2023-10-10

Exploring The Development Of Engineering Design Creativity And The Role Of Spatial Skills In This Process

Clodagh REID
Technological University of the Shannon, c.reid@research.ait.ie

Sheryl SORBY
University of Cincinnati, United States of America, sheryl@mtu.edu

EXPLORING THE DEVELOPMENT OF ENGINEERING DESIGN CREATIVITY AND THE ROLE OF SPATIAL SKILLS IN THIS PROCESS

C Reid
Technological University of the Shannon: Midlands Midwest
Athlone, Ireland
ORCID: 0000-0002-8593-1730

S.A. Sorby [1]
University of Cincinnati, Cincinnati, USA
ORCID: 0000-0001-8608-4994

Conference Key Areas: *Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Curriculum Development*
Keywords: *Spatial skills, creativity, design, problem solving*

ABSTRACT

This study aims to investigate the development of creativity in engineering education and how spatial skills relate to creativity of design solutions.

Undergraduate students in the first (n=86) and fourth/fifth year (n=48) of their engineering programme were invited to participate. Students completed four spatial tests to precisely measure visualisation skills. In a separate session, students were invited back to solve two engineering design tasks: a ping pong problem where they designed a ping pong ball launcher game to meet specified criteria and a rain catcher problem where they were tasked with developing as many ideas for capturing rainwater as a water source for a remote location as they could. Students were asked not to consider feasibility, cost, etc. and to come up multiple radical solutions to the rainwater capture problem.

---

[1] *Corresponding Author*

S.A. Sorby

sheryl.sorby@uc.edu

The creativity of design solutions was assessed using Adaptive Comparative Judgement. Statistical analysis indicated significant relationships between spatial skills, students' year of study and gender. A statistically significant relationship was also found between students' creativity scores on both design challenges. No statistical differences were determined in the creativity of first and fourth/fifth year students' solutions. These findings will be discussed relative to existing research, future work, and potential implications for education practice.

1 INTRODUCTION

Preparing future engineers to solve design problems in innovative and creative ways has become an essential component of engineering education programmes [1, 2]. Creativity is at the core of design practice and strategies to develop creativity have been incorporated into various engineering programmes with the intention of preparing graduates to solve real-world engineering problems in unique ways [1]. As engineering programmes have been striving to develop creativity for the last number of years it is important to assess whether the educational structures in place are in fact contributing to the development of creativity for solving design problems. This is timely as skills reports have outlined that design for engineering is a current and future skills need [3].

When considering the development of creativity in engineering education it is also pertinent to reflect on the role of spatial skills, a key predictor of success in Science, Technology, Engineering and Mathematics (STEM) [4]. Previous research has indicated a relationship between spatial skills and creativity [4 - 6]. As spatial skills are malleable [7], the development of spatial skills could support the enhancement of engineering graduates' creative design capacity throughout their undergraduate programme. Therefore, it is important that additional research is carried out to understand the relationship between spatial skills and creativity in various contexts and how this may apply to engineering education practices.

The study outlined through this paper aims to investigate the development of creativity in engineering education through an expertise comparison of design problem solving solutions. In addition, the study will also investigate the relationship between spatial skills and creativity in the context of performance on real-world engineering design problems similar to those employed on engineering education programmes.

2 METHODOLOGY

2.1 Setting and participants

This study was carried out at a large public R1 university and based in the College of Engineering and Applied Sciences. The research participants were undergraduate engineering students in the first and fourth/fifth year of their engineering programmes. Participants were recruited through flyers which were displayed across the college. The participants engaged in two research phases. Phase one consisted of participants completing four spatial tests to obtain a precise measure of spatial skills. In the second phase participants were required to solve two engineering design tasks. Ethical approval for this research was granted by the university's IRB committee.

2.2 Data collection

The participants recruited for this research consisted of undergraduate engineering students in the first (n=86) and fourth/fifth year (n=48) of their engineering programme. Students were compensated for their participation time with gift vouchers. During the first phase of data collection the participants completed four spatial tests: Mental Rotation Test (MRT), Mental Cutting Test (MCT), Surface Development Test (SDT), and Paper Folding Test (PFT). A verbal analogy test was also carried out at this phase of the research as a control for general intelligence.

In the second phase of data collection, the participants were invited to return to individually solve two engineering design tasks: a ping pong problem and rainwater catcher problem. Fig. 1 and Fig. 2 outline the problem statements that were provided to the participants.

