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Creativity in Mechanical Design: Establishing Student Perceptions of Creative Designs and Impediments to Creative Solutions

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ABSTRACT

CONTEXT

Approaches to the measurement of creativity levels have been previously considered using methodologies such as the Creative Engineering Design Assessment method (CEDA) (Charyton, 2014) and further studies done by (Cropley & Cropley, 2000). Whilst statistical creativity measurement tools are available, a method for determining the perception and creativity levels of a particular cohort in their candidature is much needed (Belski, 2017). This study focuses on student's perceptions of what they perceive to be a creative design and the impediments to the presentation of creative solutions throughout their candidature.

PURPOSE OR GOAL

This study focused on two hypothesis. The first hypothesis focused on investigating if students' perceptions of what they consider to be a creative solution alters throughout their candidature. The second hypothesis focused on the impediments that students may have towards presenting creative solutions. Students have the potential to develop creative solutions to problems. However authors such as, (Kazerounian & Foley, 2007) identify, 'creativity blockers', whilst (Liu & Schonwetter, 2004) note 'blocks to creativity' which indicates that students prefer to present conventional rather than creative solutions.

APPROACH OR METHODOLOGY/METHODS

A longitudinal open-ended survey has been adopted as the methodology to examine the broad area of creativity in engineering students from the Schools of Aerospace, Mechanical and Mechatronic Engineering (AMME) and Biomedical Engineering at the University of Sydney. Students were surveyed whilst enrolled in design centred units of study under the conditions of Ethics Clearance Project Number 2018/630. Survey data was collected, analysed and categorised from five discreet student cohorts at different stages of their candidature. The data was used to test both hypothesis using a two-tailed proportion test (p-test) (Devore, 2017) (p. 391) method to compare adjacent cohorts incrementally.

ACTUAL OR ANTICIPATED OUTCOMES

The key observations made indicate that students' perceptions of examples of creative solutions or impediments they have to presenting creative solutions, do not alter significantly across their candidature.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The chief conclusions drawn from this study indicate that there are minor rejections of both hypothesis. These rejections are noted when comparing 2nd year vs 3rd year cohorts in students' perceptions of creativity and the impediments that they face when considering presenting creative solutions. Further qualitative research of these cohorts is required by undertaking standardised open-ended interviews, (Patton, 1980) (p. 206) to better understand the reasons for the rejection of both hypothesis.

KEYWORDS

Design, Creativity, Proportion Test

BACKGROUND

Critical thinking and creativity skills are of paramount importance in engineering graduates. Current initiatives starting from a secondary education level include the N.S.W. State Government incentive, (Education, 2021). Programs at this level of education were driven by tertiary and industry bodies that are seeking to develop students into agency rich, critical thinkers that poses leadership skills. Industry expectations noted from studies conducted by organisations such as the (QS Intelligence Unit, 2019) of engineering graduate attributes, rate creativity at 82/100 in terms its importance. However, industry satisfaction of engineering graduates level of creativity was only rated at 64/100. Engineers Australia go further by, clearly reinforcing that engineering graduates have a, 'creativity, innovative and pro-active demeanour' as part of their professional and personal attributes (Engineers Australia, 2019). There is a need for a study to better understand creativity in terms of what students perceive to be creative coupled with the impediments to presenting creative solutions. How these two paradigms may change throughout their candidature is also critically important in curriculum development and in developing the creativity skills of the 21st century engineer. Previous studies using the method of literature review by (Mullet et al., 2016) focused on teachers and identified that, 'Teachers felt unprepared to foster or identify creativity'. A similar outcome that compared tutor to student perceptions of creativity was arrived at by (Rodgers & Jones, 2017) who utilised a semi-structured interview approach to identify the value of, 'understanding creativity more in order to improve teaching activities'. A more student focused study was undertaken using the CEDA (Charyton, 2014) approach using a mixed method was undertaken by (Carpenter, 2016) who focused on four primary creativity themes resulting in recommendations to, 'understand where differences in perception exist'.

METHODOLOGY

In order to carry out the analysis to test the two hypothesis being considered are:

1. *Do students' perceptions of what constitutes a creative solution alter throughout their candidature?*
2. *Do the impediments that students may have towards presenting creative solutions alter throughout the candidature?*

The approach adopted in this study focused on using a longitudinal (across a period of twelve months), open-ended survey that contained a mixture of questions that were either in a quantitative or qualitative answer format. This survey structure was adopted to gather responses in a mixed format that included a combination of closed-ended questions and open-ended questions on a number of creativity focused topics.

