Graphic Communication: What is it and How Can we teach it to Engineering Students?

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Abstract — *In Australia, as well as internationally, Universities are looking to ensure the quality of their graduates through the development of graduate attributes. In the engineering domain there exists Professional Institution defined graduate attributes, which graduates require to effectively participate in the engineering profession. One of the primary attributes is the ability to communicate effectively. This paper explores what this might mean in the context of engineering. The paper begins with a brief examination of the diversity of communication strategies needed to participate effectively in a design team. It then focuses on the ability to communicate through the development of graphic images.*

The paper reports on the impact of a different approach to teaching graphical communications to first year university chemical engineering students. Freehand graphical representation was combined with Computer Assisted Design software (CAD) to develop a platform to improve 3D understanding as well as a means to prepare technical drawings. Central to the approach was the equal importance given to understanding and problem solving in both 2D and 3D environments. The study phase encouraged active learning and experimentation. None of the teaching was regarded as traditional as the emphasis was to contextualise learning and developing realistic solutions to real world problems. Graphic skills developed as a consequence rather than as a teacher-centred skills-based learning exercise.

This approach draws on research from the fields of visualisation and spatial ability. This includes the use of modern software to improve learning experiences and providing learners with opportunities to actively participate and control their learning tasks. The 2D and 3D connection was examined and the importance of 2D problem solving to improving 3D understanding was a main focus.

Index Terms — *CAD, Core Skills, Curriculum Design, Graphics, Communication*

INTRODUCTION

Within the Australian context there has been an increasing focus on the quality and effectiveness of the student learning experience in University programs. The momentum has been toward the enhancement of professional programs through the enrichment of the curriculum with the inclusion of a range of professional attributes. The momentum, created by this initiative has been significant in the design and engineering related disciplines. This momentum has been created in the Engineering discipline by the development, implementation and evaluation of Programs against attributes defined by the Institute of Engineers Australia. These attributes have added a measure of complexity to the delivery of the programs and, this is most noticeable in the assessment of student performance in their attainment of these attributes. This paper looks at the instructional methodology and the assessment processes of the professional attribute of communication and the design process of ideation, specifically through the means of graphics. Included in the list of attributes [1] is the ability to:

- undertake problem identification, formulation and solution
- communicate effectively, not only with engineers but also with the community at large
- function effectively as an individual and in multi-disciplinary and multi-cultural teams

The ability to draw, both formally and informally is seen as a skill set that significantly contributes to the attributes of the graduate engineer. In the following report is documented some of the considerations which influenced the development of a course for the chemical engineering program at the University of Newcastle, Australia. The process of bringing together the findings of research and integrating the appropriate practices into student learning experiences has provided a quality learning experience for the students and one which proves valuable to them in practice.

THE GRAPHICS PROFILE

The importance of drawing has a twofold advantage for the practicing engineer. The first advantage relates to the need for practitioners to be effective communicators. The second advantage is the ability to draw to support ideation during the design process. Despite this fact it has been found that many practicing engineers have difficulty in applying a diversity of techniques to both develop and communicate potential designs or solutions to problems [2].

Research undertaken [3] in an Australian engineering industry identified drawing as an invaluable competency. What became apparent was that the designers were not using the diversity of graphic methods available to them. When the designers were subsequently questioned on their use of graphic representations and the rationale for their application, it became apparent from their responses that it was because they did not know how to draw using the range of drawing techniques available. The limitation was in their skill set. The ability to sketch effectively is therefore an important skill for both communication and designing.

Also identified in this research was the role of existing artifacts to the process of design. The existing artifacts most frequently were in the form of technical drawings. Design teams would document the development in technical drawings, most frequently CAD drawings. These drawings effectively communicate designs to others so that they are able to provide comment or approval on the design concept as it progresses and ultimately to those who will manufacture the designed product. Of interest is the relationship between the sketching and the technical drawings an engineer designer must be able to use.

SKETCHING

"Engineers are notorious for not being able to think without making "back of the envelope" sketches of rough ideas. Sometimes these sketches serve to communicate a concept to a colleague, but more often they just help an idea take shape on paper." [4].

