INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
8–9 SEPTEMBER 2022, LONDON SOUTH BANK UNIVERSITY, LONDON, UK

USING DIGITAL TECHNOLOGIES FOR COLLABORATIVE CONCEPTUAL DESIGN

Joseph MILLS and Ross BRISCO
Department of Design, Manufacturing and Engineering Management, University of Strathclyde, United Kingdom

ABSTRACT
Since the COVID-19 worldwide pandemic outbreak, and the requirement to 'stay at home' and 'work from home', we, as a collaborative species have been forced to find ways of computer-supported collaboration. Going beyond global design and distributed design. We now find ourselves as a human race, not with a desire to collaborate using computers, or with a requirement, but it is now a necessity. In many ways, a paradigm shift has occurred.
This research investigates the use of novel technology to support student teams in the conceptual design phase of an engineering design project. A review of published literature identified a lack of understanding in the impact that a digital distributed environment can have on the outcomes of a collaborative ideation task. The literature suggested there would be little to no change between working in a collocated and digital distributed environment.
An experiment was designed that asked 16 participants working in pairs to complete an ideation task in both a synchronous traditional collocated environment and a synchronous digital distributed environment. The results from the experiment suggest that conducting the ideation task within a digital environment has a negative effect on the outcomes of the ideation task.

Keywords: Computer-Supported Collaborative Design (CSCD), conceptual design, design technology, ideation, concept generation

1 INTRODUCTION
Technologies to support design development are commonplace. 3D Computer Aided Design (CAD) has long been established as an industry standard for the later stages of the design process including detailed design, embodiment design, finite element analysis and manufacture and assembly modelling[1]. CAD software has been developed to support the creative design phases in 2D and 3D [2], and in recent years in particular with novel technologies such as Virtual Reality (VR). There has been a focused effort to develop CAD tools for design engineers. However, there has been a lack of focused development of CAD tools within the conceptual design stage of the design process which has resulted in minimal uptake within industry and education [3].
Throughout concept generation, designs are quickly evolving, the focus is not on great detail but more so on generating and adapting high volumes of concepts quickly [2], [4]. The initial concept generation phase is free flowing in nature and requires creativity from the designer to produce sketches that allow others to visualise their ideas. These sketches are vital while working collaboratively as it allows team members to modify, adapt and evolve the ideas to progress through the concept development [5].
The issue with the use of CAD tools within conceptual design is the required level of detail can hinder the creativity of the designer. Although sketches are incomplete and rough, CAD tool's completeness can discourage the designer from modifying and adapting the concepts [6]. This is due to CAD tool's rigidity and need for a high level of detail which is not required throughout the conceptual design phase.
In a digital space, a useful tool to replace paper is a digital whiteboard, however, the usefulness and effectiveness of this design tool has been questioned. Tang et al., [3] investigated the differences between digital and physical sketching. Teams were given a sketching task to conduct in both environments. By assessment of experts, the designs created in both mediums were of equal quality with a slight preference towards the outcomes of the physical sketched posters. Mulet et al., [7] investigated the role of technology in the novelty of designs. By assessment of experts, the novelty of the designs

created by teams in a collocated space and in a distributed online space were equal. There were several technical issues with the technology which may have been improved.

Jensen et al., [8] conducted an ideation activity using physical sticky note and a tablet and sticky note software. Experts determined similar levels of quality in the concepts created using physical sticky notes and digital. The research was limited in the use of one tablet used by one team member where typical sticky note activities allow all participants to take part at the same time.

Brisco et al., [9] created a digital design tool based upon an established design method 6-3-5. The tool enabled students to draw sketches based on an original idea or the ideas of other team members. Students had no preference for or against using the tool and there were several technical issues in its use.

Pre-pandemic research was focused on technologies to support distributed work as a novel concept, as secondary to in-person working. Now, research must consider remote working as the default, or as equal [10]. One solution to this problem would be the development of distributed digital design methods that are as effective as those well established and used in a collocated physical space. To do so, the design research community must build an understanding of the similarities and differences between collocated design activities and distributed design activities facilitated by computer technologies. This requires researchers to look beyond the norm and develop design methods inspired by technology functionality, and not as an afterthought. Solutions must allow those who have the knowledge to contribute to a product development to do so in person or digitally with equal impact. Universities and businesses can prepare for any mode of learning and working. The best design methods, online or offline, can be chosen to ensure resilience when barriers to physical working arise.

