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Problem-Solving with Industrial Drawings: Supporting Formal Graphics Language Development for Malaysian Engineering Graduates*

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The globalisation of manufacture has forced many developing countries in Asia to respond to the exacting requirements of quality and interchangeability that involve complex and diverse conventions for graphical and geometrical product specifications. Competing pressure for international recognition of engineering qualifications has reduced the time available in Malaysian universities to teach a range of practical skills, including those of reading and interpreting engineering drawings (RIED), although Malaysian industry has identified inadequacies in the RIED skills of recent graduates. This paper reports the deliberate use of incidental learning to increase RIED skills in groups of undergraduate engineering students by replacing the familiar line illustrations of parts and machines in the learning tasks of a conventional analytical subject with sets of formal engineering drawings. Participants who were engaged for 14 hours of practical problem solving work in the subject and a parallel CAD-modelling subject, gained measurable skills in RIED. Since the increase in participants' RIED skill did not require alterations to the existing educational objectives of the subjects, the time allocated to problem-solving within those subjects or additional RIED teaching expertise, an expansion of the approach is recommended.

Keywords: incidental learning; graphics education; engineering drawings; problem based learning

1. Introduction

Malaysia is ideally placed to participate in south-east Asia's manufacturing boom. With a well established western-style education system, ready access to international transport routes, a stable economy, widespread use of the English language, yet low labour costs, Malaysian industry is able to attract manufacturing contracts from well beyond the region [1]. Modern manufacturing demands high quality, facilitating component interchangeability and multi-site co-ordinated construction. The detailed specifications for component geometry and assembly are most commonly contained in formal engineering drawings, typically prepared by the design originator and passed onto the manufacturer. Consequently, Malaysian industry has to respond to the demands of complex manufacturing specifications that arise from diverse geographical and geo-political locations.

While most of the graphical conventions for manufacturing drawings are universal, there are important local differences that must be accommodated by contract manufacturers. For example, while ISO 128 (commonly used throughout Europe and in most of Asia, including Malaysia) is based on first angle projections, alternative standards such as the British BS888, United States ASME Y14.3M, Japanese JIS B 0001 and Australian AS/NZS1100 use third angle projections. Most education and training programs understandably focus on their local standard. Nevertheless, it is sometimes possible to misread an engineering drawing based on an unfamiliar projection system, and thereby manufacture a "left hand version" of the intended product.

Even within otherwise similar projection systems, differences in the conventions used to simplify and communicate complex shapes can give rise to errors. The conventions for representing screw threads, for example, involve the use of uniform width, full and dashed lines in ASME Y14.3M, but alternating width full lines in BS8888.

It is apparent that in some countries, such as Malaysia, there is a greater requirement for manufacturing engineers to be familiar with the drawing conventions from elsewhere. This places additional demands on the engineering education and accreditation process since a lack of familiarity with the alternative conventions gives rise to potentially costly errors.

In this paper we identify the shortcomings in graduate skill in reading and interpreting engineering drawings (RIED) that Malaysian industry has raised and find that the existing undergraduate manufacturing engineering program at a typical

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Malaysian university does not develop RIED skill much beyond that of an introductory drafting course. We then show that a subtle adjustment to the way otherwise conventional analytical subjects are presented can improve undergraduates' RIED skill without altering the established curriculum, increasing student workload, or requiring any new RIED teaching skills.

2. Research background and context: The industrial problem

2.1 Malaysian industry survey

After a small group of Malaysian engineers expressed concern to the Universiti Teknikal Malaysia Melaka (UTeM) about graduate engineers' capability in reading and interpreting engineering drawings, the authors constructed an online survey, exploring local industry's requirements in RIED skill and the deficits in those skills. The survey questions were checked for validity with the pilot group of engineers who raised the issue.

The survey comprised twelve pairs of questions, seeking responses on a Likert scale. For example, a question "My graduate engineers understand the concept of third angle projection" was followed by the question "I require my graduate engineers to understand the concept of third angle projection".

After sending the survey to 100 Malaysian companies, we received 34 responses from supervisors who averaged more than four years overseeing engineering graduates. The Cronbach's alpha score for the questionnaire responses was 0.92, indicating high consistency. While some of the issues raised were not regarded as being especially important for all graduate manufacturing engineers (such as an ability to read pipework diagrams), all twelve desired graduate capabilities raised in the survey were reported as being inadequate [2].

The three issues of most concern, with deficits of at least 1.0 on the five-point Likert scale were perceived shortcomings in graduate ability to: (a) visualise the 3D form of an object represented in an orthogonal multi-view drawing, (b) interpret orthogonal assembly drawings, and (c) identify design faults from drawings. There were real, but lesser concerns (in excess of 0.6 deficit) about convention- and application-specific shortcomings. The survey indicated that the authors' initial perception that the special demands of Malaysian manufacturing industry for advanced RIED skill may have been the root cause of its concern was incorrect. Graduates were perceived to lack some of the most fundamental abilities to read and interpret generic orthogonal drawings, and especially to understand the three dimensional relationships depicted in those drawings.

2.2 Malaysian undergraduate abilities in RIED

Following the industry survey, the authors sought to discover if the principal perceived shortcomings in graduate RIED skill existed during a typical undergraduate engineering course. The Australian authors had utilised an established RIED exercise [3] to explore learning and psychological issues in the development of RIED skill, and made this test [4] available to the Malaysian authors. The ten-minute RIED test comprised a third angle dimensioned drawing of a gear pump (Fig. 1) and 12 associated questions. This test was selected because questions required interpretations of the 3D form (five questions), the analysis of the assembled components (five questions), and practical issues (four questions); questions that corresponded to the three most critical issues raised in the industry survey.

After the RIED test was approved by the professional engineers who helped structure the industry survey, and completed by a pilot group of volunteers at UTeM, it was undertaken by 252 engineering students from all year levels at UTeM. The results of this study [5] yielded three key findings.

