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A COMPARISON OF THE BEHAVIOUR OF STUDENT ENGINEERS AND PROFESSIONAL ENGINEERS WHEN DESIGNING

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1. Introduction

Student studies play an important role in design research and have formed the basis of much of the experimental work carried out within the field [Corremans 2009], [Cross et al. 1996], [Lopez-Mesa et al. 2009]. However, relating findings from students in an experimental context to practitioners in the wild has proved difficult [Cash et al. 2011], [Cross 2007]. As such a need has been identified for a link to be developed between industrial and experimental contexts as highlighted by [Cash et al. 2011]. This paper introduces a study aimed at providing such a link for a number of situations commonly studied using student participants e.g. [Smith 1998], [Stones et al. 2010]. Further to this, it uses existing coding schemas to analyse the data – taking the first step towards validation of experimental studies of students by virtue of comparison with data from previous industrial studies [Howard et al. 2010], [Huet et al. 2007], [Robinson 2010]. The paper begins by presenting the method before a selection of the results are examined and subsequently compared to industry.

2. Method

The study approach presented in this paper allows the researcher to examine several parts of the design process during a single study, allowing for comparison across a range of design tasks. However, before the experimental method can be detailed it is important to first consider the participant population. For the purposes of this paper the authors focus on the findings of the student study before relating it to existing industrial studies within the field. This approach has been adopted in order to validate the student study against existing work before carrying out a final validation using practitioners. As such, the following sections outline the student population and the experimental stages including their associated tasks and technical setup.

2.1 Population

The student population used in this study consisted of twelve final year undergraduate mechanical engineering students randomly selected from a sample of 40 students. This group of twelve was then split into four teams of three for the study. Participants were given background tests (in the form of questionnaires) to characterise their experience, creative style (using the KAI test [Kirton 1976]) and creative thinking (using the Torrance test [Torrance 1968, 1998]). Further to this, using these questionnaires provided a baseline comparison against which future studies involving industrial practitioners could be compared – an essential step in the validation process. The students each came from a background of training within the mechanical engineering course at the University of Bath. In addition to this they had all completed the ‘Product Design and Development’ course and had a representative spread of industrial experience when compared to the larger student body (approximately 80% of the participants having at least one year of industrial experience). This information as well as further contextualisation data was elicited using a questionnaire given to each participant.

The KAI and Torrance tests

The KAI test is a questionnaire-based assessment of creative style and attempts to assess how easy/difficult participants find it to present themselves consistently as having various traits e.g. 'a person who is patient'. These are then scored, summed and compared to a predefined range of scores to assess creative style. This is carried out over a limited time period to force participants to put down their 'gut feeling' for each answer. In contrast to this the Torrance test is assessed using a series of timed drawing challenges where the participant is given basic shapes (e.g. a circle) and asked to creatively draw as many objects or pictures as possible, based on these shapes, within ten minutes. The full test consists of three distinct challenges each lasting ten minutes. These are then scored using a number of different measures to give an overall rating for creative thinking [Torrance 2007].

2.2 Study stages

The study itself is split into four stages that each focus on a different aspect of the overall design process. These stages are linked by a common design task which is introduced to the participants incrementally at each stage – giving increasingly specific briefing information as the study progresses. This allows the participants to be artificially moved from early to later stages in the design process. The four stages are summarised in Figure 1 and are as follows:

- Stage 1: 50 min – individual information seeking based on an initial broad brief.
- Stage 2: 50 min – group brainstorming session based on a preliminary specification.
- Stage 3: 90 min – individual detailed design development based on a detailed brief.
- Stage 4: 50 min – group design review and selection session using all the given information.