Students enrolled in units of study that had either an introductory or design focus offered at either the School of Aerospace, Mechanical and Mechatronic Engineering or the School of Biomedical Engineering at the Faculty of Engineering and IT, University of Sydney were given the opportunity to take part in the survey. The students who took part in the survey were distributed between: first year-first semester (these are students who had only been part of a cohort for a number of weeks), first year (these are students that had been part of the first year cohort for more than six months i.e. previous year, mid-year entry), second year, third year, and final year or postgraduate by course work cohorts. The participating students were enrolled in either: aeronautical/space, biomedical, mechanical or mechatronics as their main stream. In total over 1000 students had the opportunity to contribute to the survey, at the time of writing, 332 responses were recorded and analysed with the available data from 'not fully completed' responses still considered. All data was considered and no 'sampling' (Creswell, 2014) of the data took place.

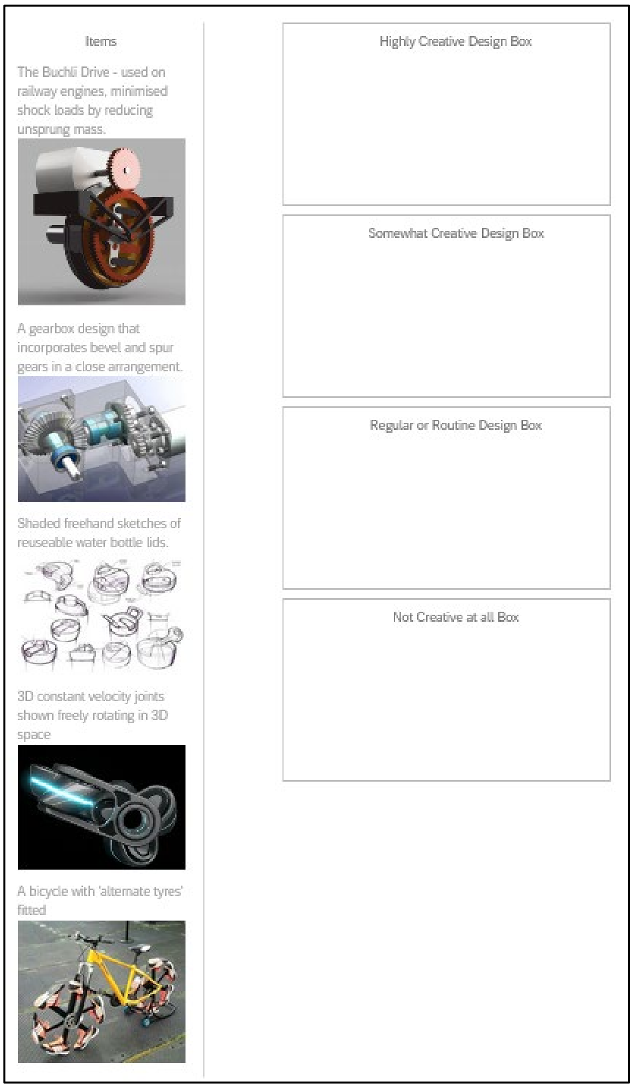
The longitudinal survey approach was initially chosen for this study as it provided flexibility with the type of questions that could be asked across a variety of cohorts over a large period of time. The rapid turnaround of results compared to interviewing members of each cohort was also a driving factor in choosing this method. The survey method also provided valuable feedback for drafting a future interview structured qualitative study, which was its key goal.

Qualtrics© was used as a platform for drafting and editing each survey question and also as a method of generating results in the form of data that was analysed using MS EXCEL©. The survey was initially tested on Tutors who were involved in the units of study being surveyed with an aim to identify points of confusion or logic errors in the flow of the script. The survey structure was defined by thirteen questions that could be categorised into six broad creativity themes that focused on: student candidature and demographics, identification and definition of creativity, method of creativity used, student extracurricular activities plus associations and barriers to creativity encountered. This study focused on analysing the themes of identification and barriers to creativity with the data stratified in terms of each student's year of candidature.

Survey Structure

Two key questions (Questions 3 and 11) which are the focus of this study are included below. Interested researchers are encouraged to contact the principal author to obtain access to all of the survey questions delivered via Qualtrics©. The typical survey question structure involved initially presenting the survey question followed by a statement to explain its axiology. No randomisation was utilised in determining the order of the questions.

Question 3 of 13: Move the following examples of design into the box which you think best fits their level of Creativity. The purpose of this question is to establish from the samples provided which YOU can relate to as being the most creative.



