the undergraduate engineering curricular focuses on theory and lacks practical focus. The authors promote the shift towards "learn-by-doing". They suggest using Pro-engineer for developing solid models and then dVMockup package to inspect computer designed sets in the 3D virtual environment. Barr et al [9] discuss an approach to teaching engineering graphics through a reverse-engineering project in small groups of four students. Students disassemble an object, make hand-sketches and use them to develop 3D solid models, which are used for rapid prototyping. Hands-on activities and team work have proved to be effective.

Martin et al [10] admit that currently there is a tendency towards the progressive reduction of teaching hours dedicated to engineering design graphics. This adversely affects students' ability to develop their spatial skills. Many students arrive at university without prior study of engineering graphics, which makes it difficult to tailor university training. The authors suggest that combining hand-sketching with CAD training helps to develop spatial abilities.

Linn & Petersen [11] gave definitions of spatial abilities in three categories: *spatial perception*, *spatial visualisation*, and *mental rotation*. Spatial ability of students can be tested by means of asking students to identify views (front, side, top, etc.) from a given axonometric view. Condor [12], believes that traditional methods of teaching engineering graphics using paper-based 2D drafting are obsolete and the solution is in the use of 3D parametric solid modelling software in teaching. Dias et al [13] discuss the use of a Visualisation Toolkit (VTK) for teaching a "3D modelling and Visualisation" elective course to Computer Engineering students using medical in nature projects. The authors indicate that the significant limitation of VTK is that its use requires advanced programming skills. The learning curve of students varied from slow to a very good progress wherein students developed spectacular examples of computer graphics.

The following concluding remarks can be made:

- There are polarised views on approaches to teaching engineering graphics.
- Many solid modelling packages enable students to produce part drawings with projections and dimensions at the click of a button. If students have poor spatial skills and do not understand how projections are produced, they will struggle to read these part drawings and will be unable to edit them, a skill frequently required in industry.
- Multi-stage training in engineering drawing requires starting from introductory training, which can be skipped by students having intermediate or advanced engineering drawing skills. Special exercises are necessary to develop spatial skills.

2. Approaches to teaching engineering drawing at QUT.

The School of Engineering Systems (SES) of the BEE Faculty at QUT discontinued teaching of AutoCAD approximately five years ago in favour of solid modelling. Within the current curriculum, the following arrangements are made for teaching engineering drawing:

- In the introductory unit BEB100 one lecture is devoted to engineering drawing, which includes an exercise. In year two, students start taking engineering units (including engineering design) with engineering drawing skills varying from zero (common for school graduates) to an advanced level for students coming from Institutes of Technical and Further Education (TAFE). Engineering drawing skills of international students vary widely as well.
- In the first engineering design unit, ENB215 Fundamentals of Mechanical Design, taught in Year Two, students study hand drawing one hour per week. During lectures and tutorials they study design procedures, tolerancing, surface roughness, and other topics. During drawing classes, students carry out drawing exercises and study drawing standards. At the beginning

of the semester students are given an assembly drawing (one assembly drawing for three to five students with an individual part specified for each student). By the end of the semester, each student has to prepare a part drawing and submit it for marking. This encourages students given the same assembly drawing to communicate with each other when they identify dimensions and select fits for joints. Students in teams of five, participate in the Design and Build Competition, which is a part of ENB215 unit, where they have to attach to the project report an assembly drawing of the device they design and build.

- The following challenges have been identified over the years of teaching this unit:
  - Many students have difficulties understanding how different views are produced in different projection angles and seeing an object in 3D space (spatial skills).
  - Due to varying initial drawing skills it is very difficult to tailor exercises because students progress with a different rate.
- To address these challenges the following approaches have been developed:
  - Students in small groups carry out a practical exercise on identifying surface roughness. Each group is given one component produced by turning and another produced by milling (see Figure 1). Using roughness samples, students have to identify roughness for each surface and mark it on a hand-sketch. Then students recommend machining methods for each surface to achieve particular roughness. This exercise helps students to get a feeling of real surfaces roughness and relate them to particular manufacturing methods.
  - A Perspex cube is used (see Figure 2). A plastic part is installed on a pedestal. The tutor leads a discussion with students, who look through different faces of the Perspex cube, to identify the main (front) view of the part. Then, several sheets of transparent films, connected by sticky tape, are put on different faces of the cube. Students look through the face and sketch what they see on the film with a whiteboard marker. When transparent sheets are unfolded, students can see how three views are produced. Some plastic components have removable parts to illustrate how sections are produced (can be seen in Figure 2 in light-gray colour).