First, RIED skill increased between the second and third year levels at UTeM ($t = 3.07$, $p < 0.002$) (Table 1). The investigation was not a longitudinal study, so it is possible that this increase arose from annual changes in matriculants' general skill levels or to teaching practices at UTeM during the previous years. However, all students had undertaken a formal study of engineering drawing in the first year, and most had engaged with engineering drawings during a CAD/CAM subject in their third year. It seemed plausible that the increase in RIED skill for the last two years arose from activities during this CAD/CAM subject.

Second, it was apparent that the UTeM students, as a group, had performed significantly worse ($t = 5.40$, $p < 0.0001$) than third year students at the University of Melbourne, who averaged 5.64 (SD 2.04, N = 180) [4] on the same test, but had never been enrolled in a self-contained subject in engineering drawing.

Third, four questions on the test were very poorly answered at all year levels. Three of those questions had a common theme in that they each required an understanding of the technology depicted in the drawing. For example, no student was able to nominate 'the spacing for bolt holes for mounting the pump', apparently because they did not realise that the slotted holes in the base were for mounting purposes. Similarly, after determining the vertical distance from the bottom of the pulley to the mounting surface, very few students were able to appreciate that this feature would have important consequences for mounting the pump on a base. Students were also unable to find the clearance at

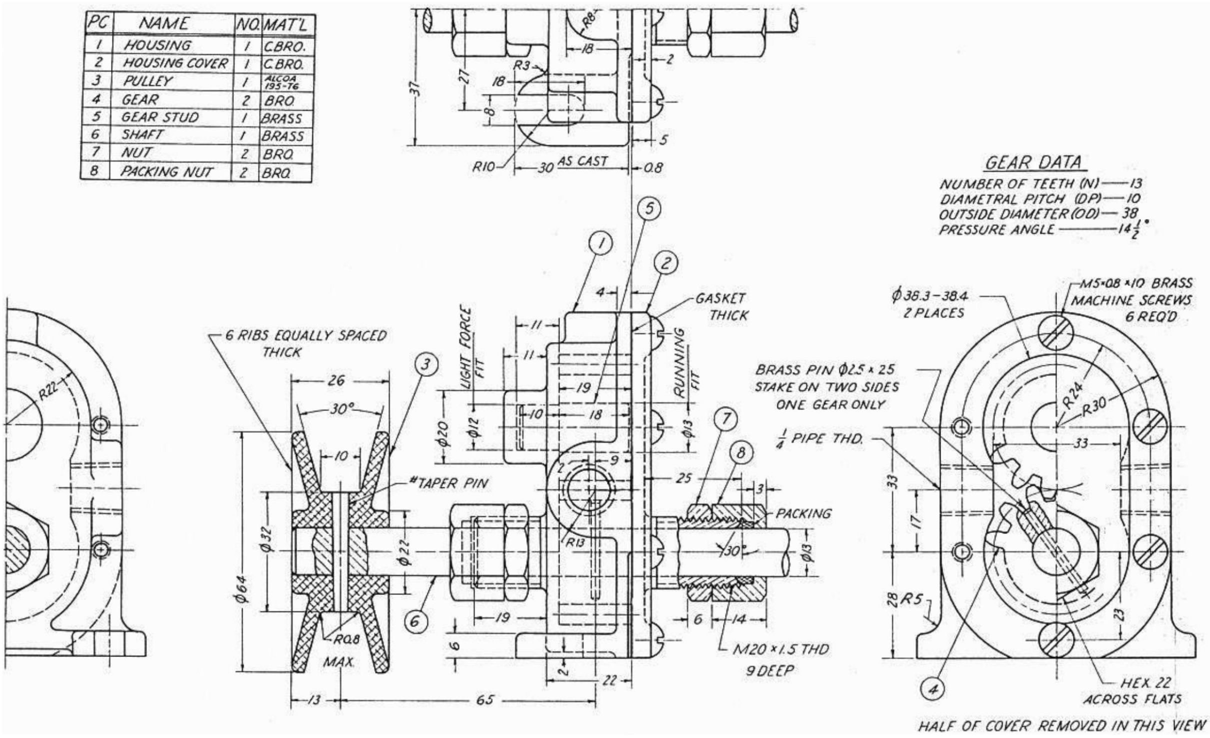


Fig. 1. Drawing of gear pump used in the RIED test to explore undergraduate skill at UTeM.

Table 1. Results from the RIED skill survey of four year levels of engineering students at UTeM

Year level	N	Mean score/12	S.D.
1	70	3.20	1.54
2	78	3.19	1.54
3	44	3.95	0.74
4	60	3.78	1.40

the tips of the gears, suggesting that the concept, or the way dimensions were depicted, were not understood.

Since student performance on this RIED test was lower than that achieved by Australian students, for whom there were no universally poorly answered questions, it was determined that RIED testing at UTeM, aimed at measuring changes in RIED skill following experimental interventions, should be limited to issues of spatial and representational conventions, and should avoid technology-based issues.

2.3 Trends in graphics education in Malaysia

Malaysian universities have signed the Washington Accord [6]. Consequently, engineering courses throughout the country fulfil requirements for a range of skills, principally analytical and knowledge-based. In common with many Western universities, the demands for 21st century engineering know-how have suppressed the more traditional 'hands-on' practical skills formerly mastered by undergraduates, and have limited the time available to develop deep familiarity with even one of the drawing standards used in Malaysia.