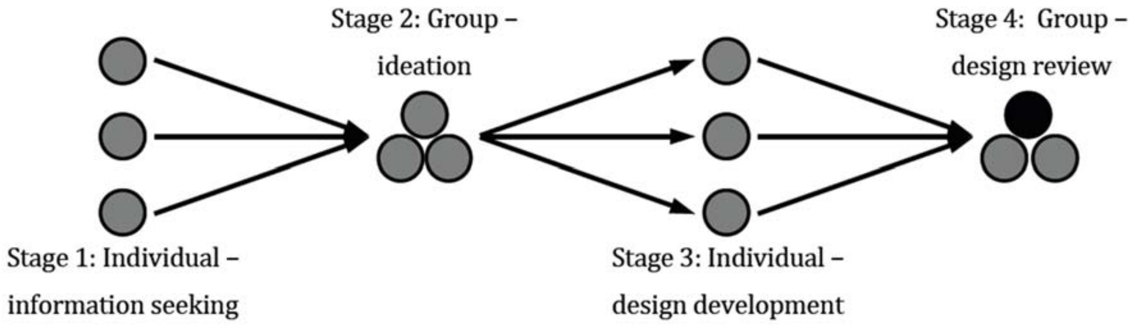

Figure 1. Experimental structure in for stages

2.3 The experimental tasks

Each task given to participants in this study was directly based on a similar task encountered during a longitudinal observational study of industry [Cash et al. 2011] and as such this section outlines the industrial task, the study task (Table 1) and the brief given at each stage (Sections 2.3.2 to 2.3.5).

Before the study began participants were given an information sheet outlining the structure of the study. They were not made aware of the study's research aims. Once the study was complete participants were given a debriefing sheet outlining the purpose of the research and their contribution to it.

Table 1. Industrial and experimental tasks

Industrial task	Experimental task
Stage 1: A representative period of individual information seeking – specifically for feasibility level technical details of a electrical component	50 minutes of individual information seeking – specifically for feasibility level technical information on camera mounting devices
Stage 2: A typical 3 person free brainstorming activity – specifically focusing on product ideas for	50 minutes of 3 person free brainstorming activity – specifically focusing on product ideas for mounting a

measurement of water use	camera on a balloon
Stage 3: No specific period used – based on typical design development activities	90 minutes of individual design development – specifically to take one camera mounting concept to prototype level of detail
Stage 4: A typical 2 person review meeting (with a clear meeting leader) – specifically focusing on test results, product planning and selection for prototyping	50 minutes of 3 person review and selection – specifically focusing on selecting a concept for further prototyping

2.3.1 Questionnaires

The background and KAI test were administered at the start of the study prior to the stage 1 brief. The Torrance test was administered after stage 4 and prior to receipt of the debriefing document.

2.3.2 Stage 1

The brief given at Stage 1 left the participants relatively unconstrained – similar to the feasibility stage of product development. The brief was as follows:

> *"You are to design a universal camera mount for use on an aerial vehicle. The aerial vehicle is to be used by an amateur photographer, primarily to take still photos. Using any means available to you search for and note down information that may help."*

2.3.3 Stage 2

The brief given at Stage 2 included an explanation of the brainstorming technique including examples, a high level specification as well as two explanatory pictures depicting the balloon configuration (Figure 2). The brief was as follows:

> *"During this task we would like you to brainstorm ideas to fulfil the following brief. The aim of this task is to generate as many viable ideas as possible within the time available. Please record these ideas on the whiteboard as they occur but feel free to make additional notes as necessary."*
> *"Using the specification provided, develop a variety of concepts capable of mounting any camera, while slung under a helium balloon. The mount must be capable of orientating the camera to any point in a hemi-spherical region underneath the balloon, and must be operated remotely."*

Specification

Total mass of camera and mount	*6kg (must take a range of cameras within weight limits)*
Cost (cost price) of the mount	*£75*
Operational life (per charge)	*1.5 hours*
Speed of operation – 360o pan	*maximum 30s minimum 10s*
Type of control	*via laptop*
Range of controller	*100m*
Range of rotation	*360o by 180o*
Volumetric size	*200 x 200 x 150mm*
Balloon connection	*flexible*
Balloon size	*spherical*

> *"The design for the balloon has already been finalised, and is tolerant of any connection or interface with the camera mount. Although you should try to minimise motion in the mount where possible, you do not need to consider vibration."*