2 METHODOLOGIES

The methodology chosen was inspired by that used by Tang et al., [3] and Mulet et al., [7] as a state-of-the-art research method identified through a literature review. 16 final year Master's students studying Product Design Engineering at the Department of Design, Manufacturing and Engineering Management were invited to take part in the study. The participants were selected because they had previous experience of working in both distributed and collocated environments.

The participants were asked to join as teams of twos and every participant had previously worked in a group with their partner. The participants were grouped in pairs due to the constraints on the time and number of participants available. Groups of two provided allowed high enough number of groups to provide a statistical analysis of the results. There were 8 male and 8 female participants. The average age was 22 years and 4 months with a standard deviation of 1 year and 4 months.

The collaborative concept ideation task chosen for this experiment was "brainstorming." Brainstorming as a concept ideation technique was originally developed in 1954 by Alex Osborn within his book Applied Imagination [11]. It is frequently used as a concept ideation technique by every level of designers, from professionals to novices [12] and is commonly carried out with the use of sticky notes. Both Ball and Treffinger argue that sticky notes are the perfect material for brainstorming as they allow many solutions to be generated and aid collaboration between teams [13]. Therefore, the selection of brainstorming through the use of sticky notes was justified as there has been extensive literature verifying it as a proven technique. It was also selected as every participant within the experiment has previous experience with it meaning they did not need time to get familiar with the ideation task

During the experiment, the participants were given two design project briefs which they used to conduct the brainstorming ideation task. The participants completed one of the briefs in a traditional environment, being offline and collocated, and one in a digital environment, online and distributed. The two briefs were chosen from a list of design briefs generated within a previous study conducted by [14]. The briefs generated within the list were designed to be of equal difficulty. To ensure the level of difficulty did not affect the results of the experiment, half of the groups completed *Brief 1* in the digital environment first and vice versa. The chosen briefs were:

Brief 1: Rain and wind Protection

Rain and wind make it difficult for pedestrians to keep dry and pose dangers e.g., slipping, falling trees. Generate concepts for products to reduce the discomfort and danger of poor weather for pedestrians.

Brief 2: Lighting in Towns and Cities

Lighting towns and cities at night have negative environmental impacts e.g., fossil fuel depletion; light pollution; and disruption to wildlife. Generate concepts for products that may improve the environmental impacts of lighting urban areas.

The experiment in the traditional environment is as follows. The participants were seated together at a desk (*Figure 1*) and were given a selection of sticky notes and black or blue pens. The participants were free to interact in any way and collaboration was highly encouraged. This experimental setup is something each participant was familiar with and had experienced during their education.

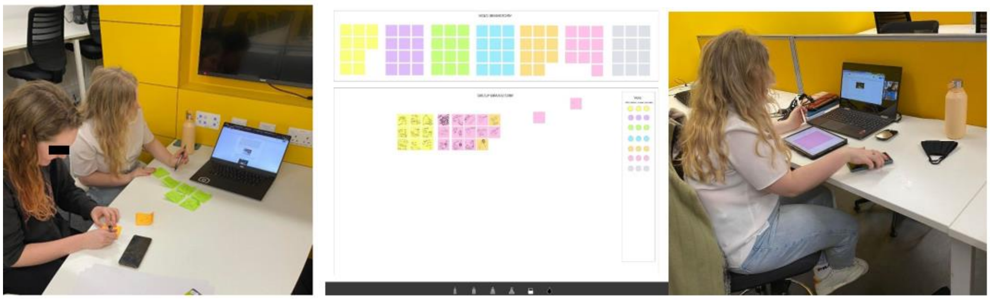

Figure 1. Students conducting the traditional (Left) and digital experiment (Centre, Right)

The digital environment involved a more complex experimental setup. First, the participants were in separate rooms to mimic a distributed design experience. Video conferencing on Zoom was provided (*Figure 1*), as opposed to the audio only experiments conducted by Jensen et al., [8] and Mulet et al., [13]. This also allowed for the team to share the experiment procedure onto the screen so they could both view the brief and instructions while completing the task. To facilitate digital sketching both group members were given an iPad 11 Pro. This minimised the limitations from poor quality digital sketching devices as identified within both Brisco et al., [9] and Mulet et al., [13].

