MEASURING MALAYSIAN UNDERGRADUATE SKILLS IN READING AND INTERPRETING ENGINEERING DRAWING

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ABSTRACT

Following a survey of representatives from Malaysian manufacturing industry that identified concerns over engineering graduates' abilities to properly interpret professional manufacturing drawings, a systematic study of relevant undergraduate abilities was initiated. A composite assembly/dimensioned drawing of a gear pump was selected to form the basis of a test that could be presented to students in engineering courses at the Universiti Teknikal Malaysia Melaka (UTeM). Twelve questions requiring the interpretation of the drawing were devised, and were distributed to industry advisors for comment. After the questions were re-structured in an increasing order of expected difficulty, 232 engineering undergraduates at all four levels were tested. The distribution of overall scores from the test fell within the planned range, with some students performing considerably better than others, indicating that the test would be suitable for further use as a pre- and post-test for follow-up investigations of methods for increasing graduate skills. However, student responses for some of the questions were noticeably poor, against initial expectations. A deeper analysis of those questions revealed that respondents required not only an ability to interpret the information presented on the drawing, but an understanding of the engineering technology contained in the drawn artifact.

Keywords: Engineering design education, engineering drawing, curriculum, industry requirements.

1 INTRODUCTION

In order to continue the advancement of a developing country, the need for competent engineers is crucial [1]. It is important to attract highly capable students into engineering disciplines. Ensuring their retention and success is critical for continued growth in the engineering field and provides workforce support needed by industries. Even though the profession attracts students of high academic ability, some students enter with weak spatial visualization skills, so interventions are needed to accommodate those students in order to maximize their learning during undergraduate studies and in their professional careers [2]. Since Malaysia was admitted to the Washington Accord as a full signatory nation alongside Germany and Singapore in 2003, there is a need to have Outcome Based Education (OBE) for a full membership to the Washington Accord [3]. Basri, et al. [*ibid*] explain that OBE focuses on outcomes in the preparation of graduates for professional practice. OBE calls for documented evidence on how the engineering program imparts and develops the graduates rather than focusing on the process in achieving the outcomes. Whether it is capabilities, qualities, attributes, or outcomes, the curriculum should be designed to achieve the desired objectives. Most importantly, in the OBE approach, the engineering programs must demonstrate that the graduates have achieved the required outcomes [*ibid*].

Malaysia has a strong interest in producing more engineering graduates in mechanical and manufacturing disciplines to have a direct involvement in the multi-national manufacturing industries that are being attracted by Malaysia's advantageous geographical, political and economical characteristics. This generates a need to have graduates with advanced abilities in reading and interpreting sophisticated manufacturing drawings that could have been prepared to a range of international drawing standards.

One of the main tasks of graduate engineers is to create designs; be they machines, consumer products, buildings or bridges. Consequently, one of the goals of engineering education should be to develop design skills in engineering students [4]. However, the success of engineering education in meeting this goal is indecisive [*ibid*]. There are some issues voiced by industries that students "cannot design".

According to a survey by American industry [5], engineering graduates in general are found to be good in engineering science, mathematics and analytical techniques but lack the ability to design. A survey to Malaysian engineering companies [6] supported the concern that students have problems reading and interpreting engineering drawings, which may be related to their modest design skills. Some Australian engineering students have been shown to struggle in design-related tasks such as the comprehension of design drawings [2], demonstrating weak responses to unstructured problems [7], solving moderately complex design problems [8] and in identifying conceptual errors in machine design [9]. Moreover, many students can excel at engineering science courses but are uncomfortable in engineering design [10, 11]. Drafting standards are not yet unified, but globalization in design, manufacture, and assembly process means that drawings produced to different standards may co-exist at any one manufacturer. There are many multinational companies from United States, Europe, and Japan operating in Malaysia. The question is: "can graduates in Malaysia read engineering drawings which are internationally prepared?" Malaysian engineering students may need to be even more versatile in reading and interpreting engineering drawings because they deal with many internationally drawn engineering drawings using various standards. Despite having much in common, there are still subtle but significant differences between drafting standards: for instance the thread representations in Figure 1.