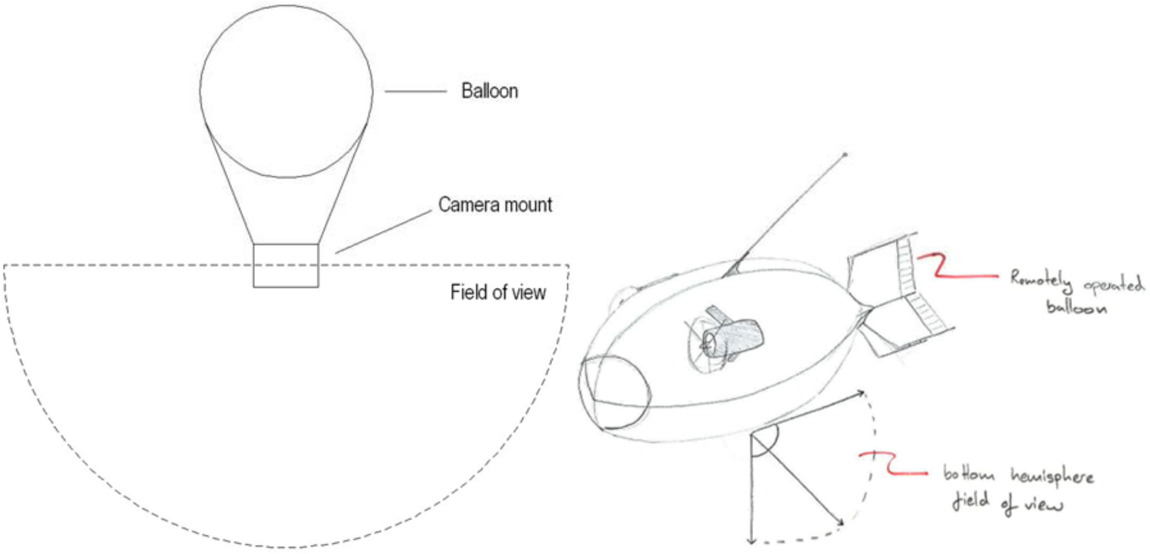

Figure 2. Balloon configuration pictures

2.3.4 Stage 3

The brief for Stage 3 contained more detailed information and encouraged the participants to develop a concept in detail. This allowed the participants to effectively develop an individual idea before the final review stage. The brief was as follows:

> *"During this task we would like you to develop one (1) of the concepts discussed during your brainstorming session based on the following brief. You are free to use the computer and notepad provided as well as any books you wish. Develop your concept to as high a level of detail as possible. Please record each action in your logbook as you proceed – Develop an appropriate, feasible, dimensioned, detailed solution."*
>
> *"**Further details***
> *Available machines for manufacture: lathe, end mill, injection moulding, laser cutter*
> *Assembly: By hand*
> *Your work from this stage will be given to a skilled technician, who will build a fully operational prototype. It must therefore include:*
> *General dimensions, all critical dimensions, materials to be used, a description of the mode of operation of all systems, a description of the method of assembly, a description of how the design completes its function and preferred methods of manufacture.*
> *Although unfamiliar with the project, the technician will attempt to fill in any information that they need, should you not provide it. As such complete as much work as you can, within the time allotted".*

2.3.5 Stage 4

The final stage instructed the participants to converge on one final idea that could be taken forward for further advanced prototyping. This allowed the participants to select or combine the concepts developed during Stage 3. The brief was as follows:

> *"During this task we would like you to review your designs (as developed in the previous task). The aim of this task is to select and develop one (or a combination of ideas) into a final concept to be taken forward to production. Please see the following: With your colleagues, and using your developed concepts, select and further develop a single, final concept that best fulfils the brief and specification. Please record this final concept on a single sheet of A3 paper."*

2.4 Equipment and setup

Individual tasks took place at an isolated work station with access to physical catalogues, reference material and the internet. A single camera was used to capture the participant and their desk area. In addition to this, a Livescribe pen [LiveScribe 2011] was used to capture logbook use and the Panopto [Panopto 2011] recorder was used to capture computer activity – via screen capture. Figure 3 gives a plan view of the participant's individual working area.

