Design and Technology Education: An International Journal

29.3

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Book Reviews

Editorial: The value of collaboration

Kay Stables, Goldsmiths, University of London, UK
Lyndon Buck, University of Southampton, UK

This issue of the journal contains four research articles which, while being varied and aimed at different educational stages, all share a focus on working across traditional disciplinary, subject or technological boundaries, by taking down walls and using pluralistic approaches. By working across traditional boundaries, the authors have shown how, through collaboration, we can help to shape and develop our own design practices and those of others in new and exciting ways. Our first research article shows how we can use concepts from science in school-based design, discusses the impact on teachers and learners, and highlights the importance of empathy in going beyond traditional design concepts and developing a broader understanding of design thinking. Our second and third articles are both transdisciplinary, firstly with design educators and ethnographers working together with undergraduates, and secondly with academics and industry collaborating to develop digital prototyping tools. Our final future article is future facing, discussing using VR as a teaching tool. We also have a reflective article which celebrates the contribution of George Hicks to the development design and technology education.

Our first issue of 2025 will be 30.1, marking the thirty year anniversary of the first DATE publication. Moving into our thirtieth year we have updated the journal's website URL to https://openjournals.ljmu.ac.uk/DesignTechnologyEducation and having a new acronym for the journal: DTEIJ – both URL and acronym a better match for the journal's title.

Thirty years ago Richard Kimbell stepped down as editor of the journal and for two decades wrote reflections for the journal on the state of play in design and technology education. For this issue he has returned with a reflection on the huge and critical impact that George Hicks, a "founding father" of modern-day design and technology education, had on the development of the subject, particularly within the UK. George Hicks sadly died earlier this year. In *George Hicks: A personal appreciation*, Richard reminds us of how significant George Hicks was as a leader, educator and thinker, in many ways decades ahead of his time. Anyone truly interested in the history of the development of design and technology education will find the article full of the visionary thinking and action of a man who contributed massively to the foundations of a progressive design and technology education, whose ideas and ideals are as important and relevant today as they have ever been.

The first research article in this issue focuses on a fascinating study of using Adaptive Comparative Judgement (ACJ) with secondary school students. In *Defining and Evaluating Argumentation Quality in the Context of Design Thinking: Using High School Students' Design Critiques from Foundational Engineering Courses*, Wonki Lee, Nathan Mentzer and Amiah Clevenger from Purdue University, USA, along with Andrew Jackson from the University of Georgia, USA and Scott Bartholomew from Brigham Young University, USA report on gaining insight into the extent to which students could critique designs by analysing the quality of their ability to use argumentation to explain and justify their critique. ACJ is an approach to making judgments by comparing pairs of design work multiple times with multiple judges, to create a rank order of the quality of the design work in process. The research focuses on learning - both by educators and students. The students were on a foundational engineering design course where design thinking was seen as an iterative, non-linear process, illustrated in their article by a particularly helpful diagram. Participants were given pairs of designs for a backpack, asked to judge which was best and to justify their decisions. The team's analysis employed a *Claim, Evidence, Reasoning* framework which emphasises empathy, ideation and insight. Where they found high quality argumentation there was evidence of user-focused empathy, design inspirations, logical rationalizations, multi-criteria evaluations, aesthetic considerations, and cultural awareness. The flip side identified vagueness, uncertainty, brevity, inappropriateness, irrelevance, gender bias, and cultural stereotyping. This article provides valuable insights for other educators and researchers into a student's ability to understand and develop creative and empathetic approaches to designing. Much previous research had used ACJ at the end of a design activity but the research reported here used the process during and at the end of the project, revealing for example, more insight into students' progress. The article is beneficial in providing an approach that can help both teachers and learners in develop deeper insight into design thinking.

The following article, also from Purdue University, has particular value in using a transdisciplinary approach involving co-teaching an undergraduate course entitled "Designing Technology for people" by academics from a Department of Anthropology and a Department of Technology Leadership & Innovation. In *Engaging ethnography in the human-centered technology design classroom*, *Sarah* Renkert, Jung Han, Sherylyn Briller, Todd Kelley and Abrar Hammoud focus on the impact of using ethnographic methods for teaching human-centred design. The course is an undergraduate elective and in the first stages students are introduced to ethnographic methods with a particular focus on participant observation, semi-structured interviews and triangulation of findings. Initially students undertake ethnographic research on their own and then work in teams and identify a user group as a focus for their designing. The article provides a case study of one team who have chosen a particularly novel user group – squirrel watchers. The team's initial ethnographic research starts by squirrels being seen as creating problems for humans, despite them being deemed 'cute' and enjoyable to watch. But as the research progresses the team's perspective shifts from solving squirrel problems to how squirrel-related experiences - for both squirrels and humans, can be enhanced. This shift in perspective moves the focal point of the research to human-centred design and design development more about opportunities than problems. A key message from the research is the benefit created by bringing together design educators and ethnographic researchers, a factor highlighted by the students themselves. The article shows how the approach impacted on students' thinking. The article also provides a constructive pause for thought for the reader!

In *Development and Evaluation of a Novel Technological Product Development Tool for Education and Industry* Jack Rutherford, Ross Brisco and Robert Lynch from Strathclyde University, UK report on the development of a digital product development tool to aid with the ideation process to generate design concepts. The growth in the use of digital whiteboard tools such as Miro, Mural and Figma for concept development among design students and educators has been impressive, but not all students enjoy their digital nature, preferring a more hybrid approach, mixing digital and physical. A 6-3-5 digital product development tool was developed with the Design Engineering Team at the National Manufacturing Institute Scotland (NMIS) where 6 team members produce 3 ideas each in 5 minutes. Team members then exchange drawings and refine each other's concepts for another 5 minutes, repeating for a total of 6 rounds. The tool was tested with focus groups and compared to more traditional paper-based equivalents, with two-thirds preferring the digital version. Some students expressed frustration at trying to draw their concepts on-screen, especially those with little previous experience of digital sketching, but most acknowledged that this would be less of an issue with practice. Participants particularly welcomed the ability to store, export and reuse concepts, making the design process more efficient, and also noted the potential of the application for enhancing learning. Educators may welcome the enhanced traceability of an individual's design process journey, which can be difficult to follow with traditional collaborative digital whiteboard tools.

Our final research article *Virtual Reality as a Supportive Tool for Design Education* by Abhay Chavan and Somik Ghosh, University of Oklahoma, USA focuses on using VR as a supportive teaching tool in design education. The study evaluated the effectiveness of using immersive VR in developing the technical and spatial knowledge of first year architecture students, showing how successful it can be when used as a supportive tool to scaffold learning alongside traditional teaching content, rather than replacing traditional content delivery. VR content was created for courses requiring visualisation, such as means and methods, and history of contemporary architecture, with students using virtual environments as supportive educational tools. Most students had little previous experience with using VR, yet most reported that VR had made a positive contribution to their understanding of the environments, their ability to retain technical information, and was a more effective way of learning 3D content based on visual memory. While some students reported discomfort through using the VR equipment, most rated the quality of VR material and ease of use positively. The authors suggest that VR tools have the potential to enhance learning outcomes and student engagement if used in conjunction with traditional teaching content. Overall, this study contributes by addressing a gap in current literature by testing the effectiveness of immersive virtual reality technologies as a supportive tool in education, particularly in the field of 3D design.

In this issue we also have reviews for three, quite different but equally valuable books providing insight into quite diverse aspects of design and technology education.

Marion Rutland has provided a review of an edited book on Maker Education - a close relative of increasing importance in Design and Technology education. The book is entitled *Maker Education meets Technology Education: Reflections on Good Practice.* It is edited by Remke M. Klapwijk, Jianjun Gu, Qiuyue Yang and Marc J. de Vries, who also contribute chapters and is published by Brill Academic Publishers. This is followed by a distinctly different book, written by John Dakers and reviewed by Matt McClean. The book*, A Nomadic Pedagogy about Technology: Teaching the Ongoing Process of Becoming Ethnictechnologically Literate* is also published by Brill Academic Publishers. The final book, *Future Prospects of Technology Education* is the fourth volume in a series from the Center of Excellence for Technology Education (CETE), published by Waxmann publishers and is reviewed by David Gill, Canada and Alexander Taylor.

We hope that you enjoy this issue and we look forward to seeing you in 2025.

George Hicks: A personal appreciation

Professor Richard Kimbell, Goldsmiths, University of London, UK

On the 28th June this year I attended the funeral of a brilliant teacher and thinker who did probably more than any other single person to create Design & Technology as a school subject. This piece is not intended as a traditional obituary, rather it is a personal statement of appreciation of his impact on design & technology generally and on my work in particular.

It should be noted at the outset that George has left behind very little of the traditional legacy of university folk. He published very little in his own name and the things he did write - some of which were extraordinarily influential - were typically internal documents at Goldsmiths College or (later) for the schools Inspectorate. Such documents then appeared as Departmental or Faculty documents at Goldsmiths or (later) as the Government's Department for Education and Science (DES) official publications. I sit with George's London University Master of Philosophy thesis open in front of me: "*The Educational Validity of Design Studies within the Secondary School Curriculum*" (1975) and flicking through the bibliography there is not a single reference to Hicks, G. Rather, he cites practitioner bodies like the Schools' Council, and principally he draws from educational thinkers like Basil Bernstein, John White, Paul Hirst, Vic Kelly and Jacob Bronowski. George's principal motivation in the evolution that he pioneered was always educational. Over the next forty years all sorts of other priorities were argued by various factions, not least the case for vocational study, or for engineering, or for a high tech future. But George always saw Design & Technology as an *educational* force - encouraging all youngsters to develop their thinking and their problem solving, to better understand and participate in their society and culture.

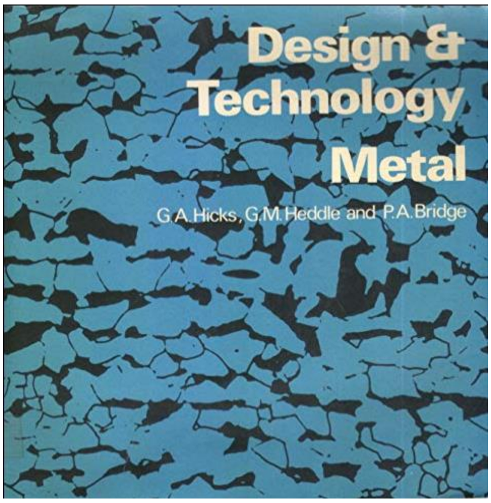
The roots of George's extraordinary contribution lay in his leadership of what - in the 1960s - was called the Handicraft department at Goldsmiths College. Handicraft Education had been strong in the 1950s and was flourishing in the 1960s, and there is no doubt that George's appointment to the Handicraft department was based on the fact of his being a skilled craftsman himself (silversmith). But George was aware of the weaknesses of an education based entirely in the acquisition of such skills and as he took over the leadership of the department he began a process of steering it from a Handicraft department to a Design & Technology department.