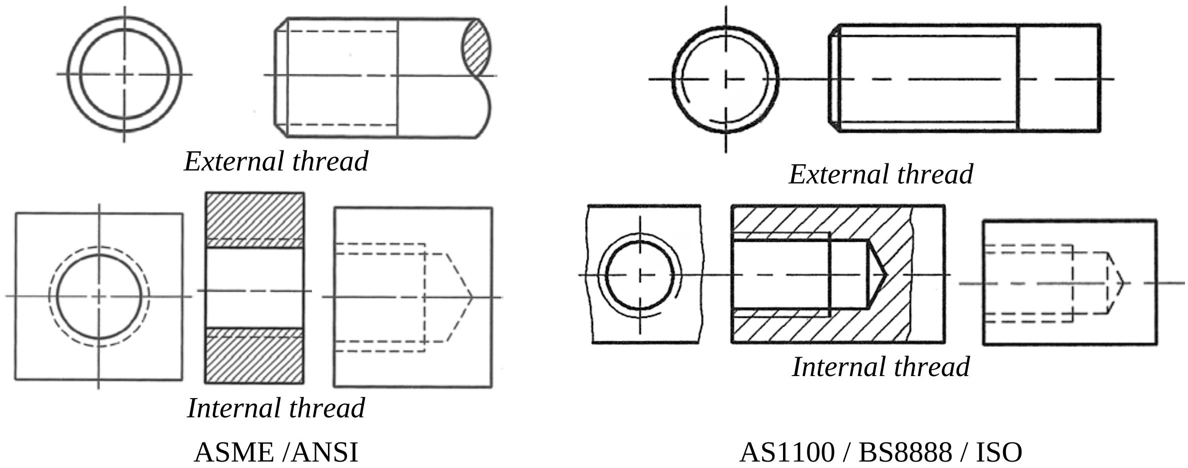

Figure 1. Difference of thread representation in different standards

In today's global economy, many parts are designed in one country, manufactured in another and assembled in yet another. Drawing standards are evolving. Companies don't want rejected parts, especially if they are created by avoidable misunderstandings. So they desire common standards and will invest so they can remain in accordance with any international standards. For example, there are differences in the decisions to adopt first angle and third angle projection. First angle projection is used throughout Europe (excluding the UK) and Asia while third angle projection is used in UK, USA, Canada and Australia [13, 14, 15].

This paper attempts to identify the major shortcomings and issues faced by graduate mechanical and manufacturing engineers in Malaysia when they are required to read and interpret engineering drawings used in the local manufacturing industry. The first phase of the research was to develop and validate a simple test that would allow us to observe whether the desired skills were present. The second phase was to administer the test to a large cohort of undergraduate engineers and to amalgamate the results in order to identify common absences of desired skills, or instances where those skills have been gained or enhanced during their studies. A third phase (not reported here) is intended to be the development and delivery of enhanced undergraduate programs so that the desired skills are gained before graduation. This paper reports on the first and second phases of the overall research program.

2 APPROACH

A survey completed by representatives from 34 manufacturers in Malaysia indicated that recent graduates in mechanical and manufacturing were deficient in several attributes associated with reading and interpreting the types of engineering drawings that were commonplace in their industries. The authors were in a position to make subtle alterations to the undergraduate courses at one Malaysian university, so were interested in quantifying graduate shortcomings prior to developing new pedagogical approaches.

The survey was able to rank the perceived shortcomings of graduates. The skills most lacking included the following abilities:

1. visualize the form of a 3D object based on the 2D representation of that object,
2. understand 2D drawings of machines with interconnected parts, such as the interpretation of conventional assembly drawings,
3. identify design faults in the machinery depicted in an engineering drawing, and
4. identify errors in the manufacturing drawings, such as any missing lines that may produce ambiguous meanings, or missing dimensions.

Our approach was to determine the extent of these (and other perceived) shortcomings in undergraduate engineers, and to determine when (or if) any desired skills emerged during the undergraduate program. This goal led to the need to test undergraduates on one or more of the desired skills. It proved difficult to devise a single test document that would explore all of the desired skills (for example, it is somewhat artificial to test the interpretation of conventional assembly drawings and the interpretation of geometric tolerancing symbols in one drawing) because not all of the desired skills would normally be required for the interpretation of a single conventional engineering drawing. Therefore our approach was to devise a series of separate tests that might be administered over an extended period. The first of such tests was selected to focus on the issues that had been identified as those requiring the most attention. Less critical issues, such as the misinterpretation of first angle and third angle projections would be left for a later exploration.