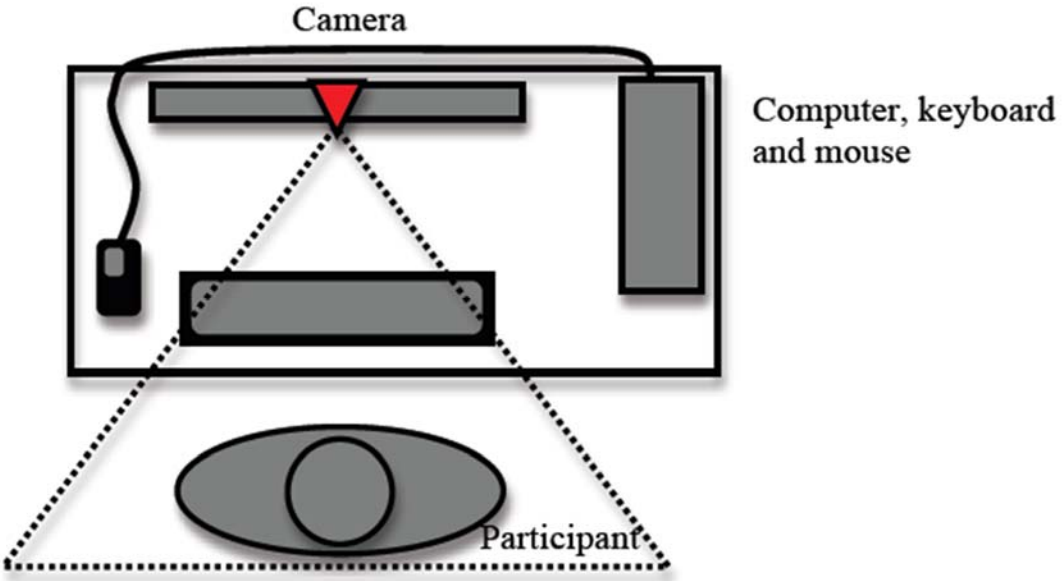

Figure 3. Individual setup

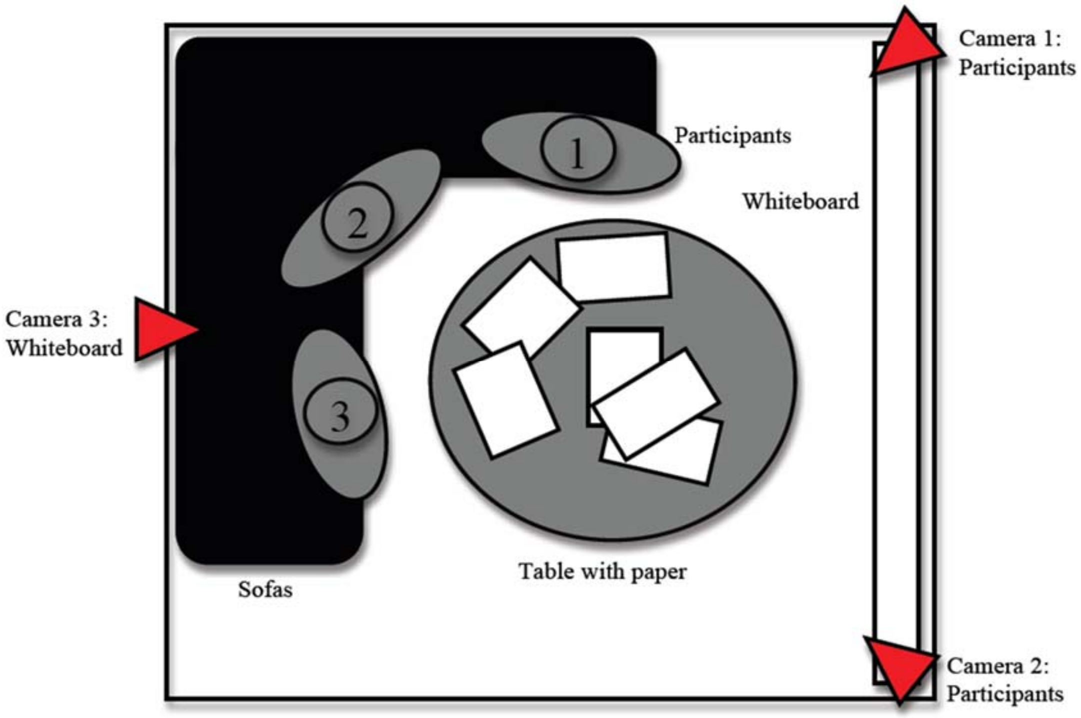

Figure 4. Group setup

Table 2. Capture technologies

Technology	What it is recording	
	Individual tasks	**Group tasks**
Cameras	1 view of participant's face, upper body and working area	2 views of group activity inc. table, 1 view of whiteboard activity
Panopto	Screen capture of participants computer, plus synchronisation of screen and camera	Synchronisation of camera feeds
Livescribe pen	Participants notepad use	Participants notepad use and audio