<drag and drop>

Question 3 of the survey used a combination of images and brief descriptive text to identify their function or purpose. The ‘Buchli Drive’ (1) (Buchli, 1919) incorporates elements of traditional mechanical design i.e. gears and linkages, combined in a compact and novel arrangement. The ‘gearbox design’ (2) image illustrates a conventional arrangement of gears driven by a face mounted electric motor. Although the ‘Shaded Freehand Sketches’ (3) image depicts an important phase of the design process, the sketches that are being drafted depict a conventional water bottle. The ‘3D constant velocity joints’, (4) image illustrates two constant velocity joints that have non-orthogonal geometry transmitting synchronous motion in three dimensional space. The final image, ‘bicycle with ‘alternate’ tyres fitted’ (4) illustrates an almost comical solution to a design problem. One potential limitation of the images chosen for the survey include the mixed use of animated (1) and (4) and fixed (2), (3) and (5) images which may introduce selection bias. Further refinement of this part of the survey in terms of image analysis is warranted by implementing visual ethnography methods (Rose, 2016) (p. 26).

Question 11 of the survey focused on the barriers that students have in presenting creative solutions. Liu and Schonwetter (2004) define these barriers as, ‘blocks to creativity’ which are also emphasised by authors such as (Christiano & Ramirez, 1993). However, these impediments do not appear to have been investigated or tested previously by the use of the survey method. Having a better understanding of the barriers that imped students from demonstrating creativity in their assessments is critical for two reasons. Firstly, insights will be gained into the impediment areas that need to be better understood and dissolved and secondly, the study may indicate that student creativity development may not be needed as students may be creative, but just unwilling to demonstrate it in their assessments.

Question 11 of 13: Have you ever felt any barriers to presenting a Creative solution?
Select as many or as few options from the list below, we would like to know what barriers you have struck when you have tried to be Creative.

- *Fear of the Unknown - Do you avoid uncertain assessment feedback by not presenting Creative solutions in an assignment?*
- *Fear of Failure - Do you avoid potential failure in an assessment by removing Creative solutions from an assignment?*
- *Reluctance to Exert Influence - Do you feel uncomfortable exerting Creative solutions on others? e.g. in group work*
- *Frustration Avoidance - Do you find it easier to not persist with a Creative solution when faced with barriers?*
- *Resource Myopia - Do you feel that you may not have Creativity skills and/or the world around you is unsupportive of Creative solutions?*
- *Custom Bound - Do you feel that a traditional approach to a solution method would better than a Creative solution?*
- *Reluctance to Play - Do you feel that approaching a problem in a 'light-hearted' way is less productive than directly arriving at a Creative solution?*
- *Impoverished Emotional Life - Do you hold back on your emotions when arriving at a Creative solution?*
- *Over Certainty - Do you check and recheck your assumptions when you arrive at a Creative solution?*

METHOD

This study utilised the statistical proportional test (p-test) as two adjoining population proportions are being considered. A t-test was not considered to be appropriate as the data collected did not have a numerical value as in the measurement of a dimension or the value obtained from a Likert scale that a mean value could be extracted from. As a benchmark, the key population examined was the first-year, first- semester cohort vs the first year cohort. The first-year first-semester cohort was an important addition to the survey as they were offered the survey within two weeks of their commencement of candidature.

Hypothesis Testing:

In order to test if the data of each cohort has similar proportions to its adjoining, the difference between each respective proportion was tested.

The hypothesis test consisted of the following steps:

$$Null\ Hypothesis \rightarrow H_0: P_2 - P_1 = 0$$

$$Alternative\ Hypothesis \rightarrow H_1: P_2 - P_1 \neq 0$$

Where P_1 refers to the proportion of students in (an example) the year 1 semester 1 (Y_1S_1) cohort and P_2 refers to the proportion of students in the year 1 cohort. The year 1 cohort was made up from students that may have been in the second semester of their first year.

Proportional Nomenclature:

$$\hat{p}_n = Proportion\ of\ Respective\ Data\ Set = \frac{X_n}{N_n}$$

$$= \frac{Number\ of\ Sucesses\ (COUNT)}{Number\ of\ people\ who\ submitted\ survey\ in\ their\ respective\ year}$$

$$Y_1S_1 \rightarrow \hat{p}_1 = \frac{X_1}{N_1}$$

$$Y_1 \rightarrow \hat{p}_2 = \frac{X_2}{N_2}$$

$$\hat{p}_{general} = \frac{X_1 + X_2}{N_1 + N_2} = Natural\ Estimator\ of\ \hat{p}$$

The analysis then compared the Y_1 cohort to the Y_{n+1} cohort i.e.

$$Y_1 \rightarrow \hat{p}_1 = \frac{X_1}{N_1}$$

$$Y_2 \rightarrow \hat{p}_2 = \frac{X_2}{N_2}$$

This analysis was repeated incrementally for Y_3 and Y_4 which was inclusive of higher years e.g. year 1 (Y_1) vs year 2 (Y_2), year 2 (Y_2) vs year 3 (Y_3) and year 3 (Y_3) vs years 4 (Y_4), 5 and postgraduates by coursework inclusive. A final, overall analysis of year 1 semester 1 (Y_1 S_1) vs years 4 (Y_4), 5 and Postgraduates by coursework was also carried out to investigate if an overall null hypothesis existed between cohorts at opposite ends of their candidature.