> *There is little doubt that earlier emphasis on the development of craftsmanship has resulted in a neglect of educational responsibilities in relation to*

i) *the development of an understanding of the cognitive structure underlying the designing of the product being made,*

ii) *an appreciation of the cognitive, affective, social and environmental elements involved in its designing.* (Hicks, G. 1975)

The 1960s was a fertile time with several official reports and research & development projects springing up within our field. The Crowther Report (1959) had exposed the weaknesses inherent in the separation of the mind (Grammar Schools/academic study) and the hand (Secondary Modern Schools/practical study). In a radical Chapter 35 they had recommended "An alternative road to learning" in which practical skills and intellectual challenge are integrated and the Schools Council sought to foster the notion. By the late 1960s, Project Technology, or School Technology was established and became influential particularly under the direction of Geoffrey Harrison. It was especially influential in particular regions (Local Education Authorities) of the UK, with Hertfordshire and Bedfordshire being the epicentre.



And at Goldsmiths, George continued to find ways to build a model of practice in the department that united designing with making and with learning. His goal was to transform the curriculum and help teachers (principally at that time craft teachers) to understand how to teach it. With his colleagues in the department he created a series of Design & Technology books for schools [metal; wood; plastics] (with Pergamon) in which they helped teachers launch real design tasks and become facilitators of their students' own thoughts and ideas.

An interesting illustration of his influence is seen in his 10 years working as an examiner for the London University Schools Examination Department (later absorbed into Edexcel, a national examination Awarding Body). Appointed originally as an examiner for 'Ordinary' level Handicraft (metalwork), in 1969 he became Chief Examiner and set about creating serious change. The existing O level had a formal examination structure with two written papers and a 3 hour practical test. In George's new plan, one of the written papers became a design paper in which students responded with sketches and notes to a number of small challenges. But the most significant change was to the practical. This was traditionally presented to students as a formal technical drawing (e.g. of a metal vice/clamp) and a set of component pieces of material to be cut and fitted accurately into the final object in 3 hours of workshop time. George did not want to dispose of the practical piece (he believed in high quality making) but he sought to adapt it to become also a design challenge. He created a 'pre-practical' paper which was essentially a design paper set 4 weeks before the practical test. Students were expected to design and make a product that was subsequently to be part of the product that made up the practical examination.

I was teaching this course in my first teaching appointment in 1970 and at the end of the course, in 1972, the practical test was to make the adjustable joint/platform of a surveyor's theodolite. The pre-practical (that my students had to design for themselves from scratch) was to create a levelling device that would enable the surveyor to set-up the theodolite table properly horizontal (in all planes). We were told to enclose all drawings and models and package them all up with the student's own levelling device attached to their final practical piece when it was sent off to the examiners. We were also to include an additional form on which the students produced their own critical reflection on their own submitted work. In 1972 the new O level examination course was launched as the London O level in Design & Technology. This was the first examination of students' Design & Technology ability anywhere in the world. Two years later, in 1974, the Advanced level examination followed with further innovations. At the launch of the A level course, the University of London announced the formal recognition of Design & Technology A level as a university entrance qualification. This had never been the case with the precursor Handicraft qualifications.

All this was more than 50 years ago and was, significantly, the vision of one man. Inevitably the transitions from Handicraft involved an enormous demand for in-service support for teachers and from 1970 George undertook a national programme of illustrated talks with teachers, LEAs, universities, and with the British Council. His lectures and workshops of course involved many practical illustrations, but they were always set within his analysis of the educational philosophy that should underpin the new programme.

His MPhil was almost the last thing that George wrote at Goldsmiths since he left in 1975 to become an Her Majesty's Inspector of Schools (HMI) where he subsequently became Staff Inspector responsible for the D&T team of HMI. He was always aware of the importance of good teaching to ensure that the new subject thrived, so the development of teachers was very close to his heart. As he pointed out in 1983

> *Teaching facts is one thing: teaching pupils in such a way that they can apply facts is another: but providing learning opportunities which encourage pupils to use information naturally when handling uncertainty, in a manner which results in capability is a challenge of a different kind.* (Hicks, G., 1983)

Responding to his own call to action, George acquired a very considerable grant to initiate a week-long Summer School at Loughborough University. In addition to central presentations, teachers could opt to study a wide range of topics that were becoming central to the new vision of Design & Technology, particularly including design approaches to learning. And he secured the very best teachers/lecturers/advisers from across the country to lead the sessions. These DES summer schools became legendary. They became so successful that they were repeated year after year throughout the 1980s and at their height, the Summer Schools attracted 200 or more teachers each year.

And of course George and the HMI team kept up a regular output of publications to support teachers' understanding of what D&T is, why it is important, and how we can best teach it.

Curriculum 11-16: Working Papers by HMI (1977)
Craft Design and Technology in Schools: Some Successful Examples (1980)
Understanding Design & Technology (1981)
Another Step Forward for Design & Technology (1983)
Craft Design & Technology 5-16: Curriculum Matters 9 (1987)
D&T 5-16 Proposals for D&T in the National Curriculum (1989)

In this last case George was a key player in the working group that formulated Design & Technology in the National Curriculum. Whilst unhappy with some of the ultimate recommendations, he continued to argue for the essence of what Design & Technology amounted to for him. This vision was captured in 2000, when subject groups were invited to publish statements about why their subjects are important in the curriculum. The Design & technology working group prepared this statement and despite being the work of a wider group, it is pure George, and it serves as a fitting epitaph.

> *"Design and technology prepares pupils to participate in tomorrow's rapidly changing technologies. They learn to think and intervene creatively to improve the quality of life. The subject calls for pupils to become autonomous and creative problem solvers, as individuals and members of a team. They must look for needs, wants and opportunities and respond to them by developing a range of ideas and making products and systems. They combine practical skills with an understanding of aesthetics, social and environmental issues, function and industrial practices. As they do so, they reflect on and evaluate present and past design and technology, its uses and effects. Through design and technology, all pupils can become discriminating and informed users of products, and become innovators."* (QCA/DfEE, 2000)

Interestingly, George did not write this statement. He had retired earlier from the Inspectorate and the point of it here is to illustrate the astonishing effectiveness of George's professional life. He had been a pioneering presence as a university teacher and schools examiner in the 1960s and 1970s bringing out the educational importance of Design and Technology for all learners. And then in the 1980s and 1990s he was such a persuasive advocate for this educational vision that he didn't need to write that magnificent statement. In the end, George's final triumph was that his colleagues and contemporaries were united with him in this vision and they wrote it for him.

References

Crowther, G., (1959) *15-18. A report of the Central Advisory Council for Education (England)*. Her Majesty's Stationery Office, London.

Hicks, G., (1975) *The Educational Validity of Design Studies within the Secondary School Curriculum. MPhil thesis.* Institute of Education, London.

Hicks, G., (1983) Another step forward for design & technology. *APU Newsletter No 4 Autumn*. Department for Education & Science, London.

Qualifications and Curriculum Authority (QCA). (2000) *Design & Technology in England: It's distinctive contribution in the curriculum*. Department for Education & Employment, London.

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Defining and Evaluating Argumentation Quality in the Context of Design Thinking: Using High School Students' Design Critiques from Foundational Engineering Courses

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Andrew Jackson, University of Georgia, USA
Scott Bartholomew, Brigham Young University, USA
Amiah Clevenger, Purdue University, USA

Abstract

This research investigates students' argumentation quality in engineering design thinking. We implemented Learning by Evaluating (LbE) using Adaptive Comparative Judgment (ACJ), where students assess pairs of items to determine the superior one. In ACJ, students provided rationales for their critiques, explaining their selections. Fifteen students participated in an LbE exercise before starting their backpack design projects, critically evaluating multiple backpack designs and producing 145 comments. Writing comments required students to discern and justify the superior design, fostering informed judgment and articulation of their reasoning. The study used the Claim, Evidence, and Reasoning (CER) framework, adapted for engineering design thinking, to analyse these critiques. The framework emphasized three aspects: Empathy (understanding user needs), Ideation (deriving design inspiration), and Insight (gaining valuable understanding from evaluated designs). We employed both deductive and inductive content analysis to evaluate the argumentation quality in students' critiques. High-quality argumentation was identified based on six codes: user-focused empathy, design inspirations, logical rationalizations, multi-criteria evaluations, aesthetic considerations, and cultural awareness. Poor-quality argumentation lacked these elements and was characterized by vagueness, uncertainty, brevity, inappropriateness, irrelevance, gender bias, and cultural stereotyping. By identifying critical elements of effective argumentation and common challenges students may face, this study aims to enhance argumentation skills in engineering design thinking at the secondary education level. These insights are intended to help educators prepare students for insightful and successful argumentation in engineering design projects.

Keywords

LbE (Learning by Evaluating), ACJ (Adaptive Comparative Judgment), CER (Claim, Evidence, and Reasoning) framework, Design thinking

Introduction

There is an urgent need to enhance young individuals' comprehension of argumentation within a scientific context (Osborne et al., 2004). Osborne and colleagues (2004) asserted that science, a field that prides itself on rationality, often falls short in teaching students about the epistemological foundations of belief (Driver et al., 2000; Duschl & Osborne, 2002; Osborne et al., 2003). Oftentimes, this failure results in students' holding simplistic perceptions of science (Driver et al., 1996, 2000). Thus, one of the vital responsibilities for the current education is to cultivate argument construction and explanation. Such instruction enhances students' ability to comprehend and employ scientifically sound argumentation (Duschl & Osborne, 2002). Osborne (2004) underscored the significance of embedding scientific argumentation within classroom settings, suggesting it serves as a heuristic methodology that augments students' ability to navigate conceptual and epistemic objectives. This integration not only illuminates students' scientific cognition and reasoning but also facilitates formative assessment opportunities for educators. Consequently, the pursuit of epistemic objectives, such as the formulation, assessment, and refinement of scientific arguments, is imperative to modern science education.