In the end, we wanted to know if the activities undertaken during a training program did improve the targeted skills so we needed to pre-test and post-test trainees. A pre-test was needed to identify what particular skills were deficient, and which were adequate. A post-test was required in order to validate the training program.

Ideally, a single test can be used as a pre-test and as a post-test. The difference in test scores can be a direct measure of the improvements that have occurred as a result of the learning activities experienced between the tests. There are risks with this approach, since there can be a ‘learning effect’ that leads to an improvement in test scores, simply because the completion of a test gives practice that boosts subsequent performances [16]. The learning effect, if any, can be quantified by the use of a control group of subjects that undertake testing at the same times as the experimental subjects. We therefore sought an objective test that could be administered to a large cohort of undergraduate engineering students as a pre-test and could be suitable as a post-test.

2.1 Test characteristics

The test was intended to determine where future remedial training should focus on reading and interpreting engineering drawings.

An undesirable outcome from the test would be a distribution of results like curves A or C in Figure 2(a). In C, the test is too easy. The result is skewed heavily to the right, which means most subjects can answer the test perfectly. The issues are that (i) the test cannot adequately distinguish differences between subject skills that might be correlated with other factors, and (ii) the test cannot also be used as a post-test since it would not detect any improvements that arose during an experimental treatment. With curve A, the test is probably too difficult. The result is skewed heavily to the left, which means most students cannot adequately answer the test. The concern is that, at the completion of a training program, individual skills may not improve by enough to identify differential improvements, such as the ‘shift’ illustrated in Figure 2(b). We would prefer the results of individual questions to fall in a range from low to high scores, with a reasonable standard deviation such as curve B in Figure 2(a).

3 A POSSIBLE TEST

The authors had access to a validated test for reading and interpreting engineering drawing ability/skill on the basis of correct answers from a dimensioned assembly drawing of a gear pump: a test previously created to check the impact of spatial abilities on the comprehension of design drawings [2]. This test had also been used as part of teaching materials in University of Melbourne and at Monash University, Australia. In the present research, the authors were interested in an aspect of novice designers’ abilities to comprehend orthogonal engineering multi-view drawings.

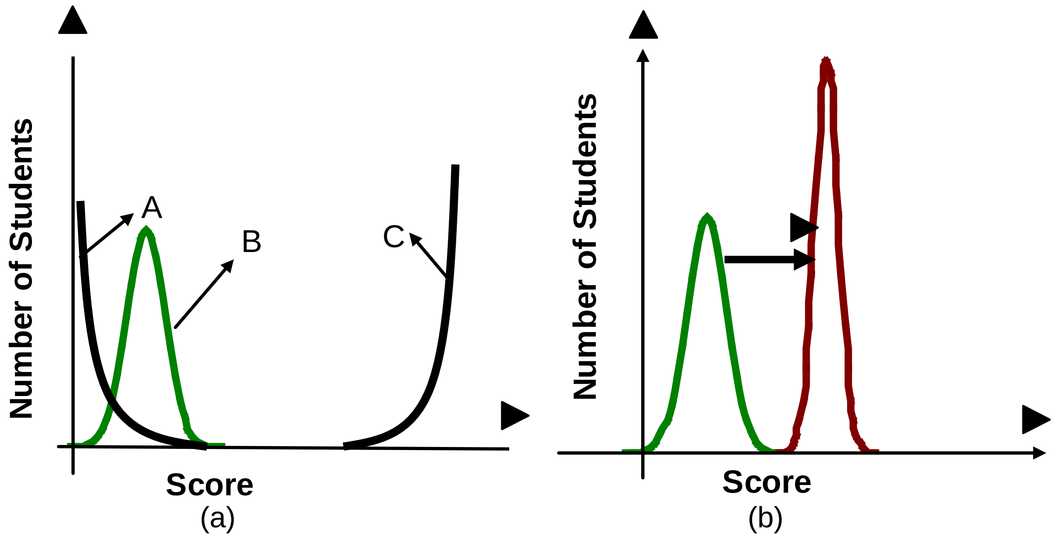

Figure 2. (indicative)
(a) Three different scenarios yielding results A, B, and C. For curve A the test is too easy, for curve C the test is too difficult, but for curve B the test gives an ideal distribution.
(b) Illustrates the desired change in distribution between a pre test and a post test.