During a preliminary investigation, MURAL was selected as the most functional whiteboard tool to support brainstorming. Participants were given five minutes to familiarise themselves with MURAL and to ask any questions on its operation. The experimental procedure was as follows: five minutes were provided to read the design brief, ten minutes to draw as many concepts as possible, and two minutes to categorise their concepts. Concepts were saved for analysis. It was emphasised to the participants that the quality of the sketches did not matter as this is not something that was being assessed within the experiment. Upon completing the first design brief the team swapped to the other environment.

Participants were instructed to produce as many concepts as they could for each brief and to then group the concepts into categories. Therefore, the characteristics which the “outcome” of the ideation tasks will be evaluated is Fluency and Flexibility. Fluency is the total number of concepts produced for one brief. This was assessed by simply counting the number of concepts produced. Flexibility is the total number of different categories of concepts produced for one brief. This was assessed by counting the total number of different categories produced.

Fluency, flexibility, originality, and elaboration are the four key characteristics for evaluating creativity with the Torrance Test of Creative Thinking (TTCT) [15] There are two reasons that originality and elaboration have not been considered within the evaluation of the ideation task outcome. Firstly, this study is not directly investigating the effect the different environments have on creativity but the outcome of the ideation task. Secondly, originality and elaboration are subjective in nature and to generate quantitative data for these characteristics at least two qualified external reviewers would be needed to remove bias from the results [16]. Due to the time limitations of this project, it was not possible to test for originality and elaboration in the concepts.

Two hypotheses were created based on the outcomes of the literature review.

H0: Participants will produce a higher fluency score while working in the traditional environment.

H1: Participants will produce a higher flexibility score while working in the traditional environment.

3 RESULTS

The total scores for both fluency and flexibility (*Table 1*) were higher within the traditional environment (Fluency=134, Flexibility=31) compared to the digital environment (Fluency=99, Flexibility=26). Using this data, the percentage decrease of both the total fluency and flexibility scores when moving from the traditional to the digital environment were calculated. The total fluency score decreased by 26.12% when comparing the traditional to the digital environment and the total flexibility score decreased by 16.12% when making the same comparison.

To test if the data was normally distributed a Shapiro-Wilk Test of Normality was conducted. This test was selected over the use of Normal Q-Q plots because the sample size was small (<50 participants). The Shapiro-Wilk test confirmed that the data was normally distributed since p>0.05 [17] for the difference between the fluency (p=0.279) and flexibility (p=0.156) in the traditional and digital environment. This confirmed that a Paired Sample T-Test could be conducted.

Table 1. Fluency and Flexibility Scores for each group in both environments

	Traditional Environment		Digital Environment	
Group	Fluency	Flexibility	Fluency	Flexibility
1	34	4	23	3
2	13	4	15	5
3	21	5	10	3
4	8	3	8	2
5	16	4	11	3
6	9	2	10	3
7	22	6	16	3
8	11	3	6	4
Total	134	31	99	26
Mean	16.75	3.88	12.38	3.25

A Paired Sample T-Test was used to identify if there was a statistically significant difference between the fluency and flexibility scores between the two collaborative environments. Participants had a higher fluency score while in the traditional environment (16.750 ± 8.68) as opposed to the digital environment (12.375 ± 5.42), a statistically significant mean increase of 4.375 (95% CI, 0.137 to 8.613), t (7) = 2.441, p =0.045, d=0.863. This was determined to be statistically significant since p<0.05 [19]. Participants also produced a greater number of concept categories within the traditional environment (3.875 ± 1.246) compared to the digital environment (3.250 ± 0.886) a mean difference of 0.625 (95% CI -0.634 to 1.88) t (7) = 1.17, p=0.279, d=0.42. However, since p>0.05 the difference cannot be considered significant.

Significance	Value
Small	0.2
Medium	0.5
Large	0.8

Figure 2. Cohen's d Significance Table

Cohen's d (*Figure 2*) was used to calculate the effect size one variable has on another. In this case, the effect size refers to the effect the collaborative environment has on the fluency and flexibility scores. Where MM is the mean difference between the two related groups and SD is the standard deviation of the mean. The significance of this effect can be approximated using Cohen's d significance table [18].
The results of the Paired Sample T-Test have shown that the effect the different collaborative environments had on fluency is large and can be considered statistically significant. However, the effect on flexibility is small and is statistically insignificant.
Although the majority of teams displayed a similar pattern considering preference for traditional over digital environment, two anomalies were found. Group two and six had higher Fluency and Flexibility scores for digital over traditional. This could be a result of individual preference or experience, something this study could not determine.