Numerous studies have highlighted that fostering students' ability to construct scientific arguments can be significantly enhanced by presenting them with contrasting theories or evidence (Keogh & Naylor, 2000; Osborne et al., 2004; Settlage & Sabik, 1997; Solomon et al., 1992). This method not only strengthens critical thinking skills but also empowers students to integrate their scientific knowledge into discussions and decision-making processes. Importantly, the skills developed through constructing scientific arguments are not limited to science but are equally valuable in fields like engineering and technology design, where reasoned argumentation is critical for evaluating, justifying, and refining solutions (Dow et al., 2009; Erduran & Jiménez-Aleixandre, 2007; Jonassen, 2011; Osborne et al., 2004).

In the engineering education context, the introduction of competing evidence presented in parallel - rather than sequentially - has been shown to positively impact learning outcomes (Dow et al., 2009). For example, Dow et al. (2009) observed that parallel presentation fosters more diverse prototyping, allowing students to explore a broader range of design possibilities, ultimately improving the effectiveness of the design process. Similarly, Karabiyik et al. (2023) found that exposing students to contrasting cases activates prior knowledge, helping them identify and emphasize key elements of domain-specific concepts. This approach aligns with the work of Schwartz & Bransford (1998), who argued that contrasting scenarios encourage learners to focus on critical differences, thereby deepening their understanding of the material.

The Learning by Evaluating (LbE) method (Jackson et al., 2023; Mentzer et al., 2023) extends the concept of contrasting case analysis into engineering design thinking. This approach actively engages students in the evaluation of contrasting engineering designs items, which are presented in parallel. Then, they are asked to provide their rationale for selecting one over another. Students apply their domain knowledge to discern and judge contrasting design cases.

This immersive evaluative process not only involves making informed judgments but also requires students to articulate their reasoning, thereby deepening their engagement and understanding. By integrating such critical comparative analysis into the learning process, LbE echoes the positive influence of contrasting evidence on learning outcomes observed in scientific reasoning.

Additionally, through LbE, students are encouraged to explore a broader spectrum of design possibilities, enhancing their design thinking capabilities and the overall efficacy of the design process (Jackson et al., 2023; Mentzer et al., 2023; Thorne et al., 2024). LbE provides insights into design thinking at the onset of a project, rather than postponing experience of critiquing until students have delved deeper into their tasks. Importantly, in LbE, the examples for evaluation were instructor-curated to align with specific learning goals or project components. Based on this strategy, researchers posit that students will not only gain a clearer direction for their project, but the comparative evaluations they undertake will also enhance their decision-making abilities as well as argumentation skills, especially when faced with open-ended challenges.

In an engineering design context, Strimel et al. (2021) explored the application of LbE to shape engineering students' design choices. A key component of this process is comparative judgment (CJ), which involves systematically comparing pairs of student work based on defined criteria to determine which is of higher quality. Unlike traditional grading, CJ relies on expert or peer evaluations through a series of binary comparisons, which are aggregated to provide a rank order of work. This approach not only reduces subjective bias but also provides valuable insights into the relative strengths and weaknesses of designs. The research findings suggest that the CJ procedure within LbE allowed students to gain valuable perspectives for improving their designs by evaluating the work of their peers, although direct feedback on their own projects was not provided as part of the process.

Mentzer et al., (2023) recently examined the nature of students' reasoning and comments using computer-assisted content analysis, complemented by a subsequent qualitative content analysis. Their research uncovered a spectrum of critical and scientific thinking skills among high school students in the realm of engineering design thinking. The CER framework, which emphasizes Claim, Evidence, and Reasoning as foundational components of constructing scientific arguments, provides a structured approach to analyzing student argumentation. However, the study applied the CER framework in its original form, without customizing or expanding it specifically for the engineering design thinking context.

Given that the CER framework is domain-specific, this study aims to identify and assess argumentation quality specifically within the engineering design context. This is explored as students engage in LbE and articulate their critiques in the comment section (see Figure 1).

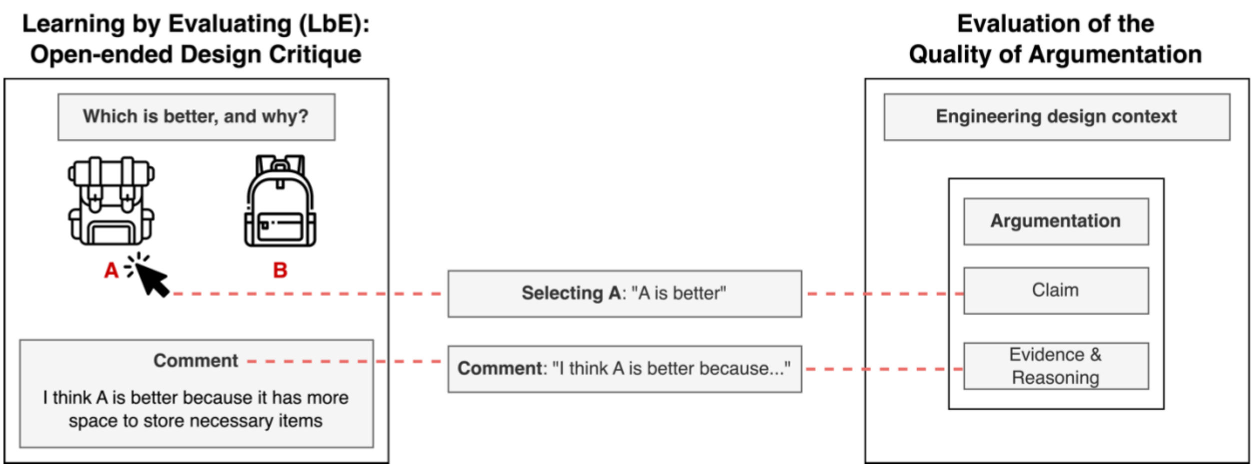

Figure 1. Research design: LbE and the evaluation of the quality of argumentation

Since CER framework varies depending on the domain (Slavit et al., 2021), this study aims to delineate and assess the quality of argumentation within the context of engineering design, particularly when students engage in the LbE and articulate their critiques in comments. This investigation will extend beyond merely evaluating the presence and elaboration of claims, evidence, and reasoning. It will also explore how these argumentation elements are applied within the essential criteria of the design thinking process. The research question for the present study is outlined as follows.

Research Question:

> *How is high-quality argumentation defined and operationalized within the context of engineering design thinking, and conversely, what characterizes poor-quality argumentation in this field?*

Examining high-quality argumentation within the context of design thinking can serve as an exemplary model for students, guiding their analytical development. Conversely, identifying instances of weak or poor-quality argumentation can spotlight specific areas that require enhanced instructional focus. By reviewing students' comments in conjunction with the categorizations of quality presented in this article, teachers can gain valuable insights into their students' understanding and reasoning. This dual approach not only helps in recognizing the current level of students' argumentative skills but also aids in determining where additional instruction or support may be necessary to foster improvement.

Literature Review

Adaptive Comparative Judgment (ACJ)

Adaptive Comparative Judgment (ACJ) is a technique developed by researchers and psychologists to evaluate complex or subjective tasks, such as open-ended responses, design projects, or creative work, through a series of pairwise comparisons. It builds upon the

Comparative Judgment (CJ) approach developed by Thurstone in 1927. Thurstone's framework posits that judges can make more precise discriminations between two items when comparing them directly, rather than assigning absolute quality scores, which can be influenced by individual biases or environmental factors. In both CJ and ACJ, judgments are made independently of others and rely on the relative quality of each pair rather than pre-defined scoring rubrics (Bartholomew, 2021). By focusing on comparative evaluations, ACJ offers a reliable and efficient method for assessing tasks that are difficult to quantify using traditional scoring approaches.

In the transition to the twenty-first century, Pollitt utilized comparative judgment, integrated multifaceted statistical analyses, and introduced the approach as Adaptive Comparative Judgment or ACJ. Literature demonstrates greater validity, reliability, and robustness of ACJ compared to CJ (Kimbell, 2022; Mentzer et al., 2021; Pollitt, 2015)-. This approach is considered "adaptive" as it employs an algorithm which assigns values to each of the objects being compared, later showing the judge comparisons of similarly valued items to fine tune the rank order rather than comparisons of paired items that are already determined to be extremely higher or lower than each other.

As an example, in 2012, Pollitt conducted a study involving 1,000 writing samples from students aged nine to eleven (Pollitt, 2012b). In this research, educators were recruited to act as judges and underwent comprehensive training. Subsequently, they were assigned the task of evaluating pairs of writing samples and determining the superior one from each pair. As evaluators engage in judgments, examples are associated with a value of one or zero (winner or loser), and then put through another series of comparisons based on similar values after the initial random judgments of pairs were made. This continued until all writing pieces were given a final rank, continually compiling based on their previous results. At the end of the test, all judges that gave feedback reported that they would rather use ACJ than their traditional form of marking (Pollitt, 2012b).

With the promise of ACJ firmly in view, researchers are actively exploring avenues for its broader application in technology, engineering, as well as design and technology fields throughout the United States (Bartholomew, 2021). Within higher education, ACJ has garnered significant attention, particularly in the context of design-related work (e.g., portfolios, presentations, and prototypes). In the context of design learning, Kimbell & Stables (2007) have explored the broader implications of comparative judgment, emphasizing its potential to enhance design-based education by fostering critical thinking and reflective practices. Their research has provided foundational insights into how comparative methodologies, such as ACJ, can be integrated into engineering and design education to promote robust assessment practices. Also, Bartholomew & Strimel (2018) examined the application of ACJ in engineering education to assess students' design portfolios. Their study highlighted how ACJ not only streamlined the evaluation process but also provided robust reliability and validity in ranking the quality of design solutions, enabling educators to identify and reward nuanced differences in creativity, functionality, and innovation. Beyond design, the potential of ACJ extends to other disciplines, including mathematics, audio content, and graphic design, demonstrating its versatility in evaluating complex, subjective tasks (Bartholomew, 2021).