Many of the drawing in engineering design are for the purpose of recording and transmitting the appearance of an object. This process is the result of the efforts of representing or recording of a phenomenon which already exists or as an idea or concept on the designer's mind until it is committed to a drawing. "The iconic (image like) nature of such drawing is interestingly reflected in the etymological link between image and imagine" [5]. In Herbert's [6] theory, sketches are used because they provide an extended memory for the visual images in the mind of the designer. Sketches allow the information to be represented in various forms such as differing views or levels of generalization. Thus he calls sketches graphic metaphors for both the real object and the formally drafted object under development. Herbert identified that sketches are a primary means of external thinking.

Ullman's [7],study states that most engineers receive little or no formal training in the skills of sketching but rather it is left to the student's, and subsequently the graduate's, natural ability. Sketching is an important form of representation in mechanical design. The data gathered during the study identified that 67% of all the drawings, undertaken by the designers in the act of designing, were sketches. Many of these sketches could have been made using drafting equipment or a CAD system. It was stated that with the average length of these sketching actions at 8 seconds, the use of instruments or computer tools could have slowed the drawing action to the point that the cognitive problem solving would be impaired. This identifies the quality of expediency is one of the positive attributes of the action of sketching.

CAD

CAD software provides engineers with a tool to produce a set of technical drawings to communicate concepts and precise details about an object being considered for manufacture and for record keeping purposes. CAD also allows an opportunity for student engineers to improve 3D understanding and to better appreciate the relationship between 2D and 3D representations. The more advanced software has intelligent 3D modelling capabilities and the commands to easily move between 2D and 3D interfaces. It also provides options to manipulate models, check for visual violations and to examine the plausibility of object design. Though not its main purpose, CAD software potentially improves spatial ability, 3D recognition and visualisation through the active participation and interactivity that is possible. Active participation contrasts with passive participation generally associated with the traditional teaching of technical drawing concepts and 3D understanding. The traditional approach should now be considered redundant in favour of new approaches made possible using the tools, commands and options available in CAD packages. Better understanding of technical drawing concepts will improve communications between design engineers and other practitioners involved from the conceptual stage of design through to the manufacturing stage at workshop level.

For the design engineer, it is difficult and not desirable to separate working and understanding in 2D from working and understanding in 3D. Importantly, designers and those that are required to interpret their work must be able to think in either of these environments and draw conclusions in the other. The ability to see the relationship is paramount and neither 2D or 3D should be regarded as more important than the other. A 3D drawing is easier to interpret but the complexity of many objects dictate that they must be represented as a set of related and sometimes comprehensive 2D drawings. In many respects, working in 2D may be more important than working in 3D. Cooper [8]was able to show through his experimental trials, that after solving problems based on orthographic views (2D), participants discriminated between isometric views (3D) of the same objects and drawings of distracter structures. Correct identification was high and it occurred without the isometric views being shown during the problem solving phase. Furthermore, Cooper's study demonstrated that the recognition of isometrics corresponding to correct 2D problem solving was substantially higher than for the recognition of isometrics related to incorrect 2D problem solving. Interestingly, the participants in Cooper's study were engineering students who had completed a beginning course in mechanical engineering which ensured a minimum level of competence.

There is evidence to suggest that observers show a preference for plan views rather than intermediate views when they explore objects. James, Humphrey & Goodale [9] report that participants in their study spent most of their time looking at the 'side' and 'front' views (plan views) of objects rather than the three-quarter or intermediate views. Furthermore, they indicate that the superior performance of participants on recognition tasks after active exploration may be a direct result of spending more time on plan views of an object. The researchers report that when participants studied the plan views of objects, they showed faster recognition of test objects than they did when they studied intermediate views of objects. The researchers concluded that studying only the plan views of an object appear to lead to a better representation of the 3-dimensional structure of the object than does studying only the intermediate views. The researchers offer an explanation for this observation in terms of a proposal put forward by Perrett, Harries & Looker [10]. Perrett and his colleagues propose that observers will concentrate on plan views because these views offer the greatest amount of change in the visibility of the object features. In contrast, the intermediate views are all perceptually similar and moving between them provides little new information about object features. This preference for plan views support the role of 2D in 3D understanding.