> In an attempt to avoid boredom at your residence hall, creative engineering students developed a challenging new game. A ping-pong ball is to be launched at a bullseye target, and points are awarded according to the accuracy of the landing. However, the ping-pong ball cannot be thrown at the target. It is up to you to design a device which will lift the ping-pong ball into the air and land it at the target. An accurate landing is desired while also maintaining a long flight time. Given that the center of the landing area is 5 meters away from the launch site, and the entire launching assembly must not be greater than 1m x 1m x 1m in dimension, design a ping-pong ball launcher for this game.
>
> Your work should contain a detailed description of your design and should include any relevant diagrams and calculations. Please clearly state all assumptions which are needed in your analysis and try to keep your design simple yet effective.

Fig. 1. Ping Pong problem instructions to participants.

> In remote villages throughout many rural, underdeveloped areas of the world, easy access to fresh clean drinking water is very limited. Villagers must often walk long distances to a fresh water source, collect the water in large, awkward bins, and then carry the water back uphill to their home. Retrieving the fresh drinking water in this manner takes tremendous amounts of time and effort. In many cases, however, rainwater is a fresh and abundant source of water, but there are no solutions for effectively capturing, storing, and distributing the water.
>
> Design ways for remote villagers to catch and use rainwater. Your solutions should focus on creating totally new designs or developing totally new ways of approaching the problem. Don't be concerned about a particular cost or size of your solution, and feel free to choose any materials you desire, as those sorts of constraints might be able to be worked out in the future.
>
> Develop multiple solutions for this problem. Focus on developing radical solutions. Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper and use drawings as necessary to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Fig. 2. Rainwater catcher problem instructions to participants.

Following this phase, the solutions created by each participant were collated and all ping pong problem solutions and rainwater catcher solutions were entered into two separate Adaptive Comparative Judgement (ACJ) sessions. ACJ is a holistic assessment tool which involves the pairwise comparison of items of work which leads to a rank order of performance based on a specified criterion, in this instance-creativity [8]. The assessors for these ACJ sessions were 108 undergraduate engineering students (n=60 assessors for the ping pong problem solutions and n=48 assessors for the raincatcher solutions). The reliability of an ACJ session is described by the Scale Separation Reliability (SSR) coefficient. In comparative judgement, there is a strong indication that this reflects an interrater reliability index [9].

3 RESULTS

Data collected for the purposes of this research was compiled in Microsoft Excel and was cleaned and analysed using IBM SPSS version 28.0.0.0.

3.1 Creativity development

The first element of the research aim was to investigate the development of creativity in engineering education. The reliability of the ACJ panel conducted to holistically assess creativity and determine a rank order of creativity amongst the cohort of participants was moderate ($SSR_{ping\ pong\ problem}$ = 0.59 +/- 0.02, $SS_{rain\ catcher\ problem}$ = 0.52 +/- 0.02).

An Independent samples t-test was conducted to address this research aim, examining the development of creativity during an undergraduate engineering programme. The development of creativity was assessed through an expertise comparison where first-year engineering students creativity ranks were compared to those of fourth/fifth-year engineering students who had engaged in the same programmes of study. Through this analysis no statistically significant differences were found between the creativity scores of first-year students (*M* = 134.61, *SD* = 78.002) and fourth/fifth-year students (*M* = 143.10, *SD* = 74.512) on the ping pong problem $t(131) = -.613$, $p = .541$. Additionally, no statistically significant differences were found between creativity rank and year of study on the rainwater catcher problem $t(126) = -.088$, $p = .930$.

This suggests that, as measured using ACJ in this context, creativity was not significantly developed during the progression of engineering students through their program of study.

3.2 Spatial skills

The second element of the research aim was to investigate how spatial skills relate to creativity of engineering students design solutions. The four spatial scores for the students were converted to composite z-scores to facilitate within sample comparisons.

A Spearmans correlation analysis was conducted to address the research aim as the spatial data was converted to rank data and the creativity data from the ACJ panel was also in a rank format. The results of this correlation analysis are outlined in Table 1 below. No statistically significant relationship was found between spatial skills and the creativity demonstrated on either of the design problems. A statistically significant correlation was found between the creativity students demonstrated in solving the ping pong problem at rain catcher problem. Additionally, a statistically significant positive correlation was found between spatial skills, year of study and gender. The correlation found between spatial skills and year of study indicates that students in the latter stages of their engineering degree programme were found to have higher levels of spatial skills. With respect to gender this finding indicates that males in the sample were found to have higher spatial skills than their female counterparts.