The test used to determine whether drawings are comprehended followed a fairly conventional format (Appendix). Four views, including dimensions, sections and hidden line representations of an assembled gear pump were arranged in the third angle convention. The test comprised twelve principal questions about the drawing. Most of those questions explored mechanical terminology, and required a mental translation of the views into 3D objects, but other questions sought to explore whether the test subjects could translate between views by recognizing the same component in different orientations. The test was scored with simple correct/incorrect (binary) counts for the responses, with a possible maximum 12 correct. The test was to be completed within 10 minutes and the subjects were to write the answers onto the given sheet.

The intended skill being investigated for each question is shown in the last column in the Appendix. The expected issues for each of those questions (Q1 to Q10) are as follows:

Q1 (*Geometry*) looks at reading/finding a dimension (a numerical value). But a test subject needs to know the meaning of ‘diameter’ & ‘shaft’, and how to relate the labels on the drawing to the table of parts.

Q2 (*Geometry*) requires an ability to locate dimension in a drawing, and results in a single numerical value.

Q3 (*Assembly, function*) attempts to determine if a test subject can find the diametral clearance by locating the outside diameter in the data, finding the “dia 38.3-38.4, 2 places” information on the drawing and deducing the answer.

Q4 (*Assembly, Function, Understanding of machinery*) explores whether the subject can determine how the overall casing is secured. There is scattered information about machine screws, placed onto the drawing instead of in the parts list, and the unusual half-view obscures the fact that all six such screws are used to hold the cover, since only four are drawn in the end view.

Q5a (*Geometry*) tests whether the subject can undertake simple deduction from geometric understanding of location of parts.

Q5b (*Function*) probes a subject’s imagination as to the practical restrictions that might affect the use or operation of the pump.

Q6 (*Function*) tests whether the subject is aware of the functional purpose of a locknut to prevent motion of a second nut that is positioned at a pre-determined place along a thread.

Q7 (*Assembly*) seeks an understanding of the functionality of a standard machine element used during the assembly of the pump.

Q8 (*Hidden geometry*) tests whether the subject understands one way to represent machine symmetry, and whether they can identify the mounting slot in the top view.

Q9a (*Assembly, Function*) is a relatively open question to see if subjects know enough about the concept of gear pumps to appreciate the critical effect of greater or lesser gear centre distances.

Q9b (*Geometry, Function*) If a subject identifies the functional importance of the center spacing, the question tests their ability to identify the parts of the assembly that might allow the spacing to be adjusted. The upper gear shaft bearing surface is identifiable in the principal elevation, and should be read as being part of the Housing. The lower shaft bearing surface should also be read as integral with the Housing (and Housing Cover), with no other component that could allow adjustment.

Q10 (*A subtle, probing question, involving a standard symbol of engineering drawing*) The absence of a definite drawn end of the shaft or a defined length placed elsewhere on the drawing results in an indeterminate dimension, and the question tests a subject's appreciation of the graphical shortcut.

Professionals working in Malaysian industry reviewed the original test. A professional offered the opinion that the question Q9a, *"What dimension is the most critical in the pump assembly"* is ambiguous, and suggested that we add, *"to ensure smooth running of the gear pump"*. One professional responded, *"I found this hard"*, perceived likely difficulties, and felt that special insights were required. Experienced engineers were able to predict where students would have special difficulties. We used the professional reviews to rearrange the questions broadly from the easier to the more difficult, except where successive questions were interdependent (i.e. split a question into parts a and b). We chose to present the easier questions at the start of the test to build confidence and to increase the likelihood that all questions would be attempted with genuine effort. For example, during the experiment, Q1 was answered well by almost all students, so was not suitable for discriminating between subjects, but the question gave subjects encouragement, and set up a positive emotional focus. Question 2 was also placed early in the test to reinforce the sense of achievement, since it too was judged to be a relatively easy question for engineering undergraduates to answer.

After a trial with a group of late-course volunteers where the wording of the questions was refined to suit their comfort with the English language, we issued the test to 253 engineering students.