Confidence Interval:

Since the number of students completing the survey is low, the use of a 90% confidence interval, a 90% critical value (CV) was used (Barlett et al., 2001). Since each test is two tailed i.e. testing if the difference is or not equal to zero as dictated in the hypothesis test, the remaining 10% threshold is divided by 2 to consider each tail.

$$p_1 = p_2 = \frac{1 - 0.9}{2} = 0.05$$

Z Testing:

In the case of a two proportions test, the test statistic, Z represents a value in a distribution that is approximately standard normal (Devore, 2017) (p. 392).

$$Z = \frac{(\hat{p}_2 - \hat{p}_1) - (p_2 - p_1)}{\sqrt{\hat{p}_{general}\left(1 - \hat{p}_{general}\right) * (\frac{1}{n_1} + \frac{1}{n_2})}}$$

P Testing:

The p value was the obtained by inserting the value of Z in each case analysed by using the online p calculator tool. (Stangroom, 2021)

Hence in the cases (as there are two sides) where;

$Z\ is - ve$, a value of $p > 0.05$ will retain the null hypothesis H_0.
$Z\ is - ve$, a value of $p < 0.05$ will reject the null hypothesis H_0.
$Z\ is + ve$, a value of $1 - p > 0.05$ will retain the null hypothesis H_0.
$Z\ is + ve$, a value of $1 - p < 0.05$ will reject the null hypothesis H_0.

The criteria form the decisions as to whether the null hypothesis H_0 is retained and therefore the two data sets have similar proportionality or the null hypothesis H_0 is rejected and the two data sets do not have similar proportionality. The analysis procedure was then performed for the cases analysed for each of the two hypothesis being considered.

RESULTS

When considering the first Hypothesis, i.e., '*Do students' perceptions of what constitutes a creative solution alter throughout their candidature?,* the results of the survey for 1st year 1st semester vs 1st year cohorts retained the null hypothesis H_0 in all cases analysed with one exception. The sole exception relates to the student perception of the creativity level of the, 'Gearbox Design' (2). In the, 'Not Creative at all Box' where the probability value (p-value) of $0.0054 < p_{x(\alpha/2)}$ 0.05 critical value (CV). This result is depicted in Figure 1.0 and implies that students have gained a greater awareness that a conventional gearbox design is not high in terms of creativity levels. One reason for this assumption is that the year 1 cohort has gained a greater appreciation of design and creativity within their first year of candidature than the semester 1 year 1 cohort. This argument is reinforced by no further statistical rejections in subsequent years noted in this category. For clarity of presentation in the bottom axis of each graph, Figure 1 the bottom axis '*Examples of Creativity*' is represented by the corresponding numbers rather than their names; 'Buchli Drive' (Buchli, 1919) (1), 'Gearbox Design' (2), 'Freehand Sketch' (3), '3D Constant Velocity Joint' (4) and 'Bicycle with Shoes' (5).