Learning by Evaluating (LbE)

Learning by Evaluating (LbE) is an educational approach based on ACJ. Previous studies that incorporated students as judges in the ACJ process (e.g., Bartholomew, 2019; Bartholomew, 2018;) recognized the contribution to learning of this participation; additionally, studies wherein critique in ACJ was made *during* a project, as opposed to the end of the project, have enabled students to apply insights from the comparative process (Bartholomew et al., 2019). Therefore, LbE amplifies these paradigmatic changes to the traditional educational experience by using *student judges in the beginning* of the design process to prime student learning. In the realm of academic assessment, LbE introduces a novel approach that empowers students to take a proactive role in their learning process. It serves as a valuable tool for them to enhance the quality of their later work, stimulate creativity in design, and effectively leverage feedback (Bartholomew et al., 2019).

Our team, supported by a National Science Foundation (NSF) grant—a U.S. program funding research and education in science and engineering—is investigating the optimal implementation of LbE to achieve desired student learning outcomes. For example, in the study conducted by Bartholomew et al. (2020), the research group introduced LbE in an entry-level college class at the beginning of their task. In this case, students were to craft Point Of View (POV) statements which help lean into designing a future solution. Students in the experimental group examined POV statements from previous years, made side-by-side comparisons, and then composed their own statements. Subsequently, students assessed their peer's statements and those of the control group, assigning rankings. The results showed that the treatment group received higher rankings on average, with 7 of the top ten POV statements originating from this group.

In secondary education, Bartholomew's 2019 study focused on implementing LbE in a seventh-grade classroom at the middle and end of the project, hence allowing students to view feedback, make corrections of their designs, and be re-evaluated at the end. Once again, the treatment group demonstrated significantly higher rankings compared to their peers who had not participated in the experiment. Furthermore, the majority of students expressed satisfaction with the ACJ process, highlighting their enjoyment of learning from peers and engaging with constructive feedback (Bartholomew et al., 2019). Literatures thus consistently demonstrates the positive outcomes of LbE as a part of the learning experience for students.

Students' Learning Through Scientific Reasoning

Scientific reasoning is a problem-solving approach rooted in critical thinking, where individuals employ all available information to arrive at informed conclusions. Scientific reasoning is related to cognitive abilities such as critical thinking and reasoning which is used when developing critical STEM activities such as developing experiments, creating hypotheses, and deducting outcomes (Bao et al., 2009). Developing scientific reasoning will help students to solve future relevant problems in the STEM context. Further, scientific reasoning is a common practice shared in science and engineering, important for applying this to STEM education. It also has a long-term impact on students' academic achievement (Bao, 2009). A teacher can cultivate a student's scientific reasoning skills by having them participate in experimental method and free inquiry learning and modification inquiry (Khoirina, 2018)

Scientific reasoning is an approach to problem-solving that is deeply anchored in critical thinking (Stephens & Clement, 2010). It involves using all available information to draw informed conclusions. This form of reasoning is intricately linked to cognitive abilities like critical thinking and reasoning, which are crucial in developing essential STEM activities, such as designing experiments, formulating hypotheses, and deducing outcomes (Bao et al., 2009). It enhances the immediate learning process and has a lasting impact on students' academic achievements. Additionally, by fostering scientific reasoning, students can effectively tackle relevant future problems within the STEM context. Moreover, as a common practice in science and engineering, the integration of scientific reasoning into STEM education is vital.

Argumentation Quality Within the Context of Engineering Design Thinking

This research evaluates the quality of scientific argumentation using the Claim, Evidence, Reasoning (CER) framework proposed by McNeill and Krajcik (2008) which concentrates on three central aspects of an argument. This framework itself is an adaptation of Toulmin's argumentation pattern, which encompasses claims, rebuttals, and justifications (Toulmin, 2003). As defined by Wallon et al., (2018), the three integral components are (a) presenting a **claim** that addresses a specific question, (b) offering **evidence** that supports the claim, and (c) providing **reasoning** grounded in scientific principles to elucidate how the evidence substantiates the claim. These components are frequently recognized as fundamental aspects of robust, high-quality argumentation.

Slavit et al., (2021) expanded upon the concept of the CER framework, suggesting that the manner in which claims are reasoned can vary across disciplines. They posited that while the fundamental concepts and principles like scientific notions remain consistent, what constitutes a quality argumentation might differ significantly from one discipline to another. For example, they highlighted the distinct nuances in the principles of argumentation across mathematics, science, and engineering. (See Figure 2.) These differences align with paradigms for professional thinking across disciplines (Cross, 1982; Honey et al., 2014; Kelley & Knowles, 2016).

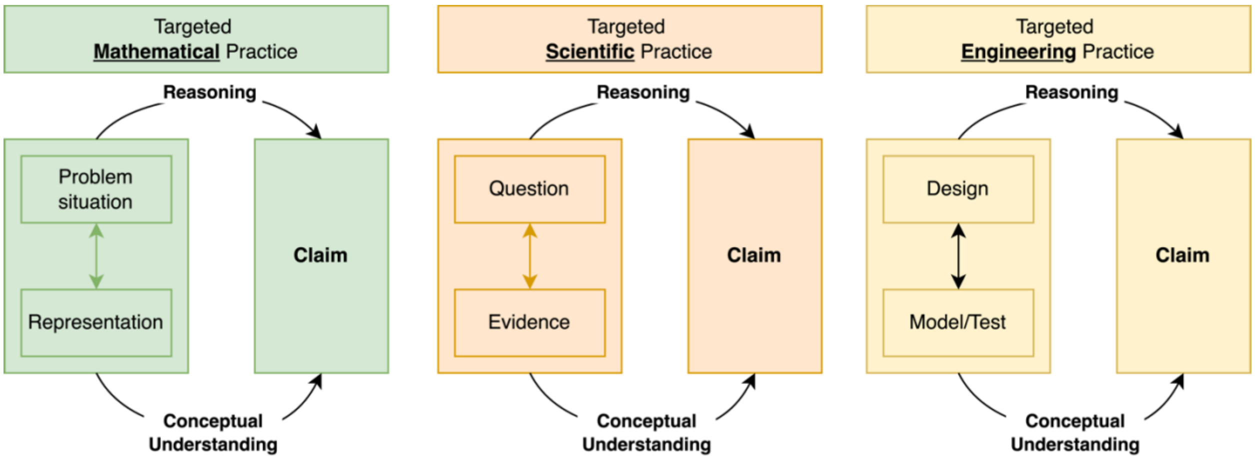

Figure 2. Disciplinary ways of thinking; using reasoning to make claims in mathematics, science, and engineering (Slavit et al., 2021)

In the LbE and engineering design context of this research, we redefined the components of scientific argumentation. Initially, a student's '*claim'* is interpreted from their preference for 'A' over 'B' or the converse, when making a comparative judgement. Consequently, their selection is conceptualized as the claim, 'Design/Artifact A is superior to B.' The image presented to the students is considered as a '*design'*. The '***model/test***' draws upon students' personal experiences and the conceptual knowledge they have acquired from their exposure to engineering design thinking thus far, because the LbE task occurs prior to the design project. Thus, students are asked to draw upon their personal experiences to conceptualize and assess the design's merits, visualizing its viability within their specified engineering design practices.

Beyond the basic components proposed by Slavit et al. (2021), evaluating argumentation quality within a given context permits the incorporation of conceptual features of the discipline. High-quality reasoning within argumentation should not only present claims, evidence, and reasoning but also demonstrate an understanding of the disciplinary practices that shape the argumentation. In the context of engineering, this includes the integration of the design-thinking process, which is central to the discipline. Students have received education in a design thinking process analogous to the methodology outlined by IDEO (2013), emphasizing its iterative and non-linear nature. Consequently, we have incorporated this process into the engineering argumentation framework as illustrated in the third image from the left in Figure 2. This integration supersedes the "design ↔ model/test" (see Figure 3). Therefore, the five stages of the design thinking process — empathize, define, ideate, prototype, and test (Dam, 2023) — have been employed to instruct students in engineering design. We posited that this non-linear and iterative procedure offers a more comprehensive representation of the engineering design thinking processes that students employ during their argumentation.

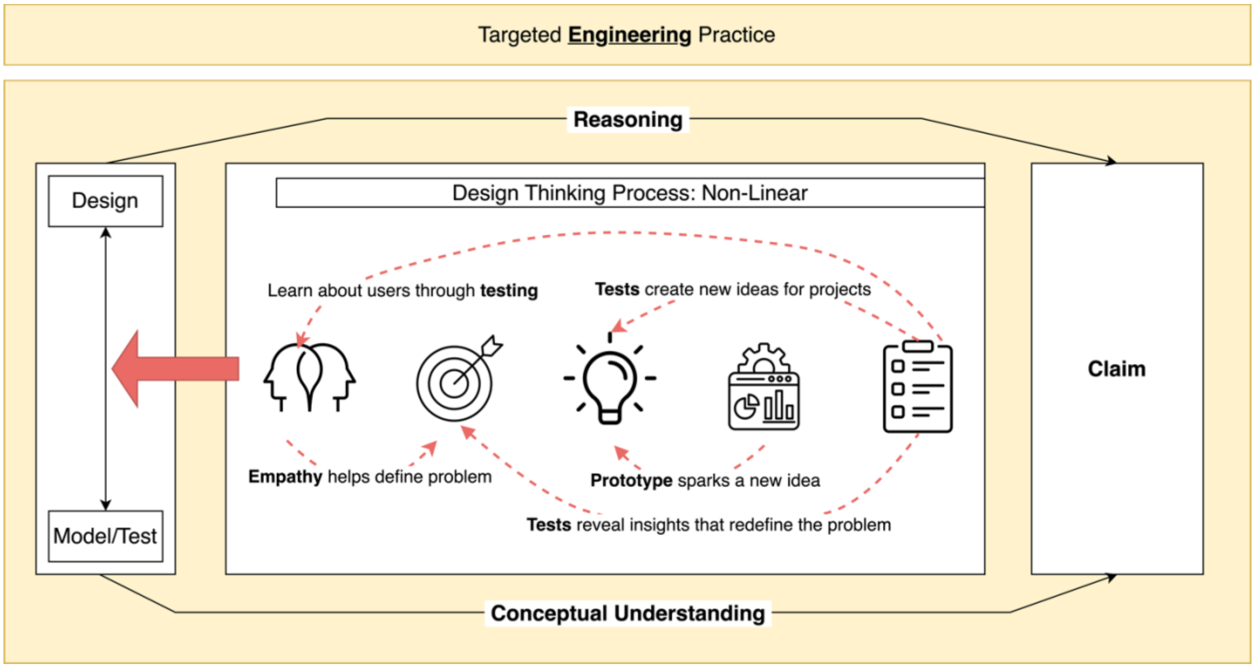

Figure 3. Engineering design thinking, embedded with a non-linear process

By integrating the iterative design thinking process into our reasoning approach, we were able to more precisely define the 'design ↔ model/test.' Subsequent team discussions led to a deeper understanding of how this process can be effectively applied in the current context and the distinct significance of each step within our framework. Figure 4 showcases the completed argumentation framework, devised for appraising the quality of students' reasoning pertinent to the present research. Initially, the framework was integrated within the discipline of engineering design. Subsequently, it was tailored to suit the specificities of the engineering design context, achieved through the application of an engineering design process. This process was instrumental in enhancing the 'design ↔ model/test' component, thereby incorporating an element of conceptual appropriateness. Consequently, we determined that high-quality argumentation is exemplified not merely by the presence of claims, reasoning, and evidence, but also by the inclusion of empathy, ideation, and insight within the students' reasoning process.