The type of learning experience appears to have a substantial impact on measures of spatial ability and 3D recognition tasks. In particular, active exploration is often compared with passive participation. For example, Duesbury & O'Neill [11]conducted a study to determine the effect of practice in manipulating 2-dimensional and 3-dimensional wireframe images on a learner's ability to visualise 3D objects. Their work examined the effects of practice in a 3D CAD environment on a learner's ability to visualise objects represented by multiview drawings such as blueprints. Their study consisted of two treatment groups (rotational and nonrotational) and one control group. The rotational group were able to rotate stimuli about any axis (X, Y and Z) and rotate from 2D into 3D. The nonrotational treatment group were able to switch between 2D and 3D but they could not rotate a wireframe model into a 2D view. The researchers found that the rotational treatment group performed significantly better than both the nonrotational and control groups on tests of spatial ability and 3D visualisation ability. They concluded that spatial ability can be improved through practice where the learner is able to see the relationship between the 2D and 3D characteristics of an object. Similarly, Johns and Brander [12]suggest that perceptual skills may be improved in a practice environment where a learner is able to actively explore, interact, manipulate and control 3D animations and simulations. James, Humphrey & Goodale [13] further argue that active exploration of novel objects compared to passive observation leads to better results on tests of object recognition.

There is also significant support for using CAD systems as a teaching medium to improve understanding of 2D and 3D technical drawing concepts. The modern software hosts a full range of tools that allow any level of accuracy, displays and manipulation. It promotes active exploration and challenges the need to continue teaching 3D concepts by the traditional methods that were based on passive observation, mental gymnastics, teacher-based instruction and objects encased in plexiglas. Bertoline [14] postulates that it is possible with CAD to determine analytic solutions to spatial geometry problems and graphically view the results. Bertoline strongly contends that the traditional methods of solving spatial geometry problems have now ended with the introduction of comprehensive CAD systems.

In summary, CAD systems allow active exploration and movement between 2D and 3D views. They also make it possible for students to concentrate on particular views and check the viability of their designs. CAD also offers a full range of tools to overcome the difficulties of traditional approaches to understanding technical drawing concepts. Essentially, CAD systems allow experiential and contextualised learning. As James, Humphrey & Goodale state: 'although there is a long tradition of research and educational policy that emphasizes the importance of "learning by doing", this idea has not often been applied to perceptual learning in vision'. The end result of the CAD experience for the student engineer may be improved spatial ability, 3D understanding and graphical communication skills.

THE LABORATORY APPROACH

There has been a great deal of interest shown in the training of engineers, demonstrated in the Report 'Teaching quality and quality of learning in professional courses' [15]. Such reports identify the large range of issues associated with the preparation and training of engineers, and they include:

- the ever changing technology landscape,
- having better communication skills
- being more effective in team works
- having highly developed problem solving skills

According to the new '*Engineering Criteria 2000*' [16] the engineering disciplines should ensure that their graduates are:

- able to design and conduct experiments as well as analyse and interpret data,
- team players in a multidisciplinary environment
- effective communicators

Logically, laboratory oriented courses form the best platform to develop these skills [17]. According to a recent US National Science Foundation (NSF) report [18], the learning experience must move from the lectures as the dominant mode to include a significant level of active learning approaches. Laboratory and internship experiences should provide the broader contexts within which to view the trade-offs in the design, development and implementation of engineering systems.

THE COURSE

In the mid 90's a concern was raised about the amount of experience chemical engineering students at the University of Newcastle had with those aspects relating to industry and with communicating design concepts. A needs analysis of the program pinpointed that students needed:

- Practical industry based, manufacturing project experience
- Risk management processes and practices
- Ability to relate design concepts to others
- Formal drawing skills

To accommodate these a course was designed which had an industrial context as a theme. The course was introduced as a first year experience to provide the students with an appreciation of what type of activities an engineer may be associated with when they are in the industrial situation of dealing with design and manufacturing processes.