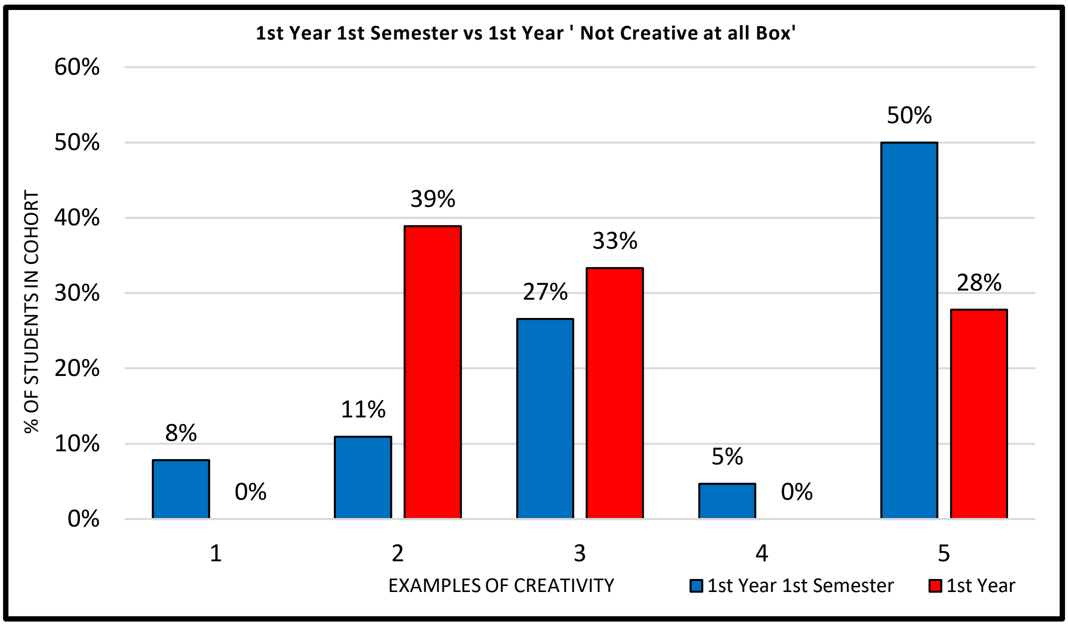


Figure 1.0 illustrates the rejection of the null hypothesis for the 'Gearbox Design' (2) when comparing 1st Year 1st Semester Students against 1st Year Students for the 'Not Creative at all Box'.

The results of the survey for 1st year vs 2nd year cohorts retained the null hypothesis H_0 in all cases analysed with two exceptions. The exception of the perception of the creativity level of the, 'Bicycle with Shoes' (5). In both the, 'Highly Creative Box' and the 'Not Creative at all Box' where the probability value (p-value) of 0.0456 < $px_{(\alpha/2)}$ 0.05 critical value (CV) and 0.0343 < $px_{(\alpha/2)}$ 0.05 critical value (CV). The 'Bicycle with Shoes' example was intended to be a facetious 'example' of improvised creativity.

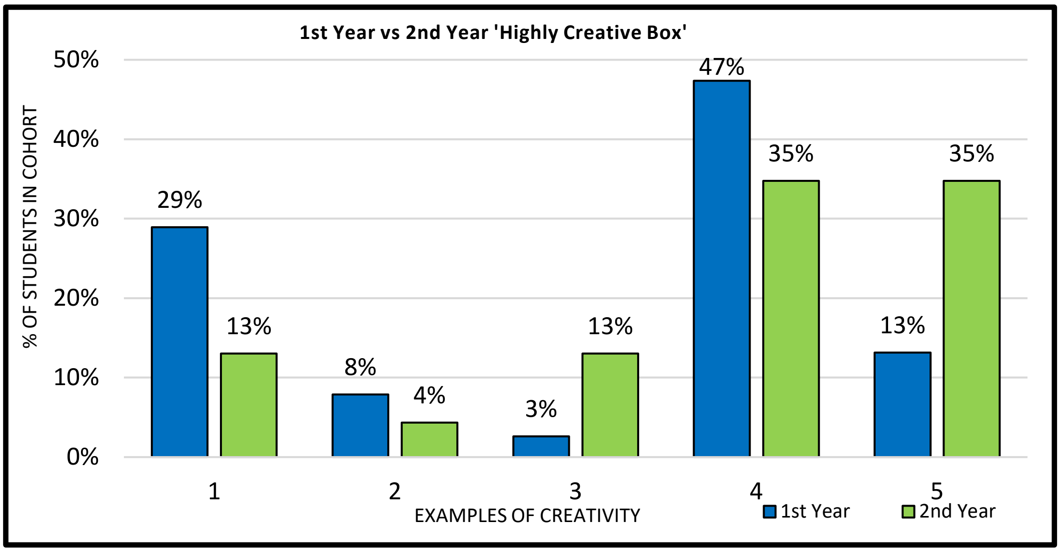


Figure 2.0 illustrates rejection of the null hypothesis for the 'Bicycle with Shoes' (5) when comparing 1st Year 1st Semester Students against 1st Year Students for the 'Highly Creative Box'.