Group tasks took place in a working area isolated from the main research space (where individual tasks were completed). This area included seating, a table, A3 paper and a whiteboard. Activity in this area was captured using three cameras – two focused on the participants (ensuring complete coverage of their activities) while a third focused exclusively on the whiteboard. In addition, each participant was again given a Livescribe pen and notepad to use during the session. Figure 4 gives a plan view of the group working area with cameras (and their orientation) denoted by the triangles. Table 2 gives a full breakdown of the technologies used and what they captured during the individual and group tasks.

2.5 Coding

Each stage was analysed using a coding schema drawn from extant literature. This ensured that the schemes had already been validated and allowed this study to play a confirmatory/validation role for student participants in a laboratory setting. Stage 3 was not coded as this was specifically designed as a development phase prior to the review meeting in Stage 4 and was not based on a specific industrial situation. The coding scheme used for each stage is outlined in Table 3.

Table 3. Coding schemas

Stage	Coding schema	
	Description	**Schema reference**
Stage 1	Focused on information seeking activity – modified to include information source accessed via the computer	[Robinson 2010]
Stage 2	Focused on idea generation – can give either high level or detailed breakdown of ideas and sub ideas produced over time	[Howard, *et al.* 2010]
Stage 4	Focused on the interactions between participants, and participants and artefacts	[Huet, *et al.* 2007]

3. Results

For the purposes of this paper the results of the analysis of are reported in detail for Stage 2 (Table 3, idea generation). This was selected as an exemplar of the method and as a preliminary examination of the data recorded as part of the study. Inclusion of further analysis is not possible due to space requirements and will be reported in a future publication. Section 2 was selected due to the robust industrial data available in the form of Howard et al.'s [Howard et al. 2010] work. This work lends itself to comparison as it assess multiple industrial teams and has made much of the raw data available for reanalysis. As such two main elements were analysed, the basic style and level of creativity of the students and the performance of students during a brainstorming session.

The first aspects of creativity to be analysed was the KAI and Torrance tests given to the students to assess their creative style and creative level respectively. These tests gave a mean for the group of 12 students which fell well within one standard deviation of the standardised 50th percentile figure provided for the KAI [Kirton 1976] and Torrance [Torrance 2007] tests (Table 4).

Table 4. Summary of KAI and Torrance test results

	KAI	Torrance
Standardised 50th Percentile	96	101
Student mean	103	107
Standard deviation	17.5	14.2

Further to the background questionnaires the data for Stage 2 (ideation) is presented here. Two main metrics were used to assess the performance of the teams – number of ideas and ideation rate (ideas per minute). In addition the analysis was split into two periods (0 – 30 minutes and then 30 – 50 minutes) in order to build on the work of [Howard et al. 2010]. Howard et al. proposed that ideation rate dropped significantly after 30 minutes of the session. As such this should also be apparent in the student data if it is comparable to that of practitioners. Combining these two metrics and splitting up the analysis allowed for an effective comparison to be made to the existing industrial work of Howard et al. In Howard et al.'s study five industrial teams were observed carrying out brainstorming sessions. For four of the teams additional stimuli were introduced after a period of time. However, for the purposes of this comparison only two of the teams reached 50 minutes without receiving any stimuli and as such all figures are based on these two teams. Figure 5 shows the cumulative number of ideas generated over the whole 50 minute session by each of the student teams.