Internationally, the requirements for graduate engineers to be competent at RIED have remained. The abilities to create drawings, and to read and interpret drawings, are separate competencies in Europe [7] and in the USA [8]. Nevertheless, there is a trend away from the undergraduate production of hand-created engineering drawings, as firstly 2D computer drawing software, then more recently 3D modelling software have automated many of the actions needed to create engineering drawings since 2000 [9]. This automation alters the way in which students learn RIED, with a decline both in psychomotor demands and in opportunities for learning, as graphics studies decline from two or more subjects to one or less [9]. At some universities (such as at the Universities of Melbourne and Monash, Australia), subjects for the formal preparation of engineering drawings have been absorbed into other studies, have been largely replaced with 3D CAD modelling, and exist as lecture topics without significant practical reinforcement.

With similar pressures on the graphics studies at UTeM, where there remained one introductory subject in engineering drawing, based on CAD software, there did not appear to be any opportunity to address industry's concerns about engineering graduates' inadequate RIED skill through adjustments to the formal content of engineering programs.

2.4 Incidental learning in the development of RIED skills: Australian experience

Even though formal graphics education and drafting skills had declined at the Australian authors' universities, it was apparent that their undergraduate students developed reasonable RIED abilities [4]. At the University of Melbourne, mechanical engineering students engaged with engineering drawings sourced from local industry in projects aimed at re-designing major assemblies. At Monash University, a whole year of engineering design studies at the second year of the program utilised semi-formal assembly drawings of increasing complexity as the basis for a range of analytical tasks. The assembly drawing in Fig. 2, for example, was used in an end-of-year formal examination to supply data for separate questions of load analysis, the selection of ball bearings, fatigue analysis, welded joint design, bolted joint analysis and the allocation of geometric and linear tolerances.

A separate technician-training program to develop their understanding of the terminology and flaws in injection moulding processes (a task that involves complex assembly drawings) found that their RIED skills developed along with their technical understanding, even though they were not instructed in any aspects of formal engineering drawing. Their learning was enhanced by the presence of the physical artefacts that were represented in the formal drawings [10]. This gave further indication that RIED skills might well develop significantly if engineering students regularly engaged with formal drawings during their non-graphics studies.

Learning that occurs without formal engagement with the discipline, while undertaking studies in other areas has long been referred to as *incidental learning* [11]. The term is also used to describe learning that is a *by-product* of another activity,

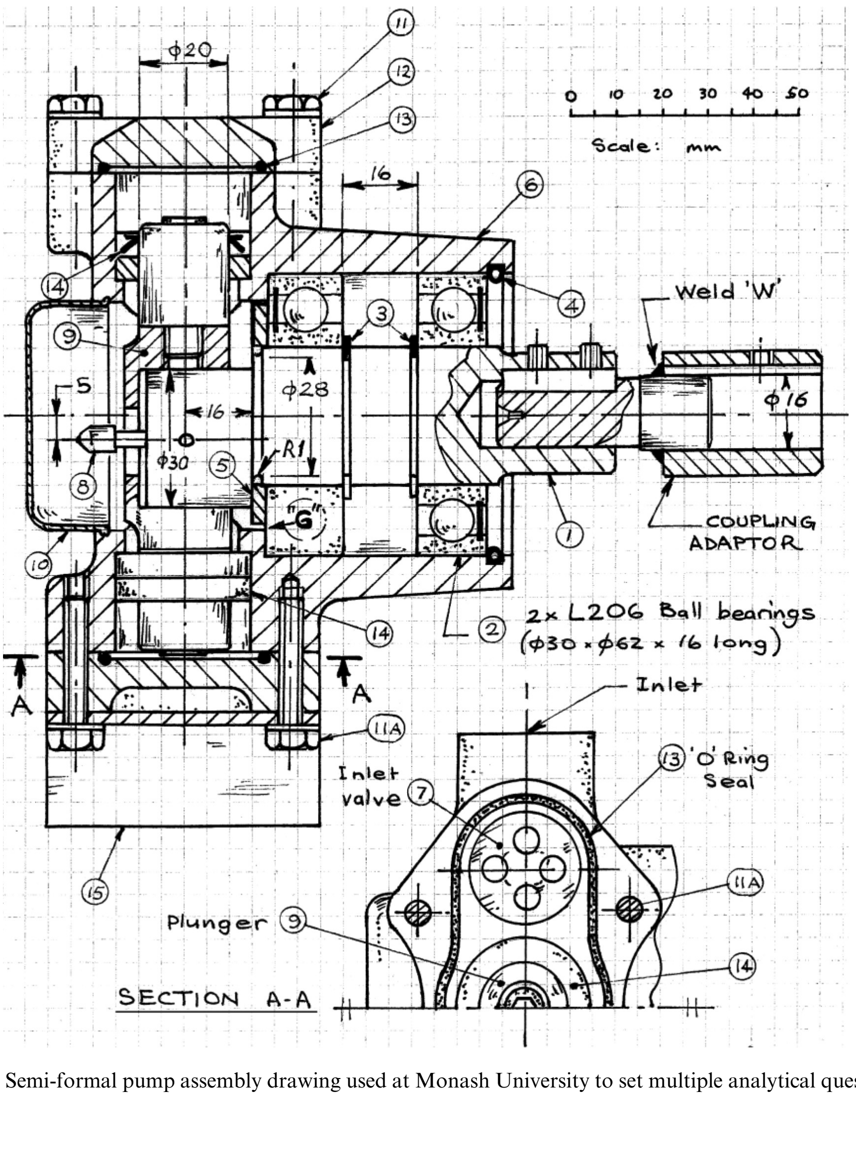


Fig. 2. Semi-formal pump assembly drawing used at Monash University to set multiple analytical questions.

and learners are not always conscious of their learning [12]. Most of the published research on incidental learning arises from observations in the workplace, since institutionalised learning (such as at universities) is typically seen as being entirely formal (*ibid*). Even though incidental learning is now widely recognised, it is not clearly defined, with definitions including 'unexpected' and 'unplanned' learning [13] contrasting with suggestions that incidental learning can be 'enhanced' by careful planning [14]. No formal studies appear to indicate the types and extent of outcomes that can arise from incidental learning, although many of the observers identify the development of affective [15] and interpersonal skills [16] in the workplace.