Table 1. Spearman correlation investigating the role of spatial skills in creativity.

Variable	1	2	3	4	5
1. Spatial skills	1.000	-.110	-.032	.279**	.234**
2. Ping pong rank		1.000	.305**	.052	-.112
3. Rain catcher rank			1.000	-.012	.104
4. Year of study				1.000	-.172
5. Gender					1.000

**. Correlation is significant at the 0.01 level (2-tailed).

4 SUMMARY

The aims of this research were to investigate the development of creativity in engineering education and the potential influence of spatial skills on the creativity of engineering students design solutions. The results outlined in section 3.1 indicate no significant differences in the creativity displayed by the first and fourth/fifth year engineering students. This is concerning as a core aim of engineering programmes is to foster the development of students creativity for design. Although, this finding does align with reports of a skills need in the area of design for engineering where there is a noted skills gap and demand in industry [3]. The findings are also similar to those of previous research which has indicated no differences in engineering students performance in another key skill, problem solving, through a similar expertise comparison [10]. The findings of the presented study suggest that more work is required in engineering education on the strategic development of creativity through engineering programmes.

Through this research no significant relationship was found between spatial skills and creativity. It had been anticipated that there would be a statistically significant relationship between these two factors as previous research has indicated a relationship between them [4 - 6]. A critical factor to consider here is the reliability levels achieved through the ACJ panel which was used as a measure of creativity in this research. The reliability of ACJ panels that are fully completed (i.e., all assessors have completed all judgements) in Technology education research is typically high, ~0.9 [8]. The reliability for the ACJ panel in this research was moderate, possibly due to the ACJ panels unfortunately not reaching full completion (i.e., some assessors did not complete all of their judgements). This may have impacted the statistical analysis for this work and as such, the findings should be tentatively considered until such a time that further work is presented to corroborate them.

5 ACKNOWLEDGMENTS

This work was made possible by a grant from the National Science Foundation (NSF #2020785). Any opinions, findings, and conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] Starkey, Elizabeth, Christine A. Toh, and Scarlett R. Miller. "Abandoning creativity: The evolution of creative ideas in engineering design course projects." *Design Studies* 47 (2016): 47-72.

[2] Anwar, Arif A., and David J. Richards. "A comparison of EC and ABET accreditation criteria." *Journal of Professional Issues in Engineering Education and Practice* (2018).

[3] Schwab, Klaus, and Saadia Zahidi. "The Future of Jobs Report 2020". *World Economic Forum*. (2020).

[4] Kell, Harrison J., and David Lubinski. "Spatial ability: A neglected talent in educational and occupational settings." *Roeper Review* 35, no. 4 (2013): 219-230.

[5] Kell, Harrison J., David Lubinski, Camilla P. Benbow, and James H. Steiger. "Creativity and technical innovation: Spatial ability's unique role." *Psychological science* 24, no. 9 (2013): 1831-1836.

[6] Kozhevnikov, Maria, Michael Kozhevnikov, Chen Jiao Yu, and Olesya Blazhenkova. "Creativity, visualization abilities, and visual cognitive style." *British journal of educational psychology* 83, no. 2 (2013): 196-209.

[7] Uttal, David H., Nathaniel G. Meadow, Elizabeth Tipton, Linda L. Hand, Alison R. Alden, Christopher Warren, and Nora S. Newcombe. "The malleability of spatial skills: a meta-analysis of training studies." *Psychological bulletin* 139, no. 2 (2013): 352.

[8] Reid, Clodagh, Gibin Raju, and Sheryl A. Sorby. "WIP: Adaptive comparative judgement as a tool for assessing first-year engineering design projects." In *ASEE Annual First-Year Engineering Experience Conference & Exposition*. ASEE, 2022.

[9] Verhavert, San, Sven De Maeyer, Vincent Donche, and Liesje Coertjens. "Scale separation reliability: What does it mean in the context of comparative judgment?." *Applied Psychological Measurement* 42, no. 6 (2018): 428-445.

[10] Reid, Clodagh, Jeffrey Buckley, and Rónán Dunbar. "Investigating the effect of engineering student's spatial ability and expertise on general complex problem solving." *Techne Serien* (2021).