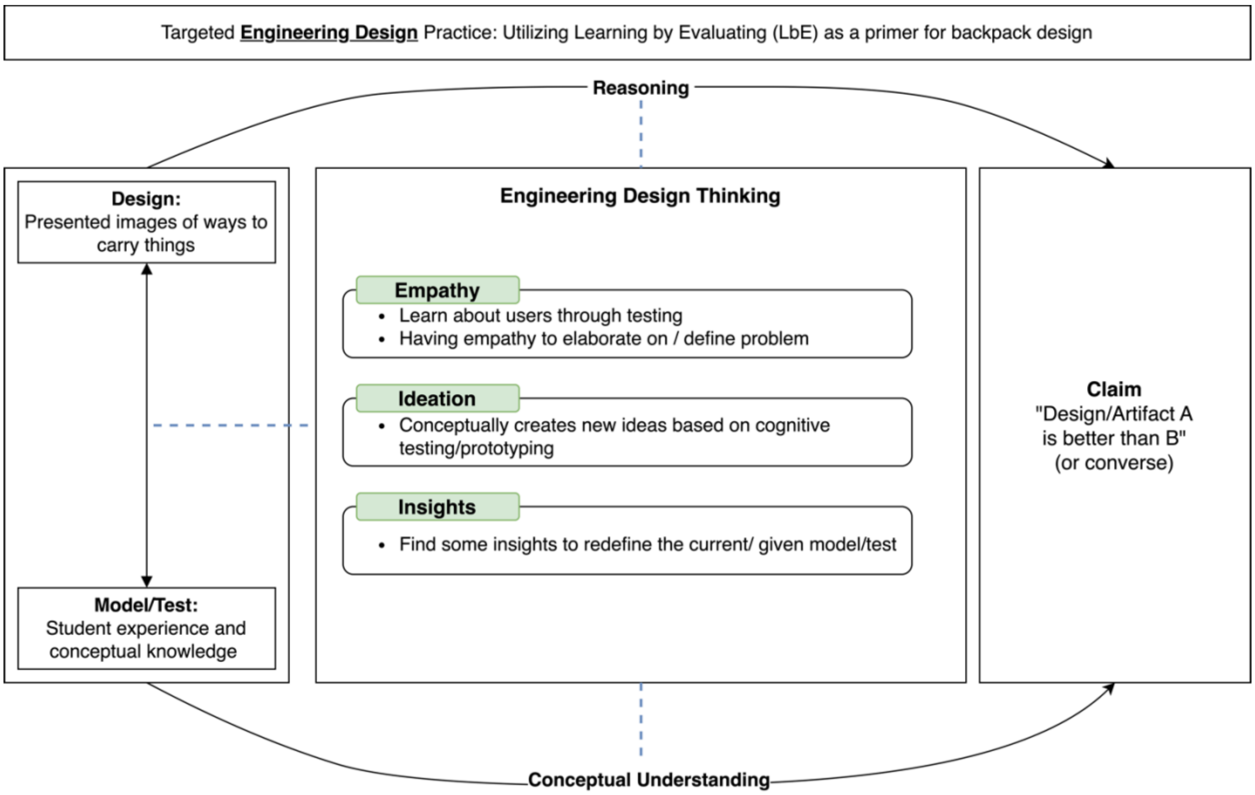

Figure 4. A framework for evaluating student argumentation quality within an engineering design thinking context

Methods

Research Contexts and Participants

The present research collaborates with DeKalb County Schools in Atlanta, a major urban school district. The district features a diverse student body, representing over 155 nationalities and exhibiting proficiency in more than 185 languages, as highlighted in the district's report(DeKalb County School District, 2021). Notably, 95% of the students participating in this research belong to groups that are historically underrepresented in STEM disciplines, predominantly Black and Hispanic populations (Artiles et al., 2005; Cain, 2012). For the Spring 2022 implementation of the project, five schools within the district participated. This included one teacher from each school (N = 5) and their respective students (N = 196), all of whom were enrolled in the foundational engineering design course, Foundations of Technology (FoT), authored by the International Technology and Engineering Educators Association's STEM Centre for Learning and Teaching.

Prior to the data collection, consent and assent forms were distributed to students, teachers, and parents/guardians, as required by the researchers' University Institutional Review Board and the school district's research coordinators. This study was implemented when teachers were delivering a similar challenge to their FoT classes—to complete a backpack design. A total of 15 students from three schools received full consent from their schools, teachers, and parents. These 15 students provided a total of 145 comments on the artifacts.

Measures and Procedures: Backpack Comparison and Critique

The overarching procedure for the present LbE session is delineated in Figure 5. The objective of this task was to encourage students to enhance their ideation process within the framework of design thinking. The web-based software, RMCompare, was utilized for this study. In the current study, the software facilitated comparative assessments, enabled commenting, and displayed the final rank during the debrief discussion.

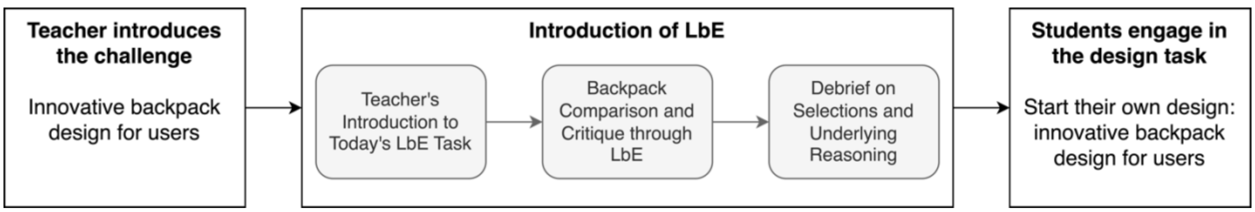

Figure 5. LbE session procedure: Backpack comparison and critique

Researchers and teachers uploaded a total of 39 diverse design items to the RMCompare software from various sources, all related to the objective of effective backpack designs. These items included images of actual backpacks as well as other visuals associated with backpacks that have the capacity to carry or hold items. The LbE task required students to select the example from a pair that they found most helpful or inspiring for their ideation process. This task provided students with an opportunity to evaluate and determine which option is superior and how it contributes to their ideation for a new product design. When introducing the LbE session, teachers prompted students to ponder the question 'What constitutes a superior backpack?' based on the following queries:

- What characteristics define an excellent backpack?
- How can each example serve as a source of inspiration for solving this problem?
- Which example might have transferable elements you want to use in your design?

Students then viewed pairs of images. In each case, they were required to select which they believed to be the better option (claim) to help them consider ways to improve their own backpack designs (see Figure 6). Right after their decision, students were required to justify their choice of one item over another. Each student made an average of 5 comparisons with a minimum of 3 and a maximum of 7 judgments. The entire experience spanned approximately 25 to 30 minutes, with the LbE comparison and critique constituting 10 to 15 minutes of that duration.

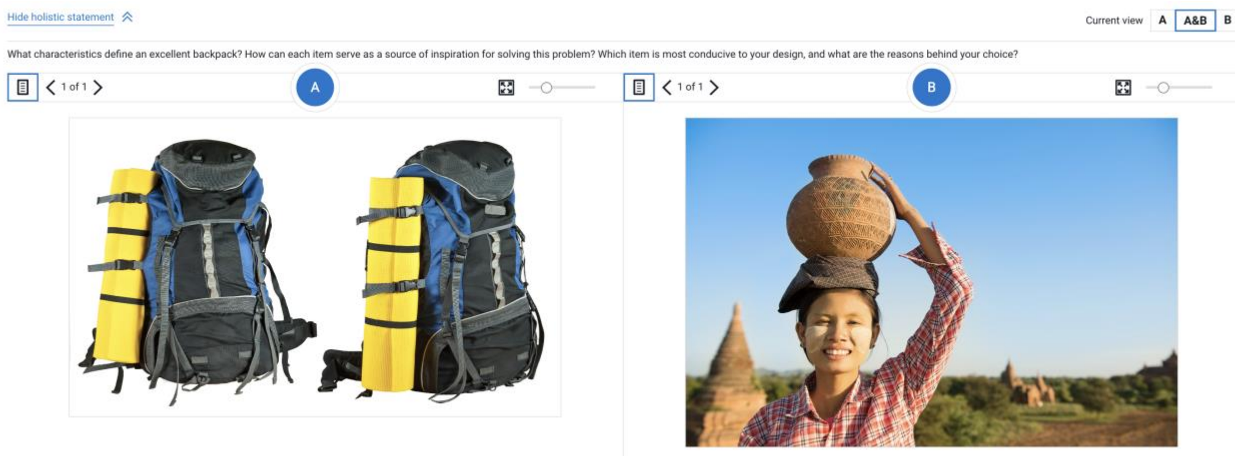

Figure 6. Screenshot of Backpack comparison session. "Left (A): ©Ivan/ Adobe Stock #337998470", "Right (B): ©cegli/ Adobe Stock #27278935"

At the end of the LbE task, teachers presented the final ranks in a wrap-up discussion. Students actively engaged in the conversation, discussing their judgments of the images, their reasons for selecting or not selecting them, and the rationale behind their choices.