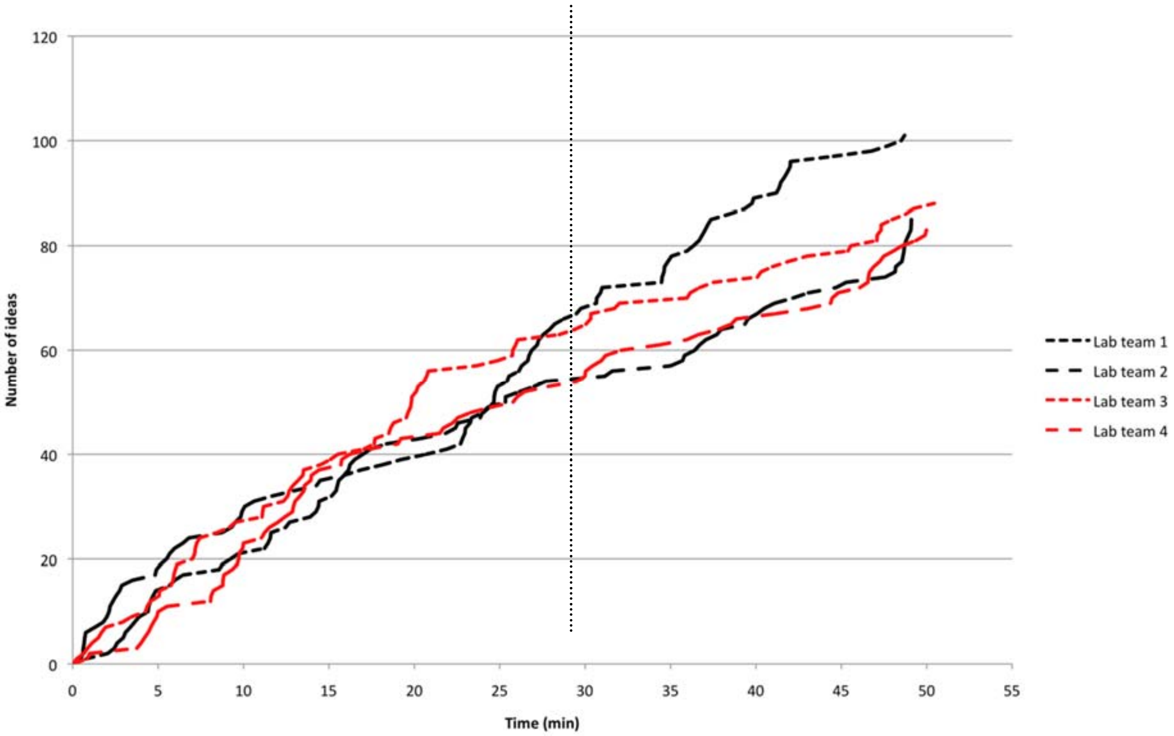

Figure 5. Cumulative ideas over time for the four student teams

In addition to Figure 5, Table 5 enumerates further details associated with each student team's performance as well as data for the industrial teams studied by Howard et al. This includes idea number and rate for 0 to 30 minutes of each session as well as the fit characteristics of linear trends fitted to the student dataset outlined in Figure 5.

Table 5. Idea generation details – For industrial data see [Howard et al. 2010]

Team	No of Ideas		Idea rates (ideas per minute)		R^2 value for linear trend line
	Total	0 to 30 min	0 to 30 min	30 to 50 min	
1	101	68	2.1	1.9	0.99
2	85	54	2.2	1.5	0.91
3	88	64	2.5	1.0	0.90
4	82	55	2.1	1.2	0.94
Mean	89	60	2.0	1.4	0.94
Industrial mean	60	44	1.4	1.0	0.98

4. Discussion

The first aspect addressed by this study was the development of a base line for the student participants using KAI and Torrance tests. These tests produced a baseline slightly (though not significantly) higher than the standardised figure given for the 50th percentile. As such it can be stated that the selected participant population provided an acceptable representative sample for the adult age group. Further to this the students also showed a range of industrial experience representative of the larger student body. It should be noted, however, that the standard figures provided for both the KAI and Torrance tests are based on the American population and as such it could be expected to differ slightly from the UK population. Unfortunately this data is not available and as such this is a possible limitation of the study until the student averages can be compared to a group of current practitioners or a much larger study of students is used to provide a statistically significant breakdown of the UK population and engineering students/practitioners specifically.