4 TEST PROGRAM

The test described above and in the Appendix was issued to all years of engineering students (years 1, 2, 3 and 4) at the departments of Manufacturing Design and Manufacturing Process, in the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UteM) Malaysia to measure the spread of students' abilities in reading and interpreting engineering drawings. This test was intended to identify current levels of skill and the spread of students' abilities at their respective years of study. The test was issued 5 weeks after the semester started for the academic year 2009/2010. The tests were held after a normal timetabled session and were administered by the respective lecturers of each class. A total of 232 students participated in the study. Their ages ranged between 18 and 21 years old. These students were selected for the study because they were the most probable candidates to become the engineers who would be regularly required to read and interpret engineering drawings.

4.1 Result and analysis

Figure 3 summarizes the score distributions for students according to their respective groups. The first digit of the group code corresponds to the year level of the group. The common test gave distributions of scores that were fortunately similar to curve B in Figure 2. We concluded that, overall, the test had the appropriate level of difficulty for the cohort involved in the study. Interestingly, there appeared to be no significant or systematic differences between the mean scores of each group, suggesting that the existing undergraduate courses at UTeM did not develop an increasing ability to read and interpret the type of drawing used in the test. Figures 4 and 5 summarize student responses to the separate questions within the test.

A desired characteristic of this test was that each question should produce a spread of responses similar to that of the overall test score (such as curve B in Figure 2). We were therefore interested in identifying those questions that were universally answered incorrectly and those that were uniformly correct. Four questions were answered poorly: Q3, Q5b, Q8, and Q10 (Figure 4). Aspects of those questions are discussed below.

The spread of responses for question 1 (Q1) was low, meaning that the question did not discriminate well (because most students gave the correct answer). However, we wished to retain a few questions having this characteristic so that a positive attitude could be established early in the test.

Questions 4, 5a, 6, 7, 9a and 9b generated useful distributions of responses that were suited for future tests.

We identified a common issue with the low-scoring questions 5b and 8. Both of these questions required subjects to use knowledge about engineering practice, and apply that knowledge to the pump illustrated in the test. The students were clearly unable to do this, and we assumed that their absence of a practical engineering background was the cause. We determined that these types of questions would not be useful as diagnostic tools without some modification.

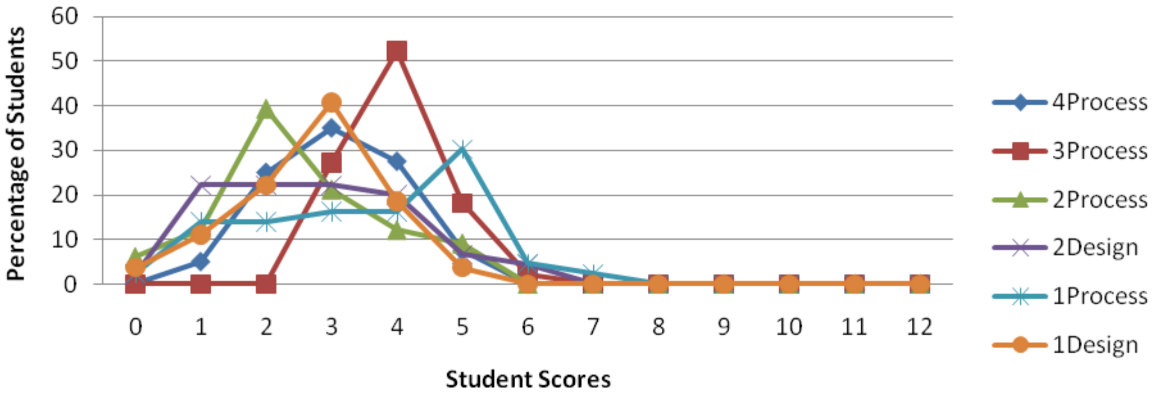

Figure 3. The scores distribution for students according to their respective groups.