Data Analysis

We employed qualitative content analysis as described by Krippendorff (2018) and further refined by Hsieh and Shannon (2005). The data analysis comprised two phases: deductive and inductive. Specifically, the data consisted of 145 comments provided by 15 students, which were analysed to identify patterns and themes related to their feedback on design items and their reasoning processes. This methodological approach, both integrative and iterative, draws from Andersson et al., (2015). It aligns with the theoretical assertion that content analysis's primary advantage lies in its adaptability to various research designs, tailored to specific research objectives (Elo & Kyngäs, 2008). Before analysing the data, we assessed whether the individual piece of feedback or reasoning provided by a student during the backpack design comparison session accurately represented the population. This involved revisiting the same backpack comparison session from the prior semester.

The Deductive Phase

We employed a deductive content analysis approach, following Krippendorff's (2018) guidelines. This method, structured on prior knowledge, suits our needs as we analyze argumentation within the engineering design thinking context. Before coding, researchers reviewed the theoretical framework for deductive content analysis (refer to Figure 4), as previously detailed. The broad categorization used as a framework in the analysis of the texts is as below (see

Table 1).

Table 1. Categorization matrix (i.e., codebook): Quality argumentation within the engineering design context

Quality argumentation criteria 1.	Quality argumentation criteria 2.	Categories based on criteria 1 and 2	Codes
Has claim, evidence, and reasoning	Appropriate for engineering design thinking context	Empathy	• Learn about users through testing • Having empathy to elaborate on or define the problem
		Ideation	• Conceptually creates new ideas based on cognitive testing/prototyping
		Insights	• Find some insights to redefine the current/ given model or test

The analysis began with in-depth reviews of written feedback transcripts retrieved from the RMCompare software, which captured students' comments and reasoning during the backpack design comparison sessions. We segmented the main coding phase into multiple rounds, coding smaller units between reliability and consensus checks.

Initially, researchers randomly selected and coded 10% of the comments using pre-defined categories from

Table 1, highlighting and coding relevant text segments. This was followed by a discussion to evaluate the framework's suitability. Subsequently, coding extended to an additional 30% of responses. The use of predetermined categories, a codebook, and a coding sheet aimed to minimize subjectivity in the coding process. After this second phase, researchers worked individually, categorizing the remaining codes to establish an initial classification. This approach revealed consistent patterns in the data, confirming the validity of the categories and their applicability across diverse responses. The findings also highlighted areas where further refinement of the categories might enhance their precision and utility for future analysis.

The Inductive Phase

Incorporating inductive analysis, researchers sought a deeper and more nuanced understanding, going beyond initial text categorizations. Specifically, this approach addressed two key limitations identified in the earlier categorization: 1) Identification of more specific sub-codes: During analysis, it became evident that more detailed sub-codes were necessary. This required the development of additional, more granular coding levels. 2) Exploring poor-quality argumentation: Existing categories failed to adequately explain instances of poor-quality argumentation. Consequently, there was a consensus to further delve into and elaborate on aspects of argumentation lacking in quality.

Units of analysis were abstracted into codes, considering their similarities and differences as outlined in

Table 1. Following collaborative discussions, these codes were categorized and regrouped according to content. This phase facilitated further abstraction, leading to the identification of three new subcategories under the 'insights' code. We also discovered a new code that shared characteristics of both empathy and insights. Furthermore, seven categories were newly established to specifically address instances of poor-quality reasoning.

Results

Researchers identified 13 distinct codes, classified into two categories based on the quality of argumentation: 'Quality argumentation' and 'Poor-quality argumentation' (see

Table 2). 'Quality argumentation' denoted desirable comments, which includes empathy, ideation, and insights. 'Poor-quality argumentation' designated comments which lack empathy, ideation, and insights. Besides these discipline-related aspects, 'Poor-quality argumentation' also referred to comments lacking clarity, essential components of reasoning, or displaying biases or stereotypes.

During the inductive phase, within the 'Quality argumentation' category, we identified six different subcodes under three main codes. Under empathy, we discovered one subcode: user-centred empathy. Under ideation, we identified one subcode: elucidation of design inspirations. For insights, three subcodes emerged: a) explanations for choices, b) detailed responses encompassing multiple criteria, and c) articulation of aesthetic attributes. Additionally, a code that encompassed both empathy and insights was identified: explanations of cultural awareness.

Conversely, in the Poor-quality argumentation category, seven distinct codes were pinpointed: 1) vagueness, 2) uncertainty or lack of knowledge, 3) excessively brief answers, 4) inappropriateness, 5) off-topic responses, 6) gender bias, and 7) cultural stereotyping. Notably, some codes exhibited overlap, especially in poor-quality argumentation. For instance, vague comments often coincided with being terse and short, complicating their interpretation.

Table 2. Overview of the content analysis: 'Quality argumentation' and 'Poor-quality argumentation'

Category	Code	Sub-code	Explanation	Example*	Occurence (%)
Quality argumentation	Empathy	User-Centred Perspectives	A comment from a design thinking perspective, which demonstrates a deep understanding and consideration of the user's perspective.	Choose B would be a good bag to bring with you for hiking and climbing up rough surfaces.	16 (10.94)
	Ideation	Explanation of design inspirations	A comment explaining inspirations from the options that have guided their engineering design process.	Helps show that my design should come with multiple parts.	7 (4.97)
	Insights	Reasoning for selecting and not selecting	A comment offers a direct comparison with explanations for why certain choices were made and why other options were not chosen.	B is more unusual and unique. However, A is more streamlined.	6 (4.4)
		Detailed comment with many criteria	A comment that provides a thorough and comprehensive analysis or evaluation by considering multiple factors or criteria.	Having a small and easy-to-carry book bag to carry around is pretty useful. Plus, the old backpacks can make your back or shoulder hurt.	7 (4.97)
		Explanation of aesthetic features	A comment of aesthetic features typically delves into the characteristics, qualities, or elements that contribute to the visual appeal, beauty, or artistic aspects of an engineering design.	I like this one better because it has more color and design.	5 (3.64)
	Empathy/ Insights	Explanation of cultural awareness	A comment provides insights into an individual's or group's understanding and recognition of various cultural aspects, practices, and values.	Option B is widely used in many traditional cultures, but seems less efficient and looks unhealthy compared to modern backpacks.	9 (6.18)

Poor-quality argumentation	Lacks empathy, insights, and ideation	Vague	A comment that lacks clarity, specificity, or detail, making it difficult to understand the intended meaning.	Cuz Mmm	23 (16.17)
		Uncertainty/ Lack of knowledge	Comments provided when a student is unsure or does not possess the necessary information or knowledge.	idk I have no idea Don't know	15 (10.43)
		Too Short Response	A comment is too brief or lacks sufficient detail.	much space don't close	15 (10.43)
		Inappropriate answer	A comment that is not suitable, expressing blaming or fault-finding.	Looks just dumb Bad design Wrong design	9 (6.18)
		Off-topic	Unrelated or not relevant to the subject or question.	My mom says I am so special! Ride	8 (5.31)
		Gender biased	A comment that exhibits prejudice or discrimination based on one's gender.	Who would use a girly laced bag as a way of carrying your stuff?	8 (5.31)
		Cultural stereotyping	A comment that perpetuates or promotes stereotypes about a particular culture or ethnic group.	Backpacks like B are smarter to use instead of commercially sold items made in country B that are incredibly low quality. Bags made in country A is ALWAYS good and fancy. They are always the best!	5 (3.64)

**Note*. Certain responses in the example may contain grammatical errors as they are direct quotations from students' responses.

Quality Argumentation

Quality argumentation in this context is defined by three key criteria (i.e., empathy, ideation, and insights), as outlined in our theoretical framework and consistent with engineering practices (see Figure 4). Empathy is highlighted when students demonstrate an understanding of user needs or apply empathy to improve a design. Ideation is valued for argumentation that shows how students can modify the presented design to enhance their own models. Insights are recognized when students extract useful information from a design, identifying its strengths and weaknesses. This framework of high-quality argumentation is further expanded upon in the subsequent content analysis. Here are detailed explanations of each sub-code, accompanied by quoted excerpts from student argumentations. Please note that some responses might contain grammatical errors, as they are direct quotations from students' responses. Additionally, to streamline the analysis, each category has been abbreviated (e.g., 'Empt' for 'Empathy') and sub-categorized with sequential numbering (e.g., 'Empt-1'). These labels are used throughout the analysis to reference specific examples.

Empathy (Empt): User-Centred Perspectives

- **Empt-1:** "…choose B would be a good bag to bring with you for hiking and climbing up rough surfaces…"
- **Empt -2:** "…the length of the user's hike is the first thing to consider. For a day hike, a pack between 10 and 25 liters should be enough. You could fit your water bottle and your picnic in this pack, as well as a jacket and sunscreen, to cater for all weather conditions…"
- **Empt -3:** "…a good bag to bring with you for hiking and climbing up rough surfaces…"
- **Empt -4:** "…arms can get tired of holding baby so you can hold him using your backpack and you also have space to put your things…"
- **Empt-5:** "…book bag becomes really heavy during the first day of school because of the number of books I carry…"

From a design thinking perspective, the 'user-centred perspectives' sub-code emphasizes empathy for users they posit for a design. It reflects a profound understanding and consideration of the user's needs. In this sub-code, students exhibited reasoning from various user viewpoints. The first three comments (Empt-1 to Empt -3) provided examples illustrate empathy towards hikers, showing an understanding of the challenges and environments they encounter while using the backpack. Besides of the hiker, in their design selection rationale, the argumentation in the user-centred perspectives sub-codes also tend to consider other user groups, such as parents with babies (Empt -4), and students carrying many books (Empt -5), demonstrating a broad application of empathy in their argumentation.

Ideation (Idtn): Explanation of design inspirations

- **Idtn-1**: "…helps me show that straps could be involved in my design…"
- **Idtn -2**: "…help the idea that my backpack design should be able to mount onto other objects…"
- **Idtn -3**: "…show that my design should be able to hold heavy items without breaking…"
- **Idtn -4**: "…shows that my design should come with multiple spaces…"

'Ideation: Explanation of design inspirations' encompasses students' comments that highlight the understanding derived from the options that have influenced their engineering design process. It details how students might assimilate inspirations gleaned from the showcased designs. Students often mentioned incorporating specific features from a preferred existing design (Idtn-1, Idtn -2). They also drew lessons from less favoured designs they did not select. They commented on how they can enhance the design and implement it in their future backpack design project (Ideation-3, Ideation-4). For instance, as seen in Ideation-4, when a backpack was perceived to have limited space, a student suggested it needed more capacity, thus will secure enough space for their own backpack design.