The course uses a valve system as the basis for a "project centred learning" curriculum structure. The students are at the stage of their program where they are starting to deal with these systems in other courses so they have a theoretical appreciation of their application but little appreciation of their form or mechanical properties. The summative assessment consists of three components:

- Manufacture of an orifice plate valve
- Freehand drawing communication exercise/test
- CAD design project

Manufacturing Assessment Item

The orifice plate valve is central to the course and articulates with the two other assessment items, to differing degrees. The students are required to manufacture a valve system using appropriate machinery. The exercise supports the students' acquisition of knowledge concerning the production of devices and the levels of tolerance required for their effectiveness. Students at the conclusion of the project have to assemble the valve system and introduce it into a pressure line to evaluate its performance. The students conduct tests on their valve across a range of pressures and they plot their results on a graph. Their valves are then assessed against the following criteria:

- accuracy of the item produced
- effectiveness of the item, documented in a flow chart report
- machining expertise displayed in the production of the item
- quality of the finished product

Each of these criteria is provided with a five level framework with descriptors for each of the outliers defined. The students through the development of the system gain an in depth appreciation of the processes involved in manufacturing as well as a hands on application of a pressure control system and its function.

Freehand Drawing Communication Assessment Item

The second assessment component is the communication exercise involving the freehand drawing. This task utilises specified engineering equipment. A number of items of equipment, valves and pressure control systems are provided which students must disassemble, document the functions of the parts and the overall function, and then reassemble the piece of equipment.

Students work in groups of 2/3 for the disassembly and re-assembly component of this task. At the completion of this component each student produces a freehand drawing representation of one of the systems. Students use the freehand drawing medium to provide the technical details of the item, the function of the item and its components and the relationship of the components to each other. The specific requirements for this task are:

- The disassembly and correct re-assembly of the equipment.
- A description of the function of the equipment and the context in which this function may occur.
- A description of the function of the critical components of the equipment.
- Extensive sketching to aid in the explanation of the function.
- The information will be logically organized and presented in an A4 folio.

The following table provides the assessment criteria used for the exercise and would also include the same five level hierarchies as described in the first assessment item.

a. Comprehendible explanations of the function of the machine and the function of the individual components of the machine 1. Effectiveness of graphics in explanation of form 2. Effectiveness of function explanation 3. Quality of the graphics 4. Choice of presentation techniques
b. Appropriate sketching of the object showing necessary detail 1. Effectiveness of graphics in description of component 2. Effectiveness graphics in component relationship explanation 3. Quality of the graphics 4. Choice of presentation techniques
c. General presentation, including choice of the types of the drawing presented 1. Organisation of drawings 2. Presentation of drawings

TABLE 1:Assessment Criteria for Freehand Drawing Exercise

CAD Assessment Item

Students were required to design a support system to hold an Orifice Plate Valve in a fixed position relative to a ceiling and wall and the concept was illustrated in a drawing that supplemented the assessment task outline. A requirement of the support system was that it had to be attached to both the wall and ceiling. It also needed to be capable of withstanding substantial vibration, be easily fitted into position, be able to hold the pipe secure and the Orifice Plate Valve needed to be capable of being opened so that the plate inside could be replaced. It was suggested to students that they imagine that a number of their support systems would be used to fix several Orifice Plate Valves into position. The assessment consisted of two related parts. The first part was a detailed 2D CAD drawing of the support system and the second part was a 3D CAD drawing of one section of the system. Students received instruction in both 2D and 3D CAD skills and the features of the software were used to help them understand technical drawing concepts. They had equal opportunity to choose between 2D and 3D environments to develop their solution to the problem. The assessment criteria included:

- viability, practicality and effectiveness of the design solution
- 2D CAD skills
- technical drawing standards
- accuracy
- 3D CAD skills
- degree of difficulty
- presentation and layout.

CONCLUSION

The course over the years has been very successful and students have rated it very highly as a learning experience. In some years it has been the most highly rated course in the Faculty of Engineering. Aspects of student work have also been evaluated by industry based professionals to ensure the validity of the student outcomes and the assessment results, these too are recognised as industry appropriate. Also of importance when considering the learning outcomes is the fact that students will utilise the skills they develop during this course in subsequent courses, this is most noticeable when students are doing their project development in their final year.

When talking with students, the aspects of the course they appreciate are the industry centred approach as well as the very hands on nature of the course. The also admit their level of confidence to enter a manufacturing type of environment is significantly increased as a result of their learning experiences. The Faculty is now looking at imbedding this type of learning experience across a broader range of programs. The Project Centred Learning approach being seen as an effective way of delivering student learning experiences.

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