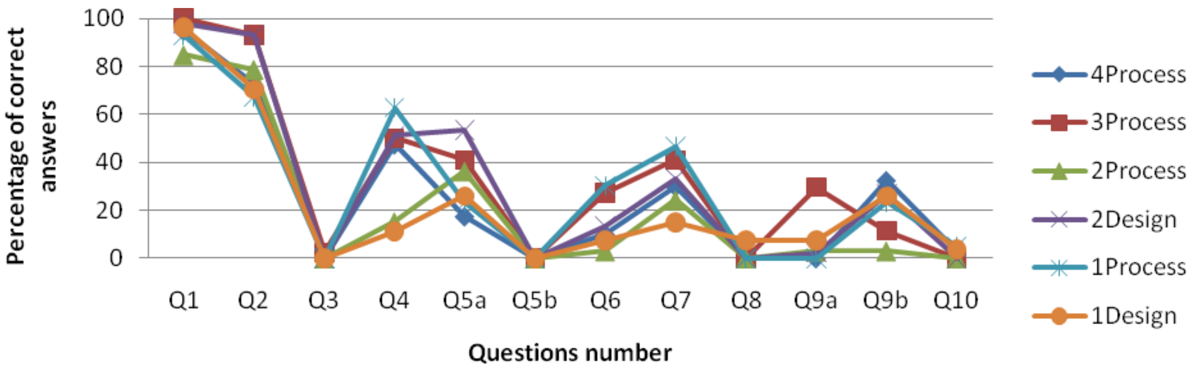

Figure 4. Percentage of correct answers (%) for each questions for all student groups.

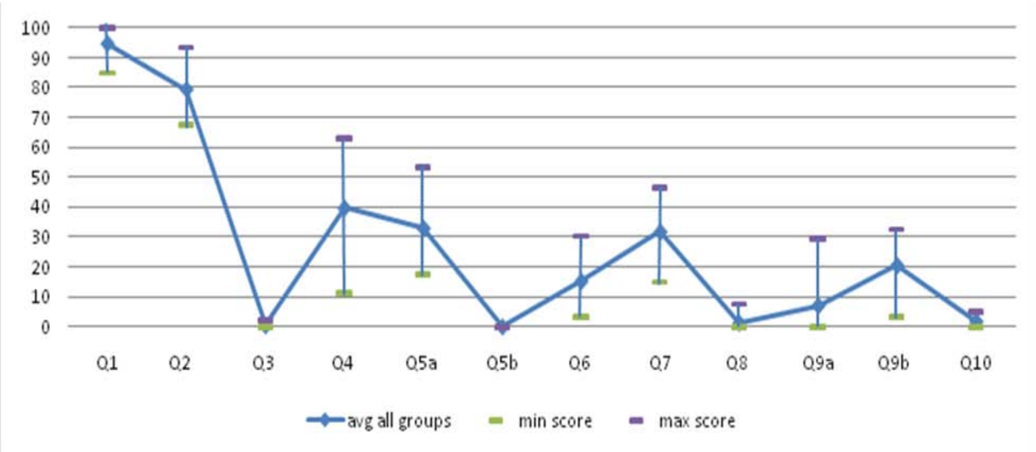

Figure 5. Percentage of correct answers (%) for each questions with average, min. and max. for all student groups.

Although question 3 was not answered correctly by any students, we were not able to identify the reason. We suspected that students were either unable to make the assumption that the outer diameters of the gears were exactly 38 mm or that the method of indicating the range of bore diameters (38.3 to 28.4) was ambiguous. We also suspected that this question was also affected by students' lack of understanding about the meaning and function of a 'diametral clearance'.

4.1.1 Analysis of Question 10

Only four students correctly answered question 10. The majority did not appear to understand that the conventionally-represented broken shaft meant that the shaft was longer (Appendix). Eighty three students left the answer blank. If students tried to calculate the length from the data supplied, the correct answer should be more than 118 mm because all the accumulating dimensions sum to 118 (Appendix). An acceptable answer could also be 'more than 118 mm'. Figure 6 illustrates the spread of numerical answers presented by students.

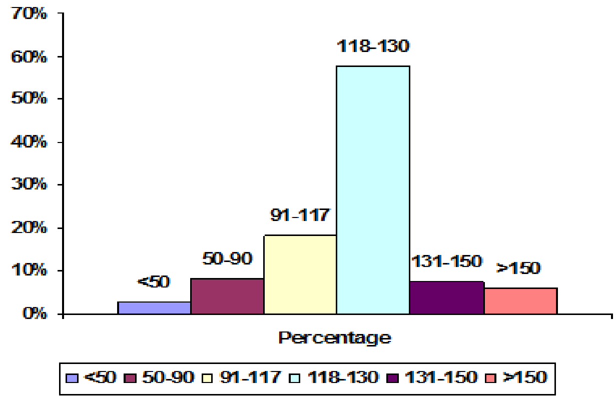

Figure 6. Percentage of responses to Q10 in within specified ranges.