Insights (Inst): Reasoning for selecting and not selecting

- **Inst-1:** "…backpacks are way more comfortable and better in ALL ways than a purse; A backpack will lay on your shoulders with straps, while a purse will irritate the skin on the inside of your elbow…"
- **Inst-2:** "A shows a backpack with only rolling capabilities while B shows multiple pockets which lets us know it can store multiple things inside of it."

As seen in the examples, students derived insights from both their chosen design and the one they did not select (Inst-1). They frequently contrasted features present in one design with its strengths, but absent or weakly displayed in the other. Such reasoning amplifies the advantages of comparing two competitive designs. Moreover, when both designs appear equally compelling, students sometimes employ user-centred perspectives as the decisive evaluation criterion (Inst-2).

Insights (Inst): Detailed comment with many criteria

- **Inst-3:** *"…looks like a good design, A backpack meant for travel, like a suitcase, but at the airport you can use it like a backpack. … It shows that you can use the strap and wheel to carry it like a travel trunk if it is heavy."*
- **Inst-4:** *"…this is more effective because you can carry more items and you have no weight on your back".*
- **Inst-5:** *"…you can adjust its length … it is more heavy duty and can also carry a lot of stuff…"*

Quality argumentation involving insights demonstrates a consideration of multiple, logically detailed criteria, indicating that students have thoughtfully evaluated various aspects of the design. For example, in learning the key features required for an effective backpack design, students show an understanding from Inst-3 to Inst-5. This approach, in contrast to brief and dismissive comments lacking substantial reasoning, highlights the students' comprehensive consideration of the multifaceted features of the better designs.

Insights (Inst): Explanation of aesthetic features

- **Inst-6:** *"…looks very impractical, but somewhat stylish."*
- **Inst-7:** *"…looks cool and that looks cool to the baby."*
- **Inst-8:** *"…like this one better because it has more colour and design."*

In earlier sub-codes, the term 'design' predominantly referred to the 'functionality' of the backpack, focusing on how it operates and serves practical purposes. However, the current sub-code 'Insights: Explanation of aesthetic features' shifts this focus, underscoring the aesthetic aspect of the backpack's design as a crucial characteristic, distinct from its functionality. Here, 'design' is interpreted in terms of the backpack's visual appeal and style ('how it will look'), rather than its functional efficiency or practical aspects ('how it will work'). Inst-6 shows how students prefer visual aspects over its practical aspects.

This emphasis on aesthetics involves considering elements that contribute to the backpack's visual attractiveness, artistic quality, and overall beauty (see Inst-7 and Inst-8). Such elements are integral to engineering design, going beyond mere functionality. By acknowledging the importance of aesthetics, we gain a deeper insight into the backpack design. This approach not only fulfils the basic functional requirements of the backpack but also delves into a more comprehensive understanding of user preferences and the product's appeal in the marketplace. Recognizing the aesthetic dimension is crucial as it can significantly influence user satisfaction and the product's success in a competitive market.

Empathy and Insights (Empt/ Inst): Explanation of cultural awareness

- **Empt/ Inst-1:** "Option B is widely used in many traditional cultures, but seems less efficient and looks unhealthy compared to modern backpacks."
- **Empt/ Inst-2:** "…lady carrying straw on her head and it would work if you don't have anything to carry an item…"

The backpack designs studied incorporate item-carrying methods from diverse cultural backgrounds. We value argumentation that demonstrates an understanding of these cultures and draws insightful interpretations from the designs. Specifically, such argumentations reflect an awareness and appreciation of various cultural practices and values (refer to Empt/ Inst-1 and Empt/ Inst-2). While students did not always prioritize traditional, ethnic carrying methods, they often displayed an understanding of the cultural context in which the backpack is used. Recognizing these cultural elements is considered valuable argumentations (Roth & Lee, 2004; Seah, 2005). It broadens students' cultural and user perspectives and promotes a more inclusive approach to product design, particularly for the global market.

Poor-quality Argumentation

Codes signifying poor-quality argumentation often exhibit deficiencies in empathy, ideation, and user insights, lacking essential argumentation components. Certain codes present little to no discernible argumentation due to their brief and dismissive nature, while others show biased or incorrect argumentation. Furthermore, as observed, brief and dismissive responses are prevalent across various codes. This means the same argumentation often simultaneously fall into three distinct categories: Vague, uncertain, and lack of knowledge.

Vague (Vg)

- **Vg-1**: "Cuz"
- **Vg-2**: "Mmm"
- **Vg-3**: "No no bag"

Argumentation deemed vague is considered as poor-quality argumentation because it leaves researchers uncertain about the comment's intent concerning the design. Argumentation seen in the examples (Vg-1 and Vg-2) are ambiguous and, therefore, categorized as vague. Additionally, ungrammatical remarks (refer to Vg-3) are also considered vague.

Uncertainty/ Lack of knowledge (Unct/ Lk)

- **Unct/Lk-1**: *"idk"*
- **Unct/Lk-2**: *"not sure"*

At times, students were uncertain or lacked the requisite experience or knowledge to express their argumentation. As a result, they offered argumentation like Unct/Lk-1 (an abbreviation for "I don't know") or Unct/Lk-2. These were labelled as 'uncertainty' or 'lack of knowledge.' Given that these argumentations do not provide even basic reasoning, they were classified as bad argumentation.

Too Short Response (TSR)

- **TSR-1:** "much space."
- **TSR-2:** "don't close."
- **TSR-3:** "better color."

While the argumentation was comprehensible, when the comment is too short in length, it lefts the argumentation underdeveloped (see TSR-1 to TSR-3). For example, the comment TSR-1 could imply that the backpack doesn't close properly, which might lead to issues such as items spilling out during movement. However, since these specifics weren't provided in the argumentation, they were categorized as insufficient argumentation.

Inappropriate Answer (IA)

- **IA-1:** "Looks just dumb."
- **IA-2:** "Bad design."
- **IA-3:** "Wrong design."

As seen in the examples above (IA-1 to IA-3), argumentation that are inappropriate, accusatory, or fault-finding were categorized as being of poor quality. It was coded in such a way because those argumentations do not offer valuable empathy, ideation, or insights in their argumentation.

Off-topic (Oft)

- **Oft-1:** "My mom says I am so special!"
- **Oft-2:** "Ride"

Sometimes, argumentation was completely irrelevant to the backpack design context, as demonstrated in the provided examples. These remarks were also classified as poor quality.

Gender Biased (GB)

- **GB-1:** "Who would use a girly laced bag as a way of carrying your stuff"
- **GB-2:** "Pink is just for girls"

A couple of designs featured lacy details and pink/red hues. As seen in the examples, some argumentation made gender-biased remarks, suggesting that such designs were solely for girls. Due to their inappropriate and gender-stereotyped nature, these argumentations were classified as poor-quality argumentation.

Cultural Stereotyping (CS)

- **CS-1:** "Products from [country A] are just bad."
- **CS-2:** "Designs from [country B] are cool."

Several designs displayed bags with culturally specific characteristics, illustrating diverse ways of transporting items. Certain explanations either continued or encouraged stereotypes linked to particular cultures or ethnicities. For instance, when a teacher presented a revised image of a backpack that evoked specific cultural associations (refer to Figure 6, which was substituted due to licensing constraints), it led students to associate the backpack with the negative or positive stereotypes they previously held. At times, these argumentations involved negative stereotypes targeting a particular culture (e.g., CS-1) or uncritically praising another (e.g., CS-2).

Figure 7. Images incorporated by teachers highlighting cultural stereotyping. OpenAI. (2023). Fictional backpack with fictional company logo [digital image]. DALL-E Image Generation.

Such argumentation was considered as poor-quality argumentation. It broadly categorizes designs based on limited examples, which can reinforce existing prejudices unless addressed and rectified.

Discussion

This study addresses the research question: “How is high-quality argumentation defined and operationalized within the context of engineering design thinking, and conversely, what characterizes poor-quality argumentation in this field?” The findings provide a detailed framework for understanding student argumentation, identifying 13 distinct codes classified into two overarching categories: 'Quality argumentation' and 'Poor-quality argumentation.' These classifications directly respond to the research question by operationalizing argumentation quality and providing nuanced characteristics of both high- and poor-quality argumentation.

The delineation of ‘Quality argumentation’, characterized by empathy, ideation, and insights, illustrates how high-quality argumentation manifests in user-centred design thinking. This aligns with the study’s objective of defining exemplary argumentation within engineering education (Dym et al., 2005). Specifically, empathy emerged as a critical attribute, with student comments demonstrating user-centred perspectives that addressed the needs and contexts of end-users. Similarly, ideation subcodes revealed creative and analytical approaches to improving design, while insights highlighted the evaluative skills essential for engineering judgment. These findings define high-quality argumentation as a combination of critical thinking, creativity, and detailed reasoning, addressing the first part of the research question.

Conversely, ‘Poor-quality argumentation’ was marked by vagueness, brevity, biases, and a lack of understanding of the design context. These attributes respond to the second part of the research question by characterizing poor-quality argumentation as the absence of depth, clarity, and inclusivity. The overlap of codes, such as vagueness and brevity, suggests a correlation between unclear understanding and weak articulation, emphasizing the need for explicit teaching practices and exposure to models of high-quality argumentation. Additionally, the presence of gender biases and cultural stereotyping underscores the necessity of fostering culturally sensitive and inclusive argumentation practices within curricula.

The implications of these findings are significant for educators and curriculum designers. To address the research question's focus on operationalizing high-quality argumentation, the study highlights the need to provide students with clear benchmarks and structured opportunities to practice argumentation skills. For poor-quality argumentation, targeted interventions are required to reduce its occurrence by explicitly teaching critical reasoning and offering corrective feedback.

The study's findings further advocate for integrating empathy, creativity, and cultural awareness into engineering education. These results suggest that instructional strategies should emphasize not only the technical aspects of engineering design but also the human and contextual elements that define quality argumentation. For curriculum designers, this means developing resources that clearly exemplify high-quality argumentation while addressing potential biases and stereotyping.

Finally, the limitations of this study, including the small sample size and the contextual specificity of the engineering design journals—shaped by the educational level, curriculum design, and instructional methods—must be acknowledged. While these constraints limit the generalizability of the findings, they also open pathways for future research. Studies that examine broader populations and varied design contexts could deepen our understanding of how argumentation quality evolves and is influenced by different educational settings.