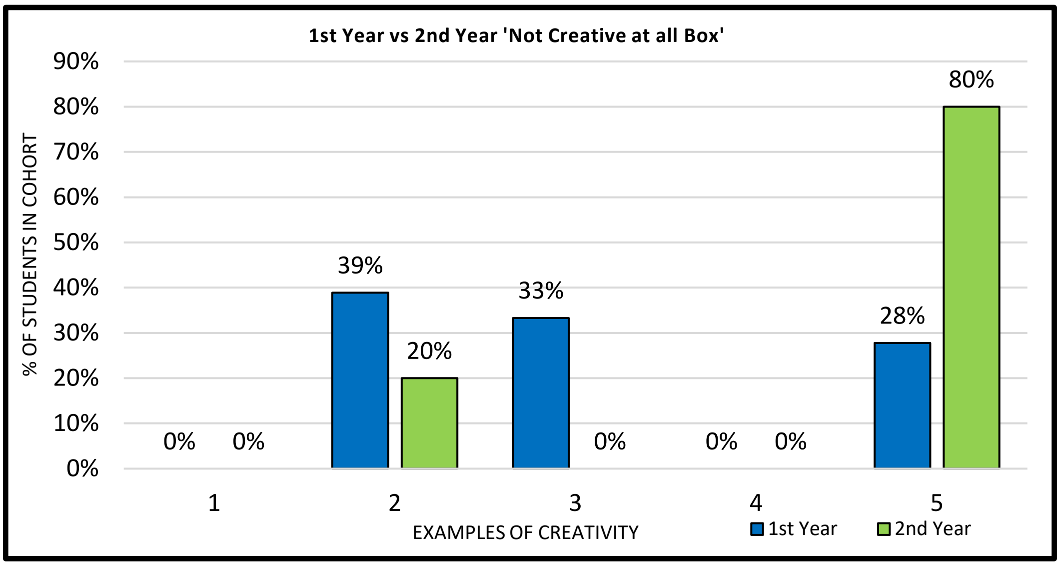


Figure 3.0 illustrates rejection of the null hypothesis for the 'Bicycle with Shoes' (5) when comparing 1st Year 1st Semester Students against 1st Year Students for the 'Not Creative at all Box'.

The ‘Bicycle with Shoes’ example was intended to be a facetious ‘example’ of improvised creativity. As the exception is noted in both of the extremes of perception of student creativity, i.e. the ‘Highly Creative Box’ vs ‘Not Creative at all Box’. This potentially indicates that this image has been interpreted differently within each cohort i.e. some students see the image as a strong example of creativity and some saw it as not creative at all. However, the smaller data set in this and in more senior cohort studies, hampers a more definite analysis. No further statistical rejections in any subsequent years were noted in this category.

The results of the survey for the 2nd year vs 3rd year and 3rd year vs 4th year cohorts retained the null hypothesis H_0 in all cases which indicated a strong level of stability in student cohorts’ perceptions of creativity throughout these three years of candidature. This may be indicative of fewer units of study that contain or promote creativity being undertaken by students. Further examination to confirm this assumption could involve a degree stream based stratified thematic study of each cohort’s curriculum on a unit of study creativity content basis.

A final analysis to compare the results of the survey for 1st year 1st semester vs 4th, 5th and postgraduate cohorts combined was undertaken to provide an overall, ‘cradle to grave’ perspective. The result for this analysis task retained the null hypothesis H_0 in all cases analysed with two exceptions.

The first exception relates to the result for the creativity level of the, ‘Freehand Sketch’ (3). In the, ‘Highly Creative Box’ where the probability value (p-value) of 0.0124 < $p_{x(\alpha/2)}$ 0.05 critical value (CV). The image depicted in the ‘Freehand Sketch’ (3) demonstrates a stage in the design process (Budynas & Nisbett, 2021) by illustrating the design of a water bottle. The exception to the null hypothesis could be connected with first year first semester students not being aware that freehand sketching plays an important part in the development of spatial skills (Sorby, 2009) and its place in the design process. In contrast, the combined 4th, 5th and postgraduate cohorts have been through the design process by completing a number of units of study that both teach and require freehand sketching skills.