4 DISCUSSIONS

Results from the experiment reveal that both fluency and flexibility scores were higher for the traditional environment. To confirm or reject the hypothesis the results underwent statistical analysis. Although there was variance in the scores between the groups, there were no data outliers that could affect the statistical analysis. The Shapiro-Wilk Test for Normality was conducted which confirmed that the results were normally distributed since $p>0.05$ for both fluency and flexibility scores [17].

The results of the Paired Sample T-Test revealed that participants had higher mean fluency and flexibility scores while conducting the ideation task within the traditional environment. The test displayed that the effect the collaborative environment had on the fluency scores was statistically significant since $p<0.05$ [19]. Cohen's d was used to calculate the size of the effect the collaborative environment had. The results showed that the different collaborative environments had a large effect on the fluency scores since $d>0.8$. Therefore, confirming that conducting the collaborative ideation task in a digital environment has a large and statistically significant negative effect on the number of concepts produced when comparing it to working in a traditional environment.

Although the mean flexibility scores were higher within the traditional environment, the Paired Sample T-Test showed that the difference was statistically insignificant and after calculating Cohen's d the results showed that the effect size is considered small. This showed that when working in the different collaborative environments there is a minimal and insignificant effect on the number of categories produced within the ideation task. However, further testing with a larger sample size and other ideation tasks could be conducted to see if the effect on flexibility is still minimal.

The results from the experiment reveal the results of the hypotheses:

H0: Participants will produce a higher fluency score while working in the traditional environment.

H1: Participants will produce a higher flexibility score while working in the traditional environment.

The results from the experiment showed that hypothesis H0 could be confirmed as the flexibility scores while working in the traditional environment were higher and the mean difference was confirmed to be statistically significant. Although the scores for the flexibility scores were also higher in the traditional environment, hypothesis H1 could not be confirmed as the analysis of the results showed that the difference was too small to be considered statistically significant. Therefore, the results from the analysis, could not confirm hypothesis H1.

Limitations of the study include a small sample size, inconsistent familiarity with the iPad as a sketching tool, inconsistent familiarity with MURAL as an ideation tool, limited evaluation of the outcomes of the ideation which may in the future include novelty, elaboration, quality and originality. The limitations of this work could be minimised through repeating the experiment with a larger sample size as this would result in more accurate mean values which could be used to display the true effect the different collaborative environments have on the ideation task. The participants chosen for the experiment should be given a longer training period with both digital sketching on the device and the use of MURAL for the ideation task so that they can be more familiar with the software. The digital set-up could also be improved by having a separate screen displaying the MURAL board as a whole, to allow better visibility of the participants partner's concepts to be used as inspiration. Finally, the experiment could also be repeated with external reviewers measuring for novelty, elaboration and originality to display the effects the collaborative environments have on creativity as a whole.

5 CONCLUSIONS

The use of CAD technology has been long established within the later stages of design, such as 3D CAD for detailed design, finite element analysis and manufacture and assembly modelling. However, there are a lack of effective technologies developed to support collaborative conceptual design as this has traditionally been completed in a face-to-face environment using paper-based sketching. This poses a risk to the design process during the move to distributed working. To support distributed 'working from home' the research community needs to build an understanding of the similarities and differences between collocated design activities and distributed design activities so that effective solutions can be developed so that conceptual design tasks can be conducted in person or digitally with equal impact.

The experiment was designed to test the effect the different collaborative environment has on the outcome of an ideation task. The experiment was complete with 16 participants. The ideation task selected for this experiment was "brainstorming" using sticky notes. During the experiment, the participants were given two equally difficult design project briefs which they used to conduct the brainstorming ideation task. The participants completed one of the briefs in the digital environment and the other brief in the traditional environment.

The experiment results concluded that conducting the ideation task within the digital environment had a large and statistically significant effect on the fluency scores, confirming hypothesis H0. There was only a small and statistically insignificant effect on the flexibility scores, therefore, H1 could not be confirmed. Further testing with a larger sample size and different ideation tasks would be required to display the effect on flexibility more accurately and confirm whether this is truly insignificant.