In summary, this study directly addresses the research question by defining and operationalizing high-quality argumentation while identifying the key characteristics of poor-quality argumentation. Its contributions to engineering education highlight the pedagogical importance of argumentation and provide a foundation for future research aimed at enhancing critical thinking and reasoning in engineering design.

References

Andersson, E. K., Sjöström-Strand, A., Willman, A., & Borglin, G. (2015). Registered nurses views of caring in coronary care – a deductive and inductive content analysis. *Journal of Clinical Nursing*, *24*(23–24), 3481–3493. https://doi.org/10.1111/jocn.12975

Artiles, A. J., Kozleski, E., Harry, B., Zion, S., & Tate, W. (2005). Addressing the Disproportionate Representation of Culturally and Linguistically Diverse Students in Special Education through Culturally Responsive Educational Systems1 Janette K. Klingner, University of Colorado at Boulder. *Education Policy Analysis Archives*, *13*(38), 2.

Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J., Liu, Q., Ding, L., Cui, L., Luo, Y., Wang, Y., Li, L., & Wu, N. (2009). Learning and Scientific Reasoning. *Science*, *323*(5914), 586–587. https://doi.org/10.1126/science.1167740

Bartholomew, S. R. (2021). Investigating the impacts of differentiated stimulus materials in a learning by evaluating activity. *Mississippi Valley Technology Teacher Education Conference*.

Bartholomew, S. R., Ruesch, E. Y., Hartell, E., & Strimel, G. J. (2020). Identifying design values across countries through adaptive comparative judgment. *International Journal of*

Technology and Design Education, *30*(2), 321–347. https://doi.org/10.1007/s10798-019-09506-8
Bartholomew, S. R., & Strimel, G. J. (2018). Factors influencing student design decisions: Comparative judgement as a method for assessing open-ended design problems. *Design and Technology Education: An International Journal*, *23*(3), 10–24. https://ojs.lboro.ac.uk/DATE/article/view/2513
Bartholomew, S. R., Strimel, G. J., & Yoshikawa, E. (2019). Using adaptive comparative judgment for student formative feedback and learning during a middle school design project. *International Journal of Technology and Design Education*, *29*(2), 363–385. https://doi.org/10.1007/s10798-018-9442-7
Cain, C. C. (2012). Underrepresented groups in gender and STEM: The case of black males in CISE. *Proceedings of the 50th Annual Conference on Computers and People Research*, 97–102.
Cross, N. (1982). Designerly ways of knowing. *Design Studies*, *3*(4), 221–227. https://doi.org/10.1016/0142-694X(82)90040-0
Dam, R. F. (2023, October 16). *The 5 Stages in the Design Thinking Process*. The Interaction Design Foundation. https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process
DeKalb County School District. (2021). *DeKalb County School District Demographics (2021-2022 School Year)*. https://www.dekalbschoolsga.org/about/
Díaz, C., Dorner, B., Hussmann, H., & Strijbos, J.-W. (2023). Conceptual review on scientific reasoning and scientific thinking. *Current Psychology*, *42*(6), 4313–4325. https://doi.org/10.1007/s12144-021-01786-5
Dow, S. P., Glassco, A., Kass, J., Schwarz, M., & Klemmer, S. R. (2009). The effect of parallel prototyping on design performance, learning, and self-efficacy. *Stanford Technical Report*, *10*. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1926ad304265f410c1f3b7419546e3edf3fde347
Driver, R., Leach, J., & Millar, R. (1996). *Young people's images of science*. McGraw-Hill Education (UK).
Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A
Duschl, R. A., & Osborne, J. (2002). Supporting and Promoting Argumentation Discourse in Science Education. *Studies in Science Education*, *38*(1), 39–72. https://doi.org/10.1080/03057260208560187
Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *94*(1), 103–120.
Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x
Erduran, S., & Jiménez-Aleixandre, M. P. (2007). *Argumentation in Science Education: Perspectives from Classroom-Based Research*. Springer.
Han, J. (2013). *Scientific reasoning: Research, development, and assessment* [PhD Thesis, The Ohio State University]. https://rave.ohiolink.edu/etdc/view?acc_num=osu1366204433
Honey, M., Pearson, G., & Schweingruber, H. (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. In *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–1288.

IDEO. (2013). *Design thinking for educators*. IDEO. https://page.ideo.com/design-thinking-edu-toolkit

Jackson, A., Mentzer, N., Bartholomew, S. R., Lee, W., Yauney, J. M., Thorne, S., & Bayah, D. (2023, June 25). *Board 332: Learning by Evaluating (LbE): Engaging Students in Evaluation as a Pedagogical Strategy to Improve Design Thinking*. 2023 ASEE Annual Conference & Exposition. https://peer.asee.org/board-332-learning-by-evaluating-lbe-engaging-students-in-evaluation-as-a-pedagogical-strategy-to-improve-design-thinking

Jonassen, D. H. (2011). Supporting argumentation in problem solving. *Educational Technology Research and Development*, *59*(3), 439–457. https://doi.org/10.1007/s11423-011-9207-1

Karabiyik, T., Magana, A. J., Parsons, P., & Seah, Y. Y. (2023). Pedagogical approaches for eliciting students' design thinking strategies: Tell-and-practice vs. contrasting cases. *International Journal of Technology and Design Education*, *33*(3), 1087–1119. https://doi.org/10.1007/s10798-022-09757-y

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Keogh, B., & Naylor, S. (2000). Teaching and learning in science using concept cartoons: Why Dennis wants to stay in at playtime. *Investigating*, *16*(3), 10–14. https://search.informit.org/doi/abs/10.3316/aeipt.104804

Kimbell, R. (2022). Examining the reliability of Adaptive Comparative Judgement (ACJ) as an assessment tool in educational settings. *International Journal of Technology and Design Education*, *32*(3), 1515–1529. https://doi.org/10.1007/s10798-021-09654-w

Kimbell, R., & Stables, K. (2007). *Researching Design Learning: Issues and Findings from Two Decades of Research and Development*. Springer Science & Business Media.

Krell, M., Dawborn-Gundlach, M., & van Driel, J. (2020). Scientific reasoning competencies in science teaching. *Teaching Science*, *66*(2), 32–42.

Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage publications.

McNeill, K. L., & Krajcik, J. (2008). Inquiry and scientific explanations: Helping students use evidence and reasoning. In J. Luft, R. Bell, & J. Gess-Newsome (Eds.), *Science as inquiry in the secondary setting* (pp. 121–134). National Science Teaching Association.

Mentzer, N., Lee, W., & Bartholomew, S. R. (2021). Examining the Validity of Adaptive Comparative Judgment for Peer Evaluation in a Design Thinking Course. *Frontiers in Education*, *6*, 1–15.

Mentzer, N., Lee, W., Jackson, A., & Bartholomew, S. (2023). Learning by Evaluating (LbE): Promoting meaningful reasoning in the context of engineering design thinking using Adaptive Comparative Judgment (ACJ). *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-023-09853-7

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020. https://doi.org/10.1002/tea.20035

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049–1079. https://doi.org/10.1080/0950069032000032199

Pollitt, A. (2012). The method of adaptive comparative judgement. *Assessment in Education: Principles, Policy & Practice*, *19*(3), 281–300.

Pollitt, A. (2015). On 'Reliability' bias in ACJ. *Cambridge Exam Research*, *10*, 1–9.

Roth, W.-M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education*, *88*(2), 263–291. https://doi.org/10.1002/sce.10113

Schwartz, D. L., & Bransford, J. D. (1998). A Time For Telling. *Cognition and Instruction*, *16*(4), 475–5223. https://doi.org/10.1207/s1532690xci1604_4

Seah, W. T. (2005). Negotiating about perceived value differences in mathematics teaching: The case of immigrant teachers in Australia. *Teaching and Teacher Education*, *21*(1), 63–80. https://doi.org/10.1016/j.tate.2004.11.001

Settlage, J., & Sabik, C. M. (1997). Harnessing the positive energy of conflict in science teaching. *Theory Into Practice*, *36*(1), 39–45. https://doi.org/10.1080/00405849709543743

Slavit, D., Grace, E., & Lesseig, K. (2021). Student ways of thinking in STEM contexts: A focus on claim making and reasoning. *School Science and Mathematics*, *121*(8), 466–480.

Solomon, J., Duveen, J., Scot, L., & McCarthy, S. (1992). Teaching about the nature of science through history: Action research in the classroom. *Journal of Research in Science Teaching*, *29*(4), 409–421.

Strimel, G. J., Bartholomew, S. R., Purzer, S., Zhang, L., & Ruesch, E. Y. (2021). Informing engineering design through adaptive comparative judgment. *European Journal of Engineering Education*, *46*(2), 227–246.

Thorne, S., Mentzer, N., Bartholomew, S., Strimel, G. J., & Ware, J. (2024). Learning by evaluating as an interview primer to inform design thinking. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-024-09933-2

Toulmin, S. E. (2003). *The uses of argument*. Cambridge university press.

Wallon, R. C., Jasti, C., Lauren, H. Z. G., & Hug, B. (2018). Implementation of a Curriculum-Integrated Computer Game for Introducing Scientific Argumentation. *Journal of Science Education and Technology*, *27*(3), 236–247. https://doi.org/10.1007/s10956-017-9720-2

Engaging ethnography in the human-centered design technology classroom

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Abstract
In design technology education, educators value student outcomes centered on concrete design ideas and a comprehensive understanding of prototyping. However, technology education must consider not only the general technology design process and quality but also human-technology interactions. Inevitably, designs for people are enmeshed in complex sociocultural contexts, inseparable from human needs, values, and desires. Given this need to comprehensively understand the user experience in design technology, ethnographic techniques are increasingly being used to holistically understand people, with the goal of improving their lives through human-centered design. To train design technology students in ethnography, this paper considers one model for teaching human-centered design, using ethnographic methods. *Designing Technology for People*, an undergraduate-level course offered at Purdue University, is co-taught by faculty from the Department of Anthropology and the Department of Technology Leadership & Innovation. Throughout the course, students gain experience conducting basic ethnographic research and analysis, in addition to developing a virtual engineer's notebook and a design mock-up, shaped by their ethnographic findings. This paper turns to one case study, "The Squirrel Squad," to ethnographically review how the course is taught and