- About twenty hand drawing exercises with increasing complexity have been developed using [14, 15], such as producing an isometric view from given three views in different projection angles and the other way around; restoring missing view; working with assembly drawings. These exercises conducted in-class are checked by a tutor (but not marked). The part drawing assignment given to students in the beginning of the semester is marked by a tutor, but this mark is counted towards the final mark for the unit only if all in-class exercises are "ticked".
- In the second engineering design unit, ENB316 Design of Machine Elements, taught in Year Three, solid modelling classes are conducted two hours per week with SolidWorks software. Students study solid modelling and at the same time work on a gearbox project. By the end of the semester they have to develop individually a solid model of the gearbox they designed. This helps students to put to a practical use solid modelling skills they have attained. The solid model and the project report are marked separately by tutors. In teaching solid modelling in-house developed introductory manual to SolidWorks available to students from a unit-specific BlackBoard site [16] and a comprehensive SolidWorks manual available on-line are used. An example of the gearbox solid model developed by a student shown in Figure 3 illustrates that many students studying this unit attain advanced solid modelling skills.

These teaching approaches combine the advantages of using hand drawing exercises, exercises on the development of spatial skills and computer-aided solid modelling. After years of practicing these teaching approaches it was thought an evaluation of the practices and an analysis of students' feedback would be beneficial. Results of this evaluation are described in the following chapters.

3. Research methodology

In teaching and social research a number of research approaches can be used, for example, experiment, survey, archival analysis, history and case study. For this research the authors have decided to focus on experiment, survey and case study as research approaches. The experiment in validating new approaches to teaching engineering graphics is a part of a larger experiment on validating new approaches to teaching engineering design. The description of this experiment is outside the scope of this paper. In conducting educational experiments researchers pursue answers to “How?” and “Why?” types of questions [17], for example, “How to teach engineering graphics?” As a research approach experiment enables control over behavioural events and is focussed on contemporary issues. Details of the experiment on teaching engineering graphics at BEE Faculty have been described in previous sections. The survey pursues answers to questions, such as “Who, what, where, how many, how much?” For example, “What do students think about approaches to teaching engineering graphics?” Both case study and survey focus on contemporary issues but do not allow control over behavioural events. Essential components of any case study are [17]:

- Study questions (usually “How?” and “Why?” type).
- Study proposition (what is the subject of exploration?).
- Units of analysis (students enrolled in particular units.
- Linking data to propositions (e.g. empirically established and predicted patterns matching).
- Criteria for validating and interpreting a study’s findings (e.g. surveys, statistical methods, interviews and document analysis such as assignments).

An important question that researchers face is whether to make the case study anonymous or not. The authors have decided to make entire case study anonymous as well as the supporting surveys and interviews.

3.1 Surveys using questionnaires

Rationale

To obtain students' feedback on teaching engineering drawing at the BEE Faculty, two sets of questions were developed: one for students completing ENB215 unit and another for students that completed two engineering design units (ENB215, ENB316). The questions were prepared by the authors and went through several cycles of refinement, involving the course coordinator for engineering degrees Dr. R. M. Iyer and the BEE Faculty teaching developer Ms. M. Boman. Both sets of questions were exempted from approval by the QUT Committee for Ethics. Limited size of the paper does not allow presenting the questionnaire and statistical analysis in full. Main finding are discussed below.

3.1.1 Statistical analysis of results of questionnaire for ENB215 unit

Out of 60 students that were given the questionnaire, 98.3% agree (A) or strongly agree (SA) that "Engineering drawing is a very important component of engineering design". 17.24% initially did not think it is important, but after taking this unit changed their mind. 40% did not do a systematic study of engineering drawing before taking ENB215 unit. 56.67% self-assessed their drawing skills from "Nil" to "Basic" before taking ENB215 unit, and 43.33% as "Good" and "Advanced". 79.31% believe that 1h per week of hand-drawing classes is sufficient to develop hand-drawing skills, 15.52% not sure (NS) and 5.17% disagree (Dis). 69.66% A & SA that working with Perspex cube helped them to improve their ability to see objects in 3D space. Students that NS or Dis already had good hand-drawing skills before taking ENB215 unit. 96.61% A & SA that teaching of engineering drawing as part of the 1st engineering design unit is a good idea. In the meantime, 56.66% are prepared to take a stand-alone unit on engineering drawing. 59.65% A & SA agree that "Working on the part drawing exercise from assembly drawing as a team member, helped them to develop interpersonal and team-work skills". 84.48% A & SA that "Studying engineering drawing helped them to learn engineering design". 82.76% A & SA that "Participation in the Design and Build competition helped them to develop and put into practical application written and graphical presentation skills gained during studying

ENB215 unit”. Finally, 84.21% A & SA that after taking the ENB215 unit they are capable of producing quality drawing.