To the authors it appeared that the relatively good RIED skills of the Australian undergraduates may have arisen from their ongoing purposeful exposures to formal engineering drawings while they were undertaking unrelated (largely analytical) learning tasks, and that such improvements in RIED skill were due to incidental learning. This observation led to the suggestion that useful gains in RIED skill might be forthcoming in UTeM students if they, too, had a greater exposure to formal engineering drawings. It might not be necessary for their Professors to be especially skilled in either producing or reading engineering drawings as long as those drawings were professionally produced, since many of the conventions in engineering drawings are intuitive or easily deduced from their context.

3. Research aim and hypothesis

The UTeM author was scheduled to teach a machine element design subject to students at his university. It was hypothesised that if the students in that subject were required to engage with formal engineering drawings in order to extract information needed to solve tutorial problems (in much the same way as was required at Monash University, as indicated in Fig. 2), they should gain a measurable amount of RIED skill. Some of the UTeM students were also undertaking a parallel study in CAD/CAM. In that subject, formal engineering drawings were used to supply data to several learning and assessment tasks, so it seemed plausible that some RIED skill development might arise from this experience as well. Taking both studies together, students could be engaged with formal engineering drawings for half of their formal contact time for a four-week period during the semester, and it was hypothesised that this exposure, amounting to some 14 hours in the classroom (only part of which would be directly associated with drawings) would be enough to develop additional, measurable RIED skill by incidental learning. The aim of this investigation was to test this hypothesis.

4. Methodology

4.1 Research design

A pre and post test quasi-experimental design with a control group was used in the study. A quasi-experimental design is most suitable when the research intent is to establish causal relationships and a true experimental design is not appropriate. A true experimental design would have required random selection and assignment of participants, but mixing participants in unfamiliar company could have posed a threat to the internal validity of this study.

4.1.1 Participants

At UTeM, one group of 43 students (Treatment group A) was enrolled in the machine element design subject and in the CAD/CAM subject, for a total of 14 contact hours with formal drawings. A second group of 52 students (Treatment group B) was only enrolled in the machine element subject, and engaged with its formal drawings for a total of 8 contact hours. A third group of 59 engineering students (the control group) was undertaking separate studies for the duration of the research period, but were not required to engage with any formal engineering drawings for that period. All three groups had otherwise similar university experiences in the Manufacturing Engineering program at UTeM, including the formal study of engineering drawing in the first year of their program, and had previously participated in the earlier RIED survey (section 2.2).

4.2 Intervention

4.2.1 Machine elements design

The UTeM author developed new tutorial material for a subject in machine element design, incorporating seven sets of formal A3 engineering drawings, including ten assembly drawings and 78 detail drawings, with a total of 161 separate orthogonal views. Tutorial problems in topics such as: joint design, spring design and contact stress were devised to draw upon the dimensional, assembly and geometric information contained in those drawings.

A conventional introductory problem in the stress analysis of a shear joint is shown in Fig. 3. When solving this problem, a student needs to realise that the diameter of the screw at the pin (10 mm) must be used to find the shearing force at the Pin, and the Pin experiences 'single shear' across the 3 mm diameter. All of the information required to

Calculate the shear stress in the PIN when a torque of 100 Nmm is applied by a person to the HANDLE.

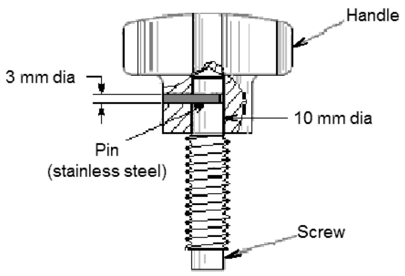


Fig. 3. Conventional tutorial problem in stress analysis.

solve the problem, and no other data, is presented in the text or on the drawing.

Fig. 4 shows the replacement drawings used for the same problem during the experiment. A sheet of detail drawings contains the dimensional and other manufacturing information for the five parts of the assembly, and a single-view assembly drawing shows how the parts fit together. We have superimposed on those two sheets, one of the strategies that students could use when solving the problem. The Handle is identified by name on the upper drawing and its role in the assembly is then sought. The interaction between the Pin, Screw and Handle is seen in the assembly, and the relevant distances (two diameters) are identified. Then the separate detail drawings of the Screw and Pin are searched for the appropriate dimensions. The diameter of the Screw is found from the hole in the Handle, and the diameter of the Pin is found on its drawing, and checked against the hole in the Handle. The tolerances on the Pin's diameter demand a closer inspection and a decision to be made (based on size range and an appreciation of significant figures).

Sixteen tutorial problems, demanding increasingly complex interpretations of the sets of drawings, were set across four topics, to be attempted during four sessions of 1.5 hours each. Participants were observed during these problem-solving sessions and their progress was noted. It was estimated that participants engaged with 106 of the 161 separate views during their tutorials, although an unknown number of additional views would have been scanned and rejected during participants' searches for data. The sets of drawings were collected at the end of each session, and were not made available at other times.

4.2.2 CAD/CAM

The CAD/CAM subject that ran in parallel with the machine elements design subject incorporated a series of 15 exercises undertaken during eight hours of supervised laboratory time, including the task shown in Fig. 5. Students were required to read orthogonal drawings and create 2D reproductions and 3D CAD models. For the exercise shown in Fig. 5, students had to recognise the internal and external cylindrical forms of the piston, its internal cones, and the cylindrical cut-out on the skirt. There were several ways in which the model could be constructed, including the use of 3D primitives, and the use of revolved sections. Other exercises included the assembly of 3D models, but, in general, the engineering drawings in this subject were less complex than those used in the machine element design subject.

4.3 Research tools

The change in RIED skill of the participants was measured by a combination of pre- and post tests. There were two reasons why the original RIED test (section 2.2) was not suitable for this study.