4.1.2 Analysis of Question 8

One hundred and eighty six students left the answer for question 8 blank. Seven students answered "33mm", which corresponds to the 33mm dimensioned between two threaded holes used as inlet and outlet, suggesting that these students did not understand the function of those two holes. This question was intended to explore subjects' appreciation of drawing-symmetry conventions, but students appeared not to know that the slotted hole is used for mounting the casing. If so, this shortcoming is about a failure to appreciate the functional characteristics of engineering elements. We anticipate that responses to this question can be improved by adding the text "…elongated slots in the lowest part of the housing".

4.1.3 Analysis of Question 5b

One hundred and seventy eight students left the answer to question 5b blank. Students appeared not to understand the issue involved. Since no one answered question 5b correctly, we assume that these undergraduate students didn't understand the way in which the pump would be integrated into a pumping system. We may retain this question if this test is to be used as a post-test because some respondents may develop a parallel practical understanding and be able to deduce a correct answer.
Two students answered "*the higher the pulley*" and "*cannot because of the pulley*" respectively, which could be interpreted as correct answers. This type of question allows subjective answers, and the interpretation then depends on or is up to the scorer. We will reword the wording on question 5b if this test is to be used in future to present less opportunity for ambiguity in the written answers. A student answered "*it cannot work properly*" which is too general to be considered a correct answer. A few more answers were, "*gear could rust*", "*used more energy*", "*cannot connect the function*", which are also phrases that are ambiguous and open to interpretation.

4.1.4 Analysis of Question 3

One student in the earlier trial obtained the correct answer (0.3-0.4mm). However 73 students answered 0.1mm which would be a valid answer if the range of bore diameters given on the drawing was interpreted wrongly, but plausibly. There is no drawing standard that includes manufacturing dimensions in an assembly drawing, and certainly not toleranced dimensions that apply to a single

part. So the 73 students would be correct if they read the toleranced diameter as 38.3mm for the gear and 38.4mm for the casing giving a clearance of 0.1mm.
In any future use of this test question, the authors will put a note or inform the subjects to not just write a number for the answer, but to also supply their reasoning.

4.1.5 Summary of observations

The biggest issue faced by students attempting the test was trying to understand how the machine worked. We had only wished to determine the critical shortcomings in students' abilities to read and interpret the conventions of engineering drawing, but we also found that with some of the questions, there was a concurrent requirement to understand the technology before it was possible to understand the question. We found that the test was too difficult where it was based on the pump's technology.

5 CONCLUSION

We determined that the test was suitable for our purposes and can be used as a post-test as well. The poorly answered technology-based questions will be retained since it is envisaged that a subsequent training program will be based on a multitude of industry-standard engineering drawings used during otherwise conventional teaching in non-design courses, and it is possible that students will thereby gain greater practical insights.