Table 6. Differences between the industrial and student studies

Possible factor	**Comparison**		**Possible significance**	**Findings from this study**
	Industrial	**Student**		
Team size	Average = 8	Size = 3	Increased team size correlates with increasing number of ideas [Godwin, et al. 1974, Hwang, et al. 1994]	The larger industrial teams produced less ideas. This could be attributed to experience, task or environment
Stage of design process	Early – ideas	Early – ideas	Design process stage can have a effect on team performance due to changing demands	There was little difference in process stage between this study and the industrial case
Experience	Experienced	Minimal	Experience has been shown to play a key role in idea generation with experienced participants producing fewer ideas [Cross 2004]	The lower number of ideas produced by industry compared to students suggests correlates with previous studies [Ahmed, et al. 2003, Judith, et al. 2007]
Specific task	Food packaging	Camera mount	Difficult to assess without further comparative studies, however, due to the similarities found here it is unlikely to play a major role	Although this was different there was still a correlation in the drop-off in ideation rate. This could, howver, contribute to the lower number of ideas
Level of constraint	Minimal	Minimal	Level of constraint can have a large effect on ideation.	Little difference
Setting	Industry – standard meeting room	Laboratory – instrumented meeting room	Difficult to assess without specific study on the strength of experimental effect in the industrial setting, however, this is unlikely to play a major role	Although this was different for the teams there was still a strong correlation in the drop-off in ideation rate

The second dimension considered is a comparison of the student teams v. industry when undertaking ideation. This comparison reveals that although the total number of ideas generated differed significantly between the student and industrial teams the amount of variation within the two groups was similar. However, due to the difference in the tasks carried out by the student teams and the industrial teams comparing the total number of ideas produced is of limited value. A more promising area of comparison is the rate of idea generation. This again showed the industrial teams to be consistently lower than the student teams, which could again be considered to be task dependant. However, a significant finding emerges when the rate of idea generation is examined with respect to time. Howard et al. proposed that the rate of idea generation dropped significantly after 30 minutes. This hypothesis is apparent in the industrial data and is clearly mirrored by the findings of this study. Both studies showed a significant drop in the rate of idea generation between 30 minutes and the remaining time (assuming no additional stimuli are introduced or other action taken). This similarity in the pattern of ideation rate drop (an average of 28% for the student teams and 29% for the industrial teams when compared to their initial values) demonstrates that although gross numbers of ideas vary based on situation or participants a common mechanism is at work which is robust even in the face of variation in team size, team composition, experience, task and setting (the basic differences between the studies of Howard et al. and those outlined here).

In order to assess the significance of this correlation in the drop in ideation rate it is necessary to consider the differences between Howard et al.'s work and the study described in this paper in more detail. Table 6 outlines the situational factors that may generate differences between the two studies and offers a brief explanation of the possible significance of each.

These conclusions are further supported by the extant literature [Cross 2004], [Judith et al. 2007]. Indeed, [Altman et al. 1999] suggest that the fact that experienced practitioners produce fewer ideas has it roots in the more efficient nature of the practitioners design process. In the case of ideation it is argued that experienced designers are more capable of parallel thinking [Seitamaa-Hakkarainen et al. 2001] and have more structured cognitive processes [Kavakli et al. 2002]. Due to these enhanced skills less iteration is needed to achieve an acceptable result, in contrast to the novices typical 'trial and error' approach – not seen in experts [Ahmed, et al. 2003]. Based on this it is possible to conclude that direct validation via [Howard et al. 2010] as well as indirect validation from literature confirms the key findings for this stage.

5. Conclusions

The prevalence of student based studies in design research has been highlighted and the need to understand and/or correlate the results of such studies with studies of practitioners has been discussed. To begin to address this a study approach is presented that allows a comparison of a study of students with respect to a number of extant studies of practitioners. The study design and data analysis method are discussed and a comparison with one particular aspect – ideation – is given in detail. A comparison of the student study and the previously reported study of practitioners reveals a strong correlation between industrial and student teams has been established in terms of the reduction in ideation rate over time. However, these findings still need to be validated with a study using the same task but with an industrial team before they can be considered fully validated.

Specific further work highlighted by the initial results outlined in this paper is the need to assess the impact of changing setting and task on idea generation and in particular the isolation of underlying or fundamental mechanisms within the experimental system which act across these variables such as the reduction in the rate of idea generation. The long term aim of this research program is to create a method which offers the possibility of comparing the performance of teams in a laboratory based setting to practitioners operating in practice.

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