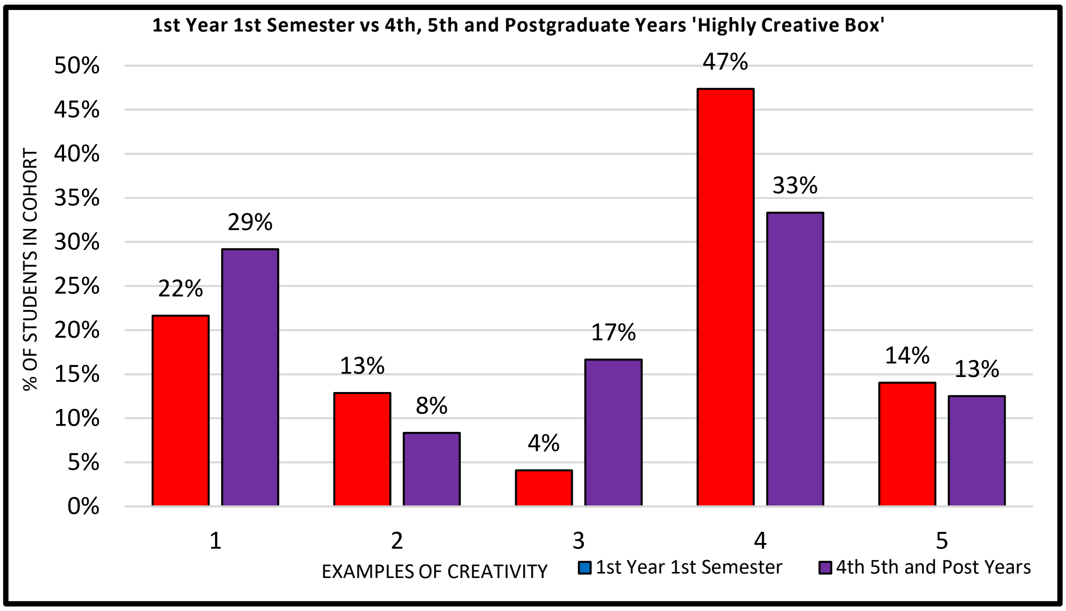


Figure 4.0 illustrates rejection of the null hypothesis for the ‘Freehand Sketch’ (3) when comparing 1st Year 1st Semester Students against 4th, 5th and Postgraduate Students for the ‘Highly Creative Box’.

The second exception relates to the result for the creativity level of the, ‘3D Constant Velocity Joint’. In the, ‘Regular or Routine Level of Creativity Box’ where the probability value (p-value) of 0.0029 < $p_{x(\alpha/2)}$ 0.05 critical value (CV). The image depicted in the ‘3D Constant Velocity Joint’ (4) illustrates a rendered non-orthogonal mechanism in motion. The 1st year 1st semester vs 4th, 5th and postgraduate cohorts identify the creativity level of the image differently. The 1st year 1st semester students potentially see the image as a highly creative example that is not routine or identifiable within the creativity domains they have so far been exposed to. The 4th, 5th and postgraduate year cohorts have been exposed to units of study and work experiences and consequently may see the image as representing a more routine example of creativity.

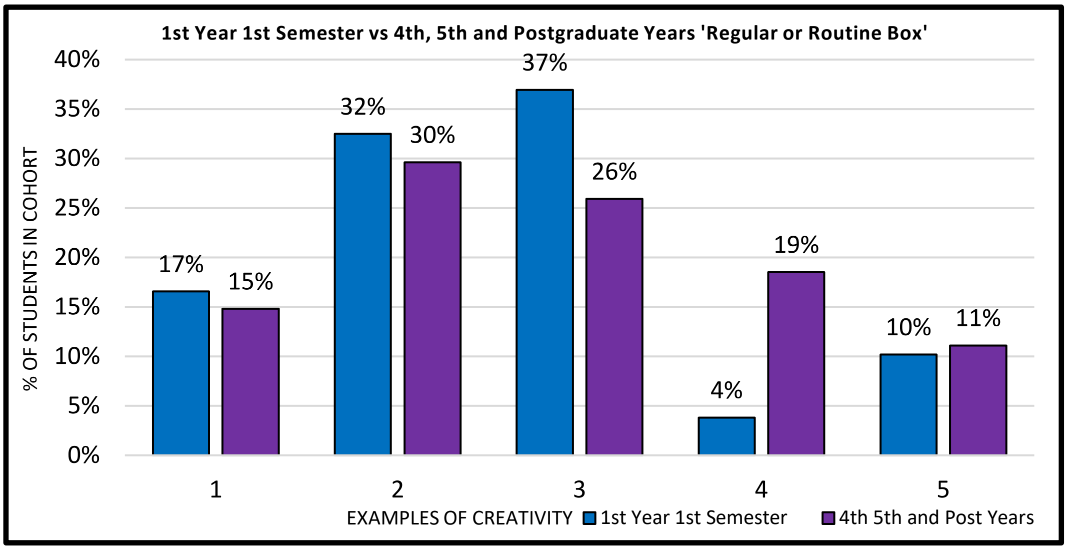


Figure 5.0 illustrates rejection of the null hypothesis for the ‘3D Constant Velocity Joint’ (4) when comparing 1st Year 1st Semester Students against 4th, 5th and Postgraduate Students for the ‘Regular or Routine Box’.