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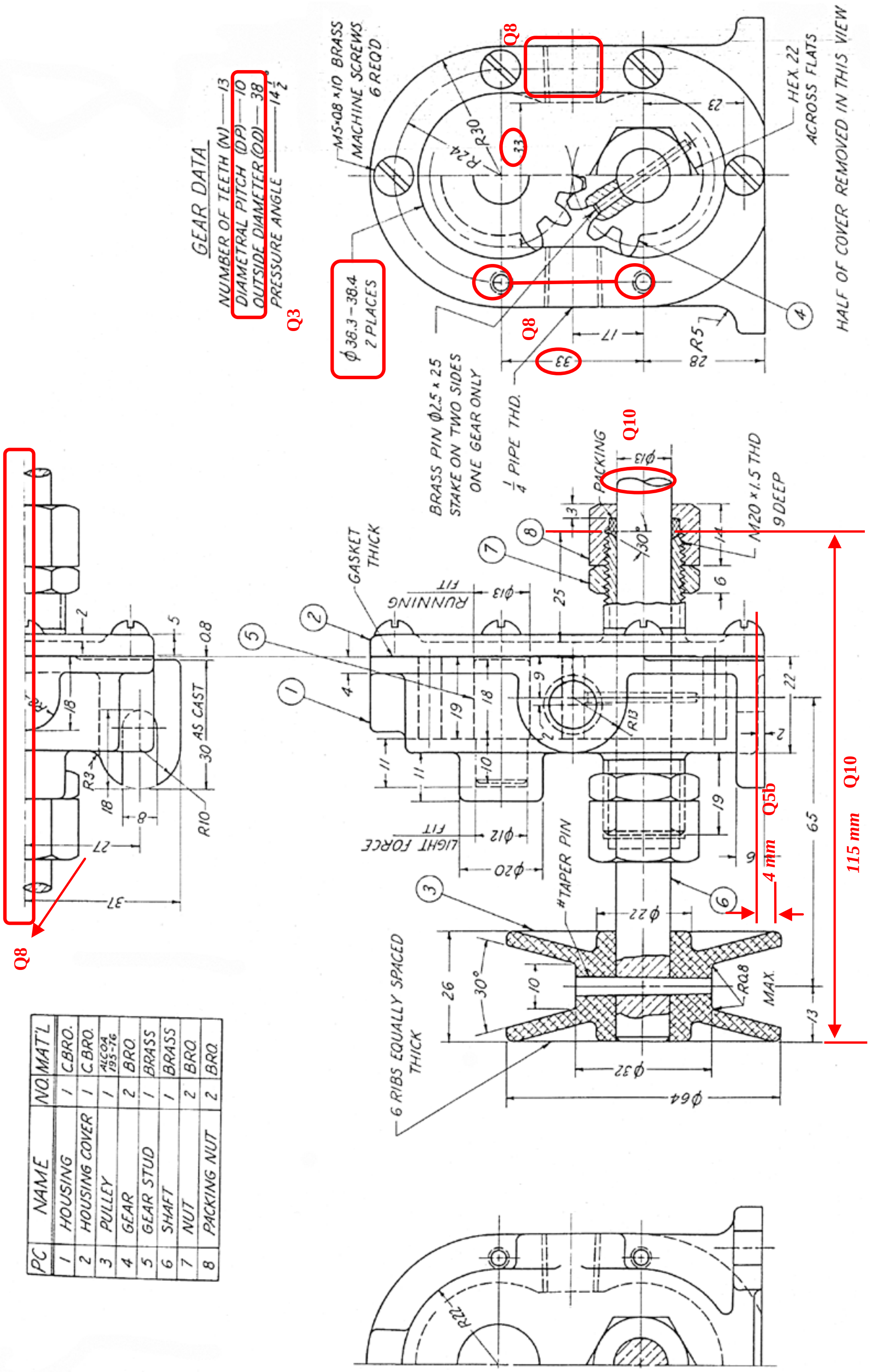
Appendix:
Test used to determine abilities in reading and interpreting engineering drawings (annotations added to highlight answers)

Examine the assembly drawing of a gear pump and
answer the questions on the other side of this sheet
(Extension problem: Gear pump assembly, 1993).



Extension problem: Gear pump assembly
Source: *Introduction to Engineering Drawing*, by W J Luzadder & J M Duff, Prentice-Hall 1993.

Test Questions, Answers and Categorisation of Questions

Qn.	Description	Answer	Question type
1.	What is the diameter of the **shaft** (part 6)?	**13 mm**	Geometry
2.	What is the overall height of the **housing**?	**91 mm**	Geometry
3.	What is the diametral clearance between each **gear** and the inside of the **housing**?	**Top gear (5)** **0.3 – 0.4 mm** **Bottom gear (4)** **0.3 – 0.4 mm**	Assembly, leading to function.
4.	How is the **cover** (part 2) secured to the **housing** (part 1)?	**6× brass machine screws**	Assembly, functional, understanding of machinery
5a.	What is the vertical distance between the bottom of the **pulley** and the bottom of the **housing**?	**4 mm**	Geometry
5b.	What implication does this have for mounting the pump?	**Cannot be mounted on a horizontal surface – requires a shoulder**	Functional
6.	What is the function of part 7, the **nut**?	**Lock the packing nut in place.**	Functional
7.	How is the **pulley** (part 3) secured to the **shaft** (part 6)?	**taper pin**	Assembly
8.	If you were to drill two holes in a mounting surface to firmly mount the pump, what would be the spacing of the holes?	**27 × 2 = 54 mm**	Difficult geometry
9a.	What dimension is the most critical in the pump assembly to ensure smooth running of the gear pump?	**Distance between gear centres = 33 mm *or*** **Distance between gears and housing**	Assembly, functional
9b.	Is there any provision to adjust this dimension?	**NO**	Functional
10.	What is the length of the **shaft** (part 6)?	**unknown**	Subtle, probing: drawing convention

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