Answering the question “What did you like most about ENB215 unit?” students overwhelmingly supported the practicality and hands-on approach, the opportunity to study hand-drawing and apply it in the design and build project. Many students insisted that hand-drawing has to be mandatory for all engineering students. Answering the question “How would you think we can improve the teaching and learning of engineering drawing in ENB215?” students suggested the following: Pay attention to hand sketching during drawing classes. Bring forward the solid modelling classes in ENB215 and combine them with hand-drawing. Increase the contact hours for hand drawing to 2h per week. Introduce more rigorous assessment of hand-drawing classes.

Responding to students’ suggestions in 2010 optional solid modelling classes 1 hour per week were introduced and also workshop staff with strong practical experience was engaged as part-time tutors to teach hand-drawing. Another survey has been conducted with two new questions. In general, it confirmed the findings of the previous survey and also showed that 87.5% students A & SA that “Engaging workshop staff in teaching hand-drawing was very beneficial for learning” and 86.36% agree and strongly agree that “Introducing optional solid modelling classes in ENB215 unit parallel with compulsory hand-drawing classes is a very good idea”. In comments students also suggested to pay more attention during hand-drawing classes to drawing technique and to working with drawing and design standards.

3.1.2 Statistical analysis of results of questionnaire for ENB316

Out of 42 students that were given the questionnaire, 86.5% completed ENB215 unit before taking ENB316, the rest came from other universities. 52.38% self-assessed their drawing skills as “Good or advanced” before taking ENB316 unit. 91.89% A & SA that “Studying solid modelling in ENB316 and hand drawing in ENB215 helped them to learn engineering design”.

91.89% A & SA that “Teaching hand drawing as part of ENB215 and solid modelling as part of ENB316 and directly linking them to design projects helped them in better understanding the practical application of engineering drawing”. 65% self-assessed their solid modelling skills after taking ENB316 unit as “Good” or “Advanced”. 31% indicated that engineering drawing skills gained during studying engineering design units helped them to get employment and/or work experience. 95.34% indicated that would be interested in further study of advanced engineering design and solid modelling.

In comments students demonstrated that they appreciate the practicality of the unit and relevance to the real world. One typical comment was “have been the most interesting units in the course so far. Also gave me ability to apply practically skills learned in other units”.

In suggestions for improvement students proposed to have more solid modelling and drawing classes and more assignments. Also they suggested bringing forward introductory solid modelling classes in ENB215 unit complementing hand-drawing classes.

3.2 Interview as a validation tool

After completion of the first engineering design unit ENB215, a reward ceremony for the winners of the design and build competition is organised. School management as well as lecturers and tutors involved in the teaching of engineering design units are invited. After the ceremony a discussion takes place in a relaxed manner where students were encouraged to speak about what they liked in teaching of the ENB215 unit and what they think can be improved. It is not surprising that students made similar points to those discussed in the analysis of the questionnaire and open-ended questions. This confirms the validity of the results obtained from the survey and questionnaire. A separate set of interviews has been conducted with the workshop staff that also confirmed that quality of drawings submitted by students to the workshop notably improved.

4. Discussion and conclusions

It is apparent that the academic community faces significant challenges with teaching engineering design in general, and engineering drawing in particular. Following are the challenges faced:

- Students are coming to study engineering degrees with drawing skills varying from zero to advanced, which makes it difficult to tailor training.
- The Bologna process with 3 + 2 scheme adds additional pressure because the undergraduate engineering degree has to be squeezed into three years instead of four.
- Less room in the curriculum results in a situation that it is more the exception than the rule when engineering graphics, tolerancing and metrology are systematically taught at universities. Engineering graduates often have poor spatial skills, are unable to produce engineering documentation of professional quality, are unable to select fits and limits, surface roughness, and are unable to read and correctly interpret engineering drawings.
- The availability of modern solid modelling software packages that enable the development of part drawings from a solid model at the click of a button creates a deceptive feeling that producing a part drawing is a "piece of cake". In the mean-time, often students are unable to edit software-produced part drawings.
- The general tendency in tertiary education to reduce the amount of assignments comes into conflict with achieving learning objectives, because if certain items are not tested, students have fewer incentives to attend classes and study hard.
- There is a shortage of qualified staff capable of teaching engineering design in general and engineering graphics in particular. Industry practitioners do not have academic backgrounds and struggle in university context because "new" universities favour "research culture" (narrowly defined). "Traditional" staff may have strong track records in research, but lack practical experience, which is essential for teaching engineering design.