First, since many, but not all of the participants had already been part of the original (anonymous) survey of RIED skill at UTeM, the re-use of this test could have produced different, but unidentifiable learning effects [17] for the proposed pre- and post testing. The learning effect would have invalidated the apparent gains.

Second, students at UTeM could not adequately answer four of the questions on the original RIED test because they could not interpret the technology associated with the question, so only eight questions (of the 12) remained as useful diagnostic measures. In view of the relatively short time period (four weeks) during which the experiment was to be conducted, it was estimated that at least 12 useful questions would be required if subtle improvements in RIED skill were to be identified.

Two different, but similar RIED tests were developed for pre- and post testing. The use of different pre- and post tests was intended to avoid superficial inflation of learning gain. It is known that if some standard tests are administered twice, before and after a treatment, in order to measure gains in skill or knowledge, the apparent increase in performance may be inflated by a learning phenomenon for the test itself [17].

The REID pre test was based on an established RIED tutorial exercise [18] involving a single component in a multi-view drawing (Fig. 6), in which respondents only had to interpret the geometrical characteristics of the drawing. The choice of test questions was partly determined by lessons learnt from the preliminary REID study at UTeM (section 2.2), and were selected from a list of 100 published questions associated with the drawing. The pre test comprised 15 diagnostic questions, with a further 10, mainly easier questions interspersed. The ques-

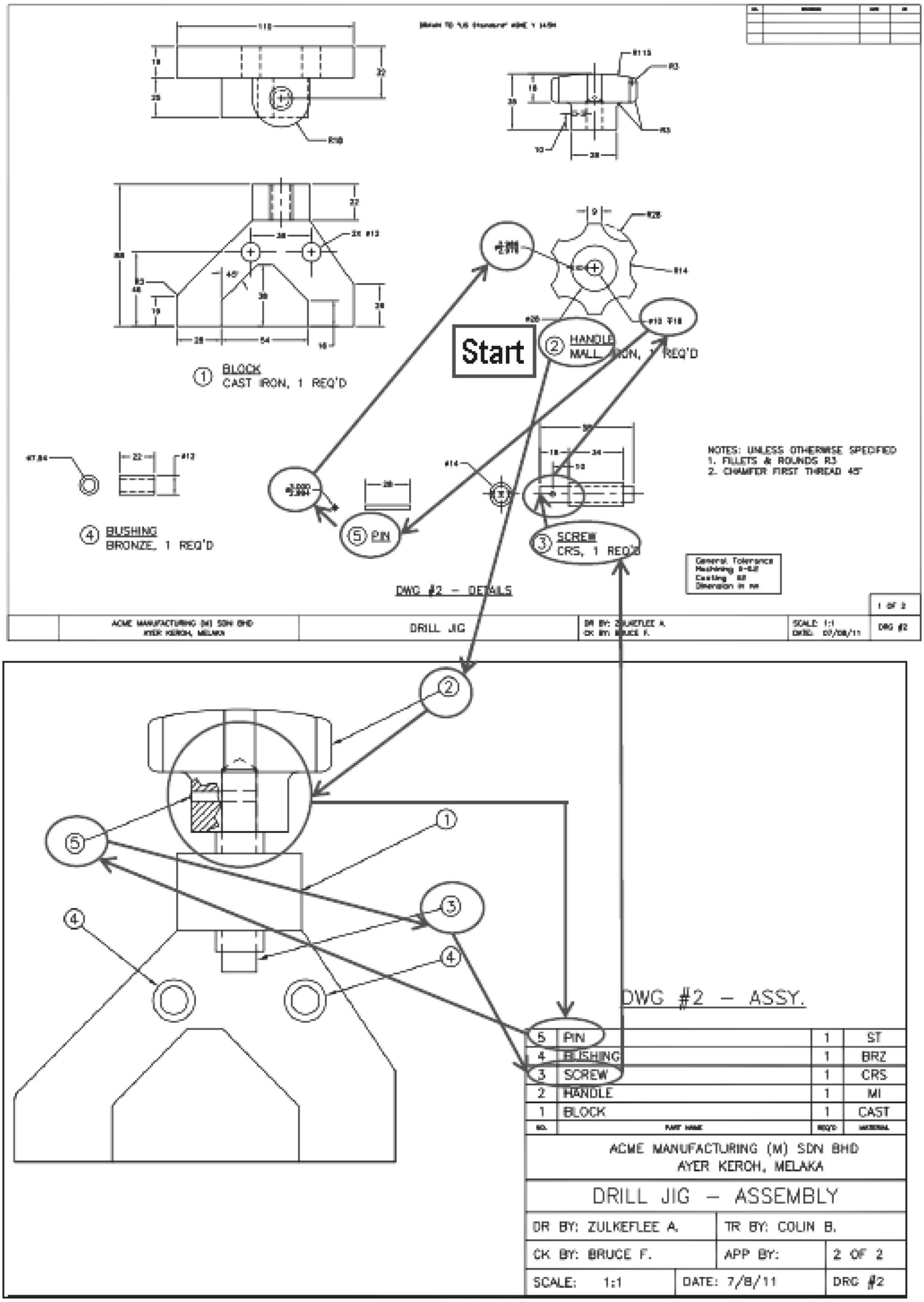
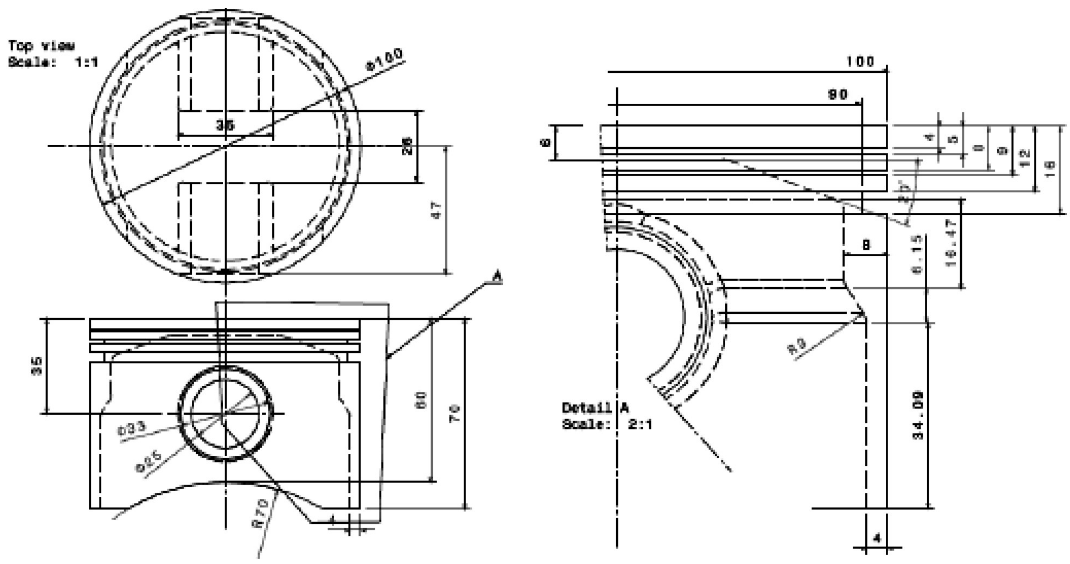