REFERENCES

[1] Vuletic T., Duffy A., Hay L., McTeague C., Pidgeon L. and Grealy M. *The challenges in computer supported conceptual engineering design*. Computers in Industry, vol. 95, pp. 22–37, 2018.

[2] Oti A. and Crilly N. *Immersive 3D sketching tools: Implications for visual thinking and communication*. Computers & Graphics, vol. 94, pp. 111–123, 2021.

[3] Tang H. H., Lee Y. Y. and Gero J. S. *Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function–behaviour–structure coding scheme*. Design Studies, vol. 32, no. 1, pp. 1–29, 2011.

[4] Zhong K., Kang J., Qin S. and Wang H. *Rapid 3D conceptual design based on hand gesture.* 2011 3rd International Conference on Advanced Computer Control, ICACC 2011, pp. 192–197, 2011.

[5] Yang Z., Xiang W., You W. and Sun L. *The influence of distributed collaboration in design processes: an analysis of design activity on information, problem, and solution*. International Journal of Technology and Design Education, vol. 31, pp. 587–609, 2021.

[6] Fuge M., Yumer M. E., Orbay G. and Kara L. B. *Conceptual design and modification of freeform surfaces using dual shape representations in augmented reality environments*. Computer-Aided Design, vol. 44, no. 10, pp. 1020–1032, 2012.

[7] Mulet E., Chulvi V., Royo M. and Galán J. *Influence of the dominant thinking style in the degree of novelty of designs in virtual and traditional working environments*. Vol. 27, no. 7, pp. 413–437, 2016.

[8] Jensen M. M., Thiel S.-K., Hoggan E. and Bødker S. *Physical Versus Digital Sticky Notes in Collaborative Ideation*. Computer Supported Cooperative Work (CSCW) vol. 27, no. 3, pp. 609–645, 2018.

[9] Brisco R., Grierson H. and Lynn A. *Lessons learned in the development of an online 6-3-5 digital design tool for distributed idea generation*. DS 110: Proceedings of the 23rd International Conference on Engineering and Product Design Education (E&PDE 2021), 2021.

[10] Duehr K., Kavakli E. and Albers A. *Improving distributed collaboration – methods for identification and developing of improvement potentials*. Procedia CIRP, vol. 100, pp. 750–755, 2021.

[11] Osborn A. F. *Applied Imagination; Principles and Procedures of Creative Thinking*, 3rd ed. New York: Scribner, 1954.

[12] Gonçalves M., Cardoso C. and Badke-Schaub P. *What inspires designers? Preferences on inspirational approaches during idea generation.* Design Studies, vol. 35, no. 1, pp. 29–53, 2014.

[13] Ball L. J., Christensen B. T. and Halskov K. *Sticky notes as a kind of design material: How sticky notes support design cognition and design collaboration*. Design Studies, vol. 76, 2021.

[14] Hay L., Duffy A., Grealy M. and Campbell G. *Quantitative and qualitative data from a functional magnetic resonance (fMRI) study of ideation in product design engineering*. Dataset DOI:10.15129/a82c32a8-689a-4be5-a61f-17d60eaad10c 2019.

[15] Torrance E. *Torrance tests of creative thinking*. Norms-technical manual. Research edition. Verbal tests, forms A and B. Figural tests, forms A and B. Princeton: Personnel Press, 1966.

[16] Wodehouse A., Maclachlan R. and Gray J. *The best form of medicine? Using humour to enhance design creativity*. International Journal of Design Creativity and Innovation, vol. 2, no. 3, pp. 125–141, 2014.

[17] Rochon J., Gondan M. and Kieser M. *To test or not to test: Preliminary assessment of normality when comparing two independent samples*. BMC Medical Research Methodology, vol. 12, no. 1, pp. 1–11, 2012.

[18] Cohen J. *Statistical Power Analysis for the Behavioural Sciences*. Statistical Power Analysis for the Behavioural Sciences, 1988.

[19] Andrade C. *The P Value and Statistical Significance: Misunderstandings, Explanations, Challenges, and Alternatives*. Indian Journal of Psychological Medicine, vol. 41, no. 3, p. 210, 2019.