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RESPONSES OF NOVICE DESIGNERS TO UNSTRUCTURED PROBLEMS

Colin Burvill, Martin Leary and John Weir

Abstract

The development of novice engineering designers is assisted at the earliest levels by building problem solving skills within well-defined problem domains [1]. These early experiences are structured to provide success measures and build design confidence, but then proceed progressively from the familiar to the unfamiliar. This paper discusses the performance of novice designers when introduced to increasingly unstructured problems, and in particular, those that require creative responses.

Keywords: Industrial case study, cognition and learning, training of designers, design education process, user evaluation

1 Introduction

The objective of this study is to record and analyse the experiences of group of novice designers (students nearing graduation) to increasingly open-ended and unstructured industry-based problems. Their experiences will be compared to responses from experienced design practitioners who acted as industry clients. The responses of novice designers to the two major design tasks of their final year of undergraduate study has been investigated:

Task 1: A substantial task, completed in small groups, within an unfamiliar working environment, responding to problem definitions within a real–life, industry. The novice designers work on these problems in a quasi-professional manner, approximating that of a professional design bureau [2]. The analysis presented in this paper is based on 45 industry projects completed in the first half of 2002. All novice designers provided questionnaire responses, as did over 60% of the industry clients.

Task 2: A less substantial task with a minimum of administrative structure, that involves recording, processing and evaluating information delivered in seminars by senior design practitioners from the local engineering and manufacturing sector. The task is completed individually and offers the novice designer freedom to present responses and evaluations in a creative manner. The analysis of this task is based on 110 submissions.

2 Task overview

Studies of the performance of novice designers in tasks 1 and 2 have been compared relative to the quality of their submitted outcomes (ie. the final academic mark awarded for each task) and the responses available from surveys completed by both the novice designers and their experienced industry clients/mentors. Insights obtained from the industry client responses, often represented by experienced design practitioners, are compared with those obtained from the novice designers [3][4]. Existing research has been used to assist the process by which review data is processed and reported [5][6][7]. The following sections provide an overview of the two tasks and highlight the expectations and support framework offered to the novice designers.

2.1 Task 1 : Industry based project

Each team of two or three novice designers was required to provide creative, innovative and practical contributions in response to the problem description offered by their industry client. Most industry clients are from the manufacturing and engineering sectors, with a small number from the energy production, research and agricultural sectors. Weekly academic mentoring was mandated to encourage ongoing progress and to simulate a professional design-studio working environment. Academic mentors offered minimal intellectual support except when needed to ensure a maintenance of project momentum. A distinct project description was provided to each of the 45 teams at the outset of their project. All teams completed different projects with no task overlap, despite a number of teams completing projects for the same industry client.

A series of document templates (eg. Scope of Works, Progress Report and Final Report) and details of administrative expectations, including generic professional and academic expectations for the task, were provided to each of team. Following the completion of all projects, the experiences of industry collaborators and novice designers were surveyed, the results of which are included in section 3.

Outcomes associated with task 1 that were analysed include:

- Comparisons between the quality of each project outcome, from the perspective of experienced designers (academic and some industry mentors), industry clients and the novice designer;
- A review of novice designer performance by experienced designers (the authors and other academic colleagues). A two-stage assessment procedure is used, where the academic supervisor supplies an initial mark and a one–page assessment sheet to a review panel of experienced design academics who review all project reports and their associated marks. This maximises uniformity and fairness as, for example, a project involving "product based" design is usually more readily structured and realised than that for a "system based" design, especially for novice designers.

2.2 Task 2 : Response and evaluation of practitioner seminars

Task 2 is completed individually, and in 2002, was focused on eleven seminar presentations delivered by professional engineering design practitioners from a wide range of industry environments including: electric power generation, forged component manufacture, electro-hydraulic systems engineering, container crane fabrication, pump innovation and manufacture, Royal Australian Navy engineering, and automotive suppliers.