Fig. 4. Annotated set of drawings used during the experiment for the tutorial problem described in Fig. 3.



A	PISTON	Bad	Ave	Good	Weightage	Marks
	Ability to	1	2	3		18
1	Construct EXTERNAL & INTERNAL piston feature (Detail A & R70) [doom/flat/cavity]				3	
2	Construct INTERNAL PAD feature Dia35 (Top View)				1	
3	Construct BOSS feature Dia33 (Front View)				1	
4	Design intent [ALL ROUNDS, CORNERS & EDGES R3] (R1 at INTERNAL PAD)				1	
	TOTAL					

Fig. 5. Solid modelling task associated with the CAD/CAM subject.

tions (refer Appendix) were approved by the industry-based engineers who assisted in the earlier survey, refined with a voluntary group of ten undergraduate students (when a suitable test duration of 10 minutes was determined), required participants to calculate dimensions by combining sizes across different views (11 questions), associate lines and shapes across views (5 questions), ascertain 2D shapes (3 questions), identify edges (3 questions) and other (3 questions).

The 10-minute RIED post test used in the research was a modified version of the RIED pre test, with extra (but flawed) parts added to the image, turning it into a dimensioned assembly drawing (Fig. 7). The same 15 diagnostic questions were retained, and a further five new questions based on the assembly were added (refer Appendix). The five additional questions were devised to throw light on students' abilities to interpret the assembly and in particular to identify flaws in the design, seeking to explore the three important issues raised during the earlier industry survey (section 2.1).

4.3.1 Data gathering procedure

The RIED pre test was administered to the treatment groups before they began the problem tasks and to the control group. The UTeM author delivered the subject in machine element design for four weeks, during which period the treatment groups had access to the set of engineering drawings for solving the tutorial problems. Due to the individualised seating arrangement in the tutorial room, participants in the treatment groups sometimes found it awkward handling the A3 booklet of drawings, although these participants nevertheless appeared motivated by the challenge of interacting with real engineering drawings. The treatment and control groups completed the RIED post test six weeks after they had taken the pre test.

5. Results and discussion

Analysis of the RIED pre test results found its Cronbach's Alpha to be 0.715, indicating good internal consistency [19]. Item analysis determined

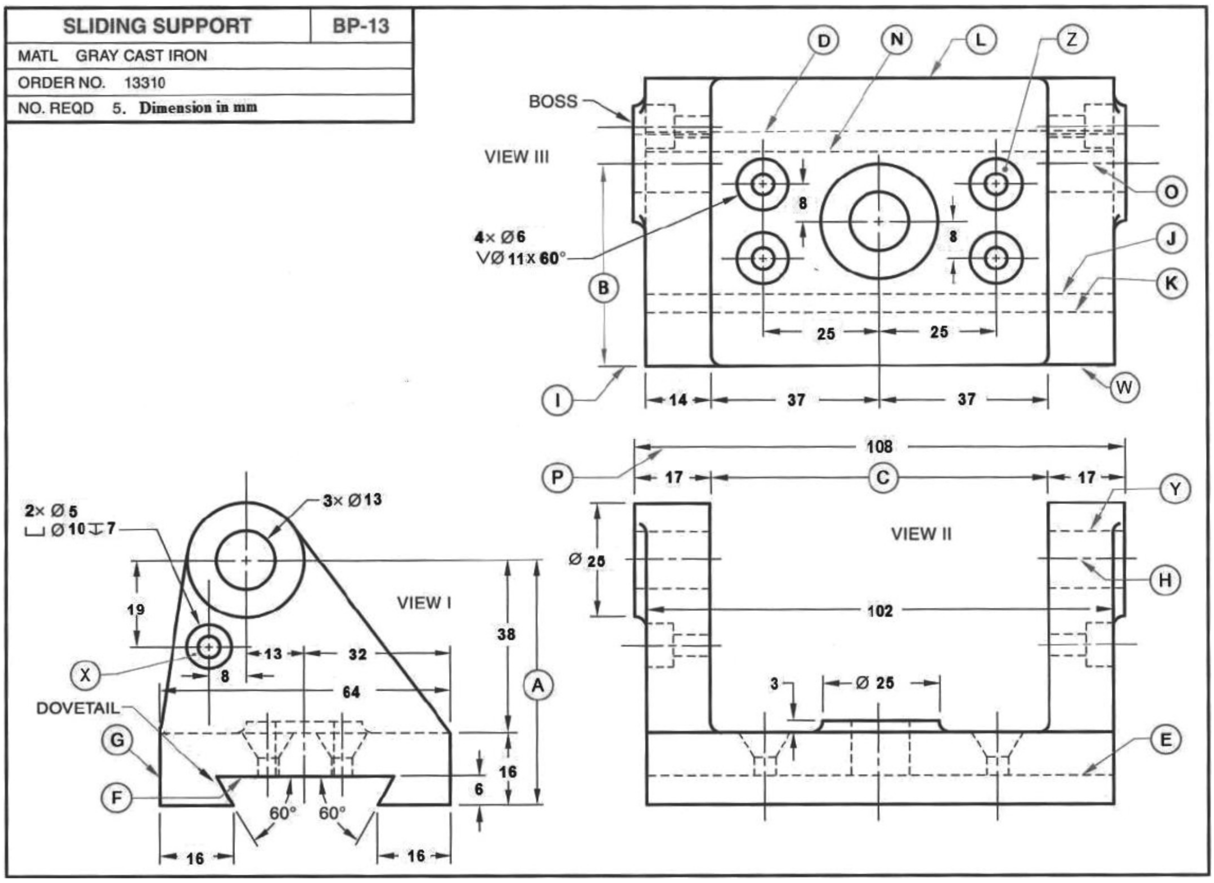


Fig. 6. Component drawing used in the RIED pre-test.

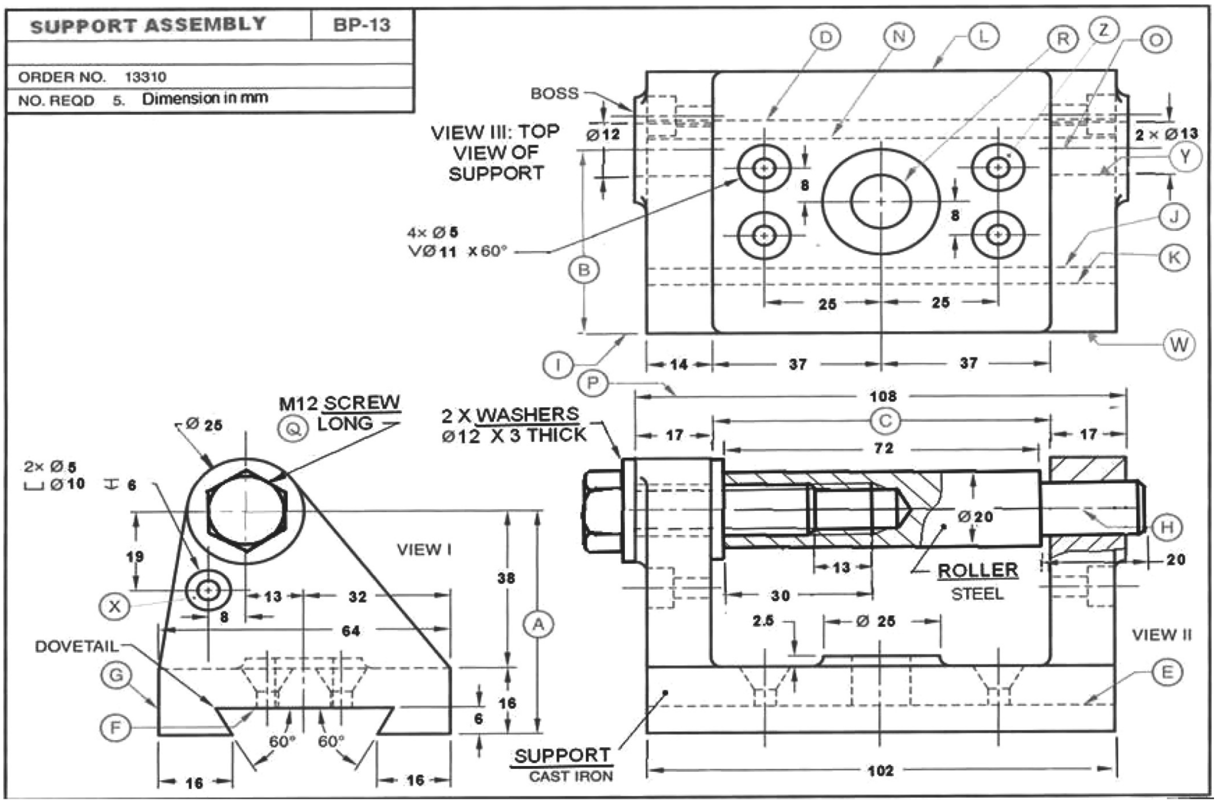


Fig. 7. Assembly drawing used in the RIED post-test.

Table 2. Statistics for the experiment

Group	Machine Design (MED) hrs	CAD/CAM (CAD) hrs	RIED Pre-test (25 Q)	N	Mean RIED Gain	SD RIED Gain	Comparison with control-Tukey HSD
Treatment A	6	8	12.7	43	2.42	3.59	$p < 0.001$
Treatment B	6	0	13.4	52	1.11	2.94	$p < 0.15$
Control	0	0	8.78	59	-0.03	2.40	–

the Difficulty and Discrimination Indices [20] for each of the 15 questions in the pre test. The Difficulty Index ranged from 0.25 to 0.75 for 14 of the questions, indicating that most questions had intermediate difficulty. No Discrimination Index was negative, with all but two questions being good discriminators ($D > 0.2$). A similar analysis for the same 15 diagnostic questions in the RIED post test found that the Difficulty Index now ranged from 0.26 to 0.79, and the Discrimination Indices from 0.18 to 0.80. Students did not cope well with the five assembly-based questions in the post test, with Difficulty Indices between 0.11 and 0.32 and Discrimination Indices from –0.04 to 0.33 (two Indices were negative).

The three groups' results are shown in Table 2.

The control group participants' mean RIED gain was –0.03 (SD 2.4, $p > 0.9$). This indicated that there was no significant learning effect for the pair of RIED tests, meaning that the measured difference between an individual's RIED pre- and post test scores, when testing is separated by at least six weeks, does not require an adjustment to accommodate a learning effect. Treatment group A's mean RIED gain (2.42) was very significant ($p<0.001$). The Cohen's effect size value ($d = 0.84$) suggested a high practical significance [21]. Treatment group B's mean gain was not significant.

A multiple regression determined the relationship:

$$\text{RIED Gain} = -0.03 + 0.19\ \text{MED} + 0.16\ \text{CAD} \quad (1)$$

The regression $R = 0.32$ is significant (ANOVA $F(2, 151) = 8.57$, $p < 0.0003$), and the coefficients of the treatment types are meaningful ($t = 2.03$, $p < 0.044$ and $t = 2.15$, $p < 0.032$ respectively). The similarity of the coefficients (0.19 and 0.16) indicates that the separate studies of Machine Element Design and CAD/CAM contributed similar gains in RIED skill per hour of purposeful exposure to engineering drawings (approximately 5 to 6 hours exposure per point gain). Incidental learning in previous years of the CAD/CAM subject now appeared to be responsible for the increased RIED performance of levels 3 and 4 of the survey group (section 2.2).

Within the treatment groups, male participants gained a mean of 1.95 ($N = 53$, $SD = 3.20$), while females gained a mean of 1.63 ($N = 42$, $SD = 2.87$). A t-test indicated that the gender difference was not significant ($t = 0.51$, $p = 0.70$).

Treatment group A's performance on the additional five assembly-based questions was encouraging, but scattered, with a mean of 1.6 ($SD = 1.06$), and somewhat better than Treatment group B's mean score, at 0.74 ($SD = 0.59$). Nevertheless, the level of performance was consistent with the observation, made during the original RIED survey of students at UTeM, that students had difficulty interpreting the implications of the technology represented in a RIED test.

5.1 Observations and expansion

The additional RIED skill was developed without increasing students' workload, and was achieved economically since drawings were readily obtained from external sources and the UTeM author simply used his time to set normal learning tasks that accessed those drawings. Students showed extra enthusiasm while they engaged with the formal drawings, and it appears likely that motivation would be continued in subjects, including fundamental studies, that included exposure to relevant contemporary engineering practice. Since there are many analytical (engineering science) subjects scattered throughout the BE program at UTeM (in common with conventional study programs delivered elsewhere), it will be possible to apply this approach to at least one subject per semester, using the same set of engineering drawings throughout. Alternatively, drawings from different industrial sources may be selected to expose students to the different graphics standards.

Throughout the investigation, care was taken to avoid any suggestion to students that the approach was intended to increase RIED, so the outcomes could be fully attributed to incidental learning. Unprompted feedback from some students indicated that they became progressively more comfortable with their engagement with the drawings. Since the principal task in the CAD study was to construct alternative images and models from the formal drawings supplied, it could not be determined whether alternative CAD software might be more efficient or beneficial in developing RIED skill. It appeared to the authors that the benefit arose from relating 3D models to their 2D drawings, as with our earlier work with technicians [10], and not the use of particular CAD software *per-se*. The authors are aware that most of the drawings used in the study presented both contemporary terminology and basic mechanics of devices, and it seems plausible that students would have gained additional appreciation of these aspects via incidental learning. Further work is needed in order to quantify this possibility, and to determine if other tools, such as computer simulations can contribute in similar ways.

6. Conclusion and recommendation

When Malaysian undergraduate engineering students were purposefully engaged with formal engineering drawings in order to extract data for solving unrelated analytical and CAD problems, they gained measurable RIED skill without requiring additional graphics instruction. Since teachers do not need special skills in RIED when they create learning tasks from industrial drawings, an expansion of the approach demonstrated in our research, throughout and across appropriate subjects in undergraduate engineering programs, is recommended.

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Appendix. RIED pre- and post test questions. Diagnostic question numbers bold italic

Pre test Q No	Post test Q No	Question
1		Determine height A
2		What is the basic dimension C?
3	***1***	What is the shape of the surface represented by the line Y?
4	***2***	What line in VIEW III (top view) represents the surface G?
5		What line in VIEW III (top view) represents the line H?
6	***3***	What does the line E in the VIEW II (front view) represent? (an edge, a surface, or both)?
7		What is the outside diameter of the BOSS?
8		How deep is the DOVETAIL machined?
9		What is the angle to the horizontal at which the DOVETAIL is machined?
10	***4***	Is W an edge, a surface, or both?
11		What surface in VIEW I (side view) is represented by line E?
12	***5***	Determine dimension B
13	***6***	How wide is the opening in the DOVETAIL?
14	***7***	What is the shape of the region labelled Z?
15		Is J an edge, a surface, or both?
16	***8***	Is line J above, below, or at the same level as line K?
17	***9***	How many BOSSES are shown?
18		E corresponds to which line(s) in VIEW III?
19	***10***	What lines in the VIEW III (top view) represent the DOVETAIL slot?
20		How far off the centre of the SLIDING SUPPORT in VIEW III is the centre of the two holes in the BOSSES of the uprights?
21	***11***	Give the diameter of the largest hole(s) in VIEW III (top view)
22	***12***	Give the diameter of the stepped (counterbored) holes
23	***13***	What are the dimensions of the holes with the conical (countersunk) edges?
24	***14***	Do the holes with the countersunk edges go right through?
25	***15***	What is the shape of the region labelled X?
	16	Find two design flaws with the rotating ROLLER
	17	Find the incorrect dimension in VIEW II
	18	How many parts are there in the assembly?
	19	What is the diameter of Hole R?
	20	What is the length 'Q' of the SCREW (excluding the head)?