When the considering the second hypothesis, i.e., ‘*Do the impediments that students may have towards presenting creative solutions alter throughout the candidature?’* the results of the survey for all cohorts retained the null hypothesis H_0 in all cases analysed with one exception noted for the 2nd year vs 3rd year cohorts illustrated in Figure 6.0. In the Impediment ‘Reluctance to Play’ (7) the null hypothesis was rejected as the probability value (p-value) of 0.0448 < $p_{x(\alpha/2)}$ 0.05 critical value (CV). This result is only marginally outside of the critical value. An additional observation was that the barrier, ‘Fear of Failure’ (2), was noted as being an impediment in all except the 4th, 5th and postgraduate cohorts. This outcome is indicative of students being reluctant to take risks in introducing creativity within their assessment solutions. One potential reason for this result is that the ‘Fear of Failure’ (2) is closely linked to students, ‘fear of losing marks’ i.e. students are results driven and are not inclined to take the risk without strong resource support from the unit of study and the hosting institution.

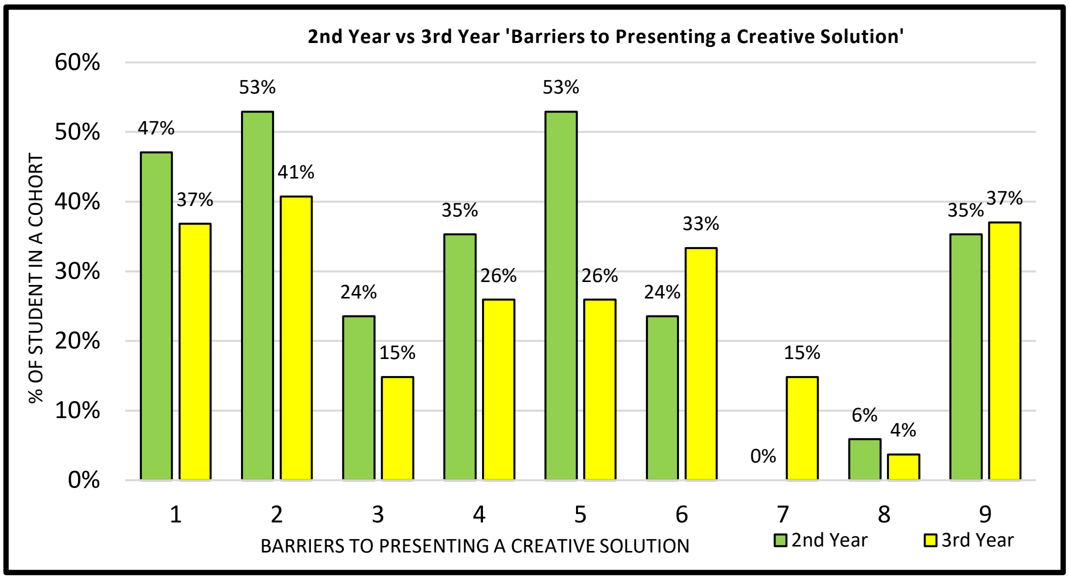


Figure 6.0 illustrates 2nd year vs 3rd year cohorts rejection of the null hypothesis in the Impediment 'Reluctance to Play' (7)

CONCLUSIONS

When considering the first hypothesis, the survey results highlight some irregularities. In the case of the interpretation of the perceived creativity level of the 'gearbox design', between the 1st year 1st semester vs 1st year cohorts is indicative of 1st year students having a greater knowledge of mechanical systems than 1st year 1st semester students this is expected as a cohort progresses through its candidature. In the case of the creativity level perceived of the 'Bicycle with Shoes' between 1st year vs 2nd year cohorts, the interpretation of a creativity level has acted as variable and indicative of the need for images within the survey that were better focused on one theme. In the third case, 'Freehand Sketch' between 1st year 1st semester students vs 4th, 5th and postgraduate year cohorts, the role that the image plays in the design process has been appreciated by the more senior cohort. This is a positive indicator of the important awareness that spatial skills plays in the teaching of the design process. In the final case of the first hypothesis, the '3D Constant Velocity Joint' between 1st year 1st semester students vs 4th, 5th and postgraduate year cohorts the results are indicative of a level of maturity in the appreciation of mechanical design as students' progress through their candidature. When considering the second hypothesis, the barrier, ''Reluctance to Play' in the 2nd year vs 3rd year cohorts, the rejection of the hypothesis is indicative that the more senior cohort is more likely to devote time to consider divergent ideation methods rather than converging on one solution. This not desirable from an educational perspective.

Although the survey presented requires some level of refinement and benchmarking against external cohorts to strengthen its external validity (*Statsdirect*, 2021), it has served the purpose of highlighting points from which to conduct further qualitative research. The use of phenomenography (Case & Light, 2011) as a methodology combined with the method of standardised open-ended interviews would serve to better understand the phenomenon. The proposed research has important implications for teaching staff and students in the teaching of creativity within the context of the design process and the future structure of design focused assessments.

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