Different universities tackle these challenges in a different way, depending on resources and expertise available. Polarised views range from looking at hand drawing as “old-fashioned and obsolete” [12] to a strong focus on hand drawing at Institutes of TAFE and some universities like QUT. The situation is aggravated by the tendency towards the progressive reduction of teaching hours dedicated to engineering graphics. One thing is evident that a shift towards Computer-Aided Design and Drafting only results in a number of shortcomings discussed above. Tertiary educators are united in one resolution - extensive use of design projects in teaching, especially projects with open-ended problems and hands-on approach to studying engineering design.

Research findings presented in this paper showed that:

- Combined teaching of hand-drawing and solid modelling provides better conditions for development of spatial skills and studying of drawing standards.
- Linking teaching of engineering drawing and Computer-Aided Design to design projects facilitates the learning of practical aspects of engineering design.
- More than 98% of surveyed students appreciate the importance of engineering drawing in study of engineering design.
- More than 95% of surveyed students indicated that they would be prepared to take an additional unit in advanced engineering design and advanced solid modelling.
- Some students suggested “making compulsory” engineering drawing classes and introducing rigorous assessment to create more incentives for study.

Tertiary educators may differ in their approaches to teaching engineering drawing, however it is difficult to deny that engineering drawing is an important component of engineering communication and engineering design. It is also apparent that the current situation in the tertiary sector with teaching engineering drawing is far from being perfect. Further research and experimentation is necessary to find ways of meeting modern challenges, refining curriculum and developing better approaches to teaching engineering drawing.

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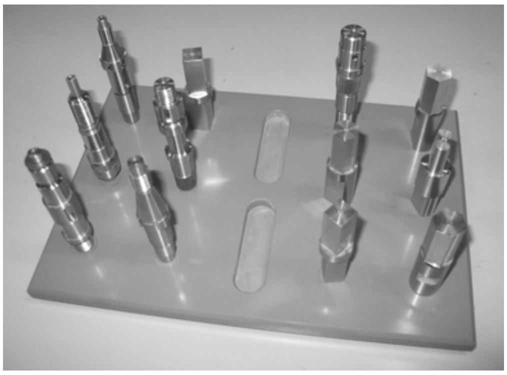

Fig. 1. Components for surface roughness prac.

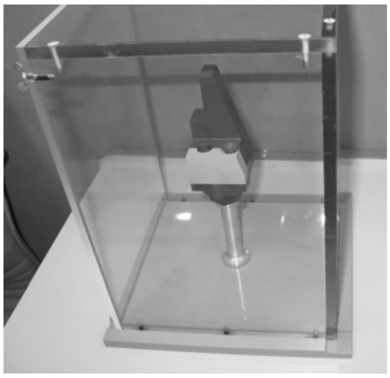

Fig. 2. Perspex cube with parts.

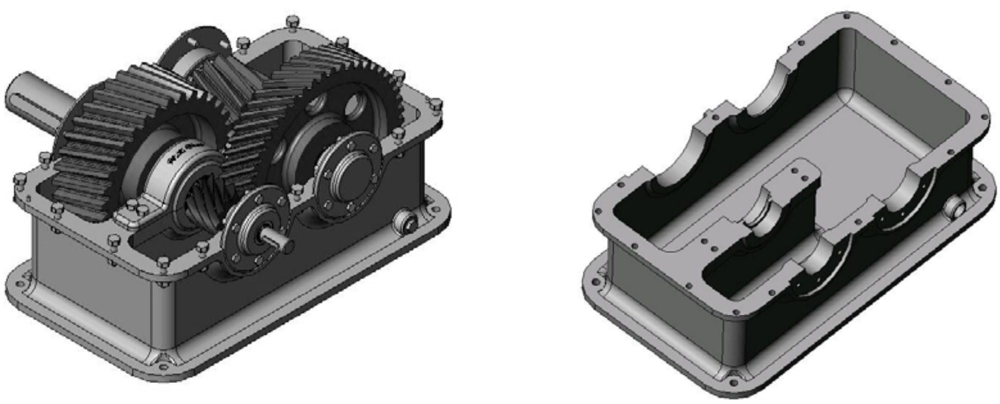

Fig. 3. Examples of solid models of a gearbox from students' projects.