Each fifty-minute presentation included a brief introduction, describing the speaker's occupation, current role and the industrial activities relevant to the presentation. This was followed by an exploration of professional engineering activities completed by the speaker. Students were required to complete a staged program of activities (without being offered a format for its completion) based on a series of requirements.

The requirements of this task, correctly distilled, included the following phases:

phase 1. Report of the specific presentation themes (ie. the technology, design or activity used as a basis for discussion) and delivery techniques (eg. case studies, observation and/or experience);
phase 2. Construct a prioritised list of the generic themes of engineering design;
phase 3. Develop a framework to present associations between the information provided during guest seminars and the list of generic themes for engineering design constructed;
phase 4. Provide a precise definition of the following measures: "quality", "relevance", "importance" and "value". Based on the structure developed in phase 3, apply a series of quality measures to relate the presentation content to the generic themes.
phase 5. Based on the outcomes of phase 4, offer an objective means of reviewing the presentations, allowing them to be reviewed from a common basis. A preferred performance measure can be chosen (systematically) from a series of alternatives. The chosen measure can be used to review presentations from a common basis, and can be used to answer such questions as: "Was there a balance between the generic themes presented?"

Novice designers were advised that the application of quantitative data was of far less value than the creative implementation of a workable framework for this kind of analysis.

3 Outcomes from case study

The performance of novice designers at an Australian university in 2002 when attempting tasks 1 and 2 is presented as a case study. Analyses make use of survey responses, academic marks, and associated interactions.

3.1 Task 1

Comparisons have been made between the quality of each project outcome from the perspective of experienced designers (academic and some industry mentors) and novice designers (undergraduate engineers nearing graduation).

Following the submission of final reports, novice designers were asked, in retrospect, at what stage they actually understood the scope of their project. Most reported that a degree of certainty was achieved when features or sub-functions of the project had been identified (figure 1, stage 2) or when the underlying engineering science was better understood (figure 1, stage 4). Most others gained certainty when they had engaged with the problem at a deeper level through the conceptual design process [1][10] (figure 1, stages 5, 6, 8).

Design teams were asked to rate the:

- Influence of the client mentor on their understanding of the project scope;
- Responsiveness of their client.

Client representatives were asked to rate the:

- Performance of the student team in carrying out the required tasks;
- Quality of the outcomes produced by the student team.

Rating options were: excellent, very good, good/adequate, poor and very poor (figure 2).

Most novice designers rated the contribution (influence) of their client mentor in the range of good to very good (69% of responses), with 63% satisfied that the client provided a clear definition of need at the outset, an important phase in the design cycle [2][8]. A wider spread of responses was apparent for client responsiveness with 31% of responses rating the client between adequate and poor.

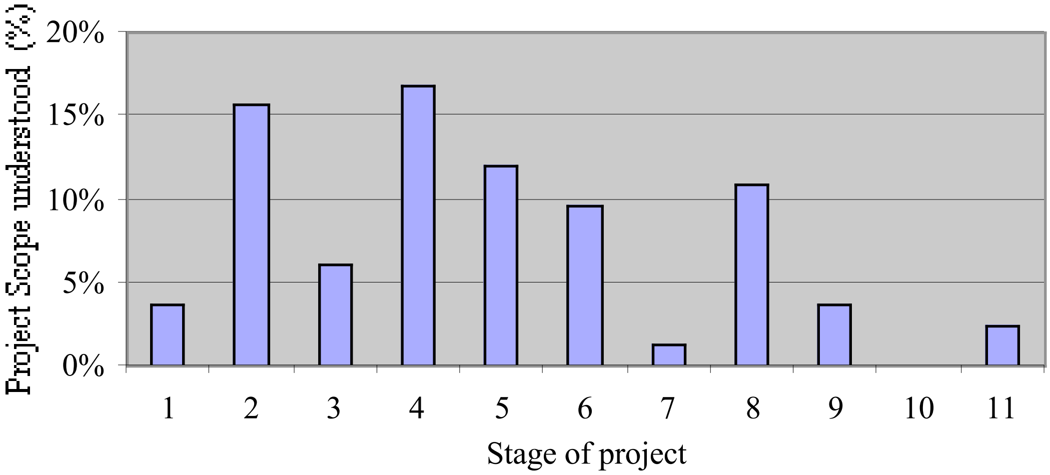

Figure 1. Novice designer responses to the question
"At what stage did you understand, with certainty, your project's overall scope?"
Y-axis: "Project Scope understood (%)" X-axis: "Stage of project" (index):
1 = development of an agreed project definition,
2 = sub-goaling (identifying features or sub-functions of the project),
3 = completing task descriptions (timetable construction),
4 = evaluation of background data and other researched information,
5 = conceptual design of alternative solutions,
6 = choosing the preferred solution from the proposed alternatives,
7 = attempts at sample calculations or creation of algorithms,
8 = experimental or computer based analysis of preferred solution(s),
9 = development of a means of interpreting analysis results (eg. comparative studies),
10 = interpreting the results of your comparative study,
11 = report writing.

The majority of clients who responded to the survey questionnaire considered novice designer performance to be good, very good or excellent (83%) leading to project outcomes that were, at the very least, good (100%). This compares with 77% of teams being confident that they provided useful contributions to their client. Implementation of design recommendations was estimated at 45% by teams (with an additional 37% unsure) and 50% by clients (with an additional 42% unsure). The majority of clients considered that design teams demonstrated a commitment to the agreed project objectives (92%).

Most design teams reported that clients maintained a consistent expectation regarding the agreed project definition (73% or responses) as embodied in the Scope of Works document (the first three stages of project development, figure 1). Of the changes later sought by clients, significant changes accounted for only 4% of the total. This is consistent with client responses (25% reported that changes occurred as the project proceeded) with the majority of clients considering the changes to be in the best interests of producing a satisfactory outcome (68%). Changes to the agreed project definition initiated by design teams were associated with:

- scope alterations resulting from a deeper understanding of the core issues/problems (27%); and,
- re-evaluating of the available time to complete tasks prior to submission, leading to a reduced scope (16%).

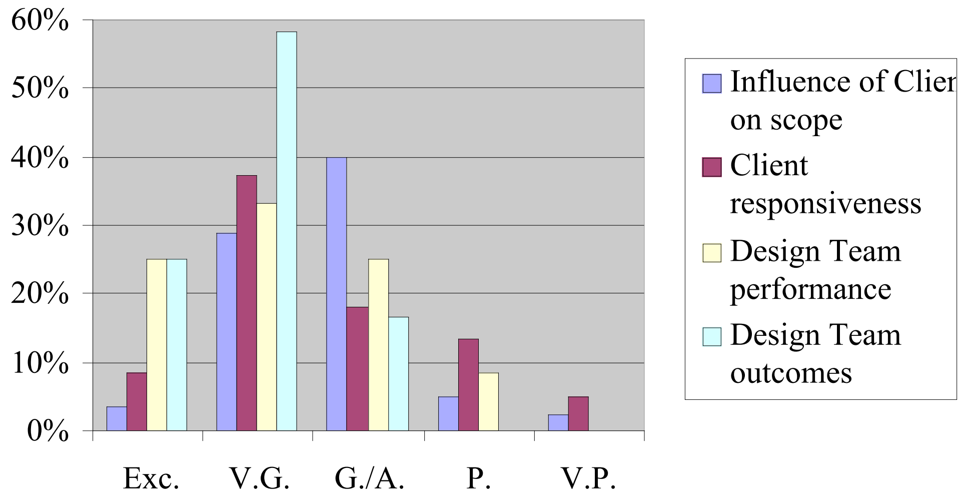

Figure 2. Questionnaire responses
Design team responses: "influence" and "responsiveness" of Client
Client representative responses: "performance" and "outcomes" of Design Team
Y-axis: Rating response (%) X-axis: Rating (index):
Exc. = excellent, V.G. = very good, G./A. = good / adequate, P. = poor, V.P. = very poor

The administrate framework provided for all participants resulted in most clients reporting that they had a clear understanding of the collaborative program (75% of responses) and the overall administration of their project (83%). Most clients reported no impediments to all parties having a clear and common understanding of the agreed project definition and scope (58%) with the major difficulties that impeded projects being: poor communication (17%), lack of "on-site" contact time (8%); and, novice designers having inadequate understanding of the associated engineering science (6%).

Only 28% of the design teams reported no impediments to progress throughout the five month project duration. The major causes of impediments reported:

- novice designers required to learn significant new engineering science disciplines to fully understand the project task (43%) – this is in agreement with industry mentor reports but both parties may have not recognised the learning phases associated with entry into any new discipline;
- Limited understanding of the actual problem by the industry client (17%).

Minor causes included: lack of commitment from industry client (6%); change in project direction as the project proceeded (6%), limited technical expertise of client (4%). Design teams were asked whether their previous studies had adequately prepared them for this substantial, semi-professional activity:

- 63% stated that the course provided an adequate preparation;
- 18% recognised engineering science deficiencies;
- 13% noted difficulties associated with dealing with problems in a professional environment (eg. compromises: technical, financial and social).

Design teams and industry clients were both asked to respond to questions of frequency of communication and the associated benefit. Significant responses from design teams: twice weekly: 30%, weekly: 13%, fortnightly: 22%, monthly: 7%. Design team responses to the overall quality of client interaction are included in figure 2. 75% of clients were satisfied with the level of interaction. During these interactions, design teams reported that 37% of client mentors were aware of, and actively engaged in conceptual and formal design methodologies, 10% of clients were aware of design methodologies but didn't encourage their use, and 17% were aware of design methodologies and actively resisted their use.

Novice designers were asked to respond to the following assertion:

The general learning outcomes in this project (eg. experiences in client interaction, use of formal project work procedures, applying engineering design methods to practical "real world" problems) are more important than the project topic itself.

At the outset of the project, 71% of novice designers agreed with this assertion. At the completion of the project, this had increased to 82%.

3.2 Task 2

This task was designed to challenge novice designers by avoiding academic guidance beyond that summarised in section 2.2 to a problem that required an appreciation of abstraction. It attempts to expose novice designers to the power of generic measures to provide a common basis for collation and analysis of seemingly disparate information. Creativity and risk-taking were encouraged, in particular, through the low relative value of the final mark compared to task 1 (figures 4 and 5). The performance of 110 novice designers has been analysed.

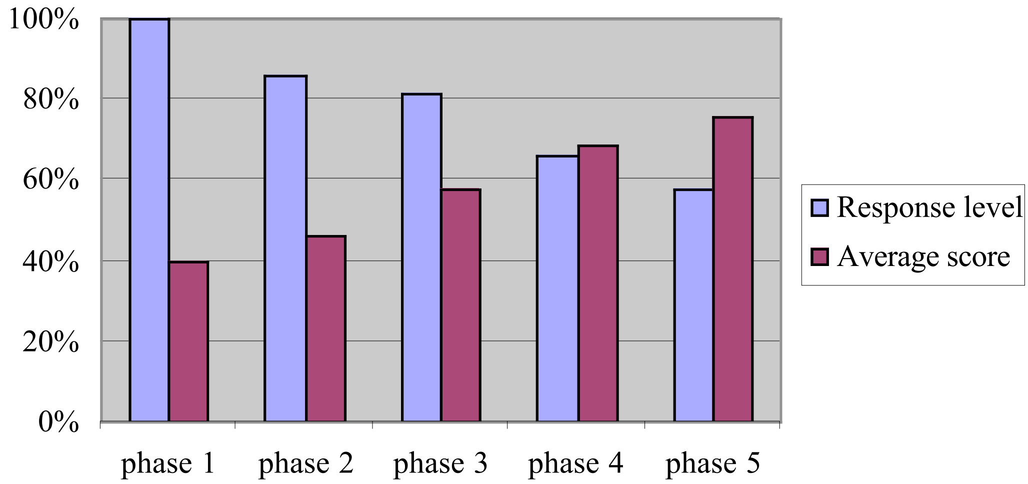

Figure 3. Task 2 responses. "Response level" indicates the percentage of submissions that included the phase (Section 2.2) identified on the X-axis. "Average score" reports the average mark for submissions that include a response to all phases up to and including the phase identified on the X-axis.

A reducing number of novice designers attempted phases beyond simply reporting the content of seminars (phase 1, figure 3). Irrespective of the last phase attempted, all submissions included all preceding phases. These additional tasks corresponding to: (phase 2) propose generic themes associated with engineering design, (phase 3) develop a conceptual tool to then, (phase 4) provide a systematic association between seminar topics and generic themes, that can then be used to, (phase 5) provide a performance measure for individual speakers and the seminar program itself.

A summary of notable statistics from the submitted responses to task 2:

phase 1. Reporting: 100% of novice designer submissions included this phase. Submissions that progressed no further than phase 1 received an average final score of 39%.

phase 2. Themes: included in 86% of submissions. Of these, all identified some generic themes, 47% created a means of prioritising the themes and 23% quoted references used to achieve this task.

phase 3. Association of theme and seminar content: 81% of submissions. Of these, the following conceptual design tools were used to assist exposition: concept map (30% of submissions); descriptive table (17%); quantitative association (ie. table, graph, list, or a combination) (57%). A few submissions used more than one tool.

phase 4. Quality measures: 61% of submissions. Of these, 82% defined their nominated quality measures and 96% offered a satisfactory means for scoring seminar presentation content against generic themes.

phase 5. Objective review: 57% of submissions. Of these, 74% contained a meaningful qualitative review with 44% explicitly identifying a performance measure and 42% reporting a series of final scores.

Few submissions calibrated the relative importance of their nominated generic themes and many estimated seminar content importance subjectively rather than attempting to apply a numeric measure. This style of submission typically contained large amounts of mostly unnecessary and irrelevant detail without reference to the specific features requested in the academic guidelines (section 2.2).

Most submissions that attempted phase 2 and 3 without producing a numeric framework struggled to accomplish phase 4. Those who based their solution on problem solving tools such as "quality function deployment" (QFD) [10] produced sound frameworks for use in phases 4 and 5. An abstraction associated with the use of QFD is that it is normally referred to as a planning and problem solving tool rather than a "seminar evaluation" tool. However, its underlying structure is ideal for creating a framework to analyse dissimilar information, whether "customer requirements" versus "engineering characteristics" or "generic themes" versus "seminar content". The relationship sought between generic themes and seminar content was very occasionally ranked but, more often, the relationship would be qualitatively assessed (i.e. a link either exists or doesn't exist).

There was some occasional integration between phases but the vast majority of submissions were presented in a linear fashion, following the academic guidelines made available. This is confirmed by the observation that all submissions included all preceding phases, irrespective of the last phase attempted.

3.3 Interactions between tasks 1 and 2

Task 1 is a substantial project with a time commitment of at least 120 hours per novice designer (no less than 240 hours per project). The major unstructured elements of this task are associated with working environment and the project itself, especially when unfamiliar engineering sciences and associated technologies are integral to a successful outcome. To compensate for these unstructured elements, novice designers are offered a great deal of administrative and management structure and support. Task 2 is far less substantial (no more than 3 hours per seminar, including seminar attendance) but seeks to challenge the novice designer to use and build upon conceptual engineering design experiences of previous years by responding to and evaluating a seminar series in a manner for which there is no obvious precedent.

The final mark awarded to each novice designer for both tasks 1 and 2 have been correlated (figure 4). A linear trend equation identifies a slight positive relationship between the two tasks although the correlation coefficient is weak (R = 0.26) [9]. The unstructured elements of Task 1 did not impede the majority of novice designers producing very good to excellent outcomes (table 1). This compares with task 2 where a minority produced excellent outcomes but the average performance is far below that for task 1, with a much larger standard deviation.

Table 1. Mark statistics for tasks 1 and 2 (2002)

	Task 1 (%)	Task 2 (%)
maximum	96.0	100.0
average	87.3	67.9
minimum	60.0	30.8
standard deviation	7.1	16.8

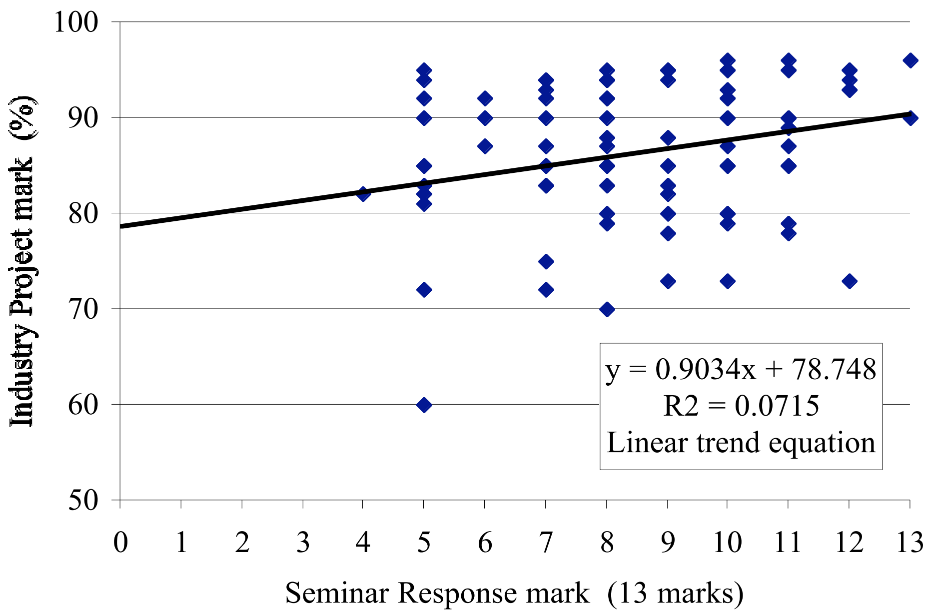

Figure 4. Comparing marks awarded to novice designers for
Y-axis: "Industry Project (task 1) mark (%)" X-axis: "Seminar Response (task 2) mark (max. 13 marks)"

4 Discussion and conclusions

The case study reported in section 3 has indicated that novice designers were better able to accommodate the unstructured elements associated with their first semi-professional project experience (task 1) than those associated with a novel approach to responding and evaluating material presented in a lecture environment (task 2).

For the majority, task 1 provided novice designers with their first experience as a professional engineer. All were prepared with project based tasks of increasing scope, complexity and administrative expectations in the preceding design subjects, so the impediments reported are consistent with experiences for which there is no precedent – perceived engineering science deficiencies and issues associated with "industrial culture" (eg. social systems, conflicting requirements, technical and financial limitations).

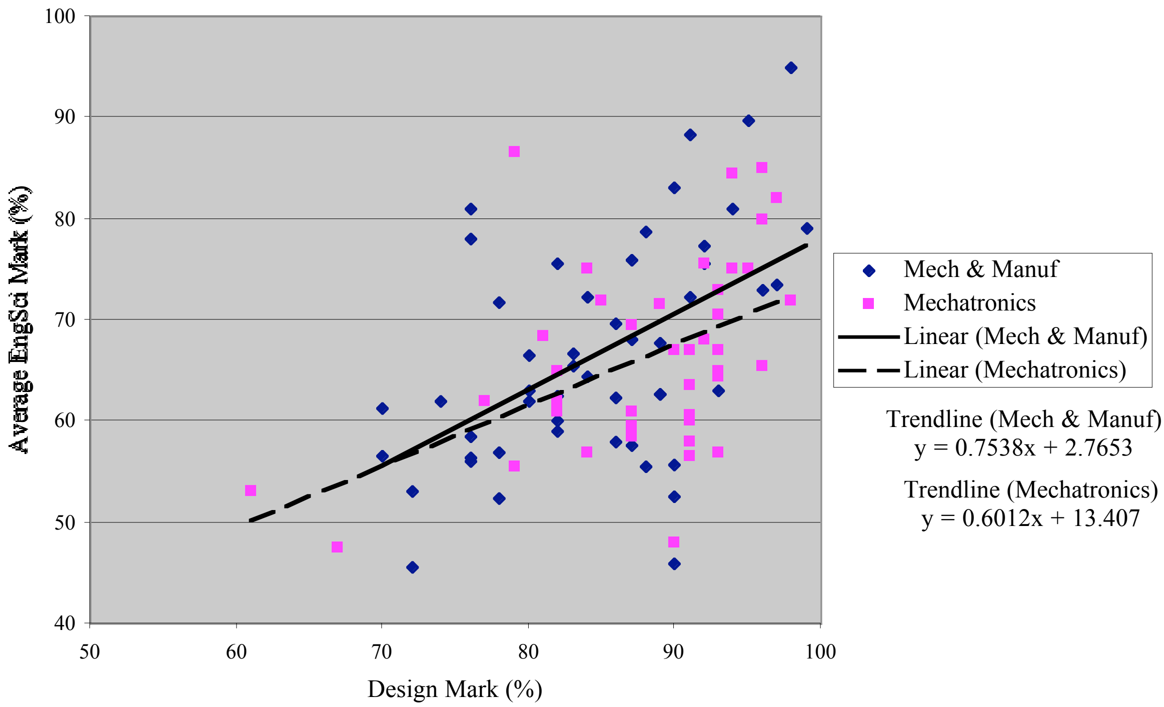

Figure 5. Comparing novice designer performance in design and engineering science subjects
Y-axis: "Average EngSci Mark (%)" is the average performance of three final year engineering science subjects (Mechanics, Thermofluids, Mechanical Systems)
X-axis: "Design Mark (%)" is a combination of tasks 1 (90%) and 2 (10%)

Given that engineering science was considered a significant impediment, a study was completed to compare novice designer performance in both design and engineering science disciplines (figure 5). A reasonable correlation was observed (R = 0.51 for Mechanical and Manufacturing and R = 0.46 for Mechatronics), indicating that there is no abnormal deficit in engineering science knowledge. A perceived or actual inability of novice designers to master new engineering science disciplines without the benefit of a formal learning environment could be the basis for this perceived impediment. Investigating this question will be one aspect of the authors' ongoing research, to improve correlations and associated arguments.

All novice designers had participated in, and responded to, hundreds of hours of lectures prior to the commencement of task 2. The two changes for which there was little or no precedent was the introduction of 11 guest presenters from industry, and the lack of precedent for the manner by which the seminar series was to be reported and evaluated. As there was no feedback asserting that any of the guest speakers could not be heard or understood, the unprecedented nature of the associated task is the likely reason why novice designers were less adept at completing this task successfully.

It has been observed that when designers begin their undergraduate training, two common reasons for poor performance are: *the question was not answered*; and, *a question other than the question being asked was answered, often extensively*. Both are present in task 2 submissions, with the presence of the second error implying that the task requirements were not correctly interpreted by the novice designer. Although task requirements had been stated explicitly (see Section 2.2), it appears that some did not understand specific meanings, either within the engineering design lexicon [11] or common language definitions.

A possible influence on the lower performance of task 2 is the large differential between the available marks for task 2 and task 1 (10% versus 90% of the total marks available), leading to a reduced time and effort investment in task 2. This could also be the basis for the reducing number of submissions that attempted phases beyond simply reporting the content of seminars (figure 3), as itemised mark allocations for were published prior to the submission date. The comparative study has provided preliminary findings that will be used to develop improved problem-based learning strategies for novice designers within unstructured creative environments.

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Corresponding author:
Colin Burvill
Department of Mechanical and Manufacturing Engineering
University of Melbourne, Victoria, Australia 3010
Tel: +61 3 8344 4545
Fax: +61 3 9347 8784
E-mail: colb@mame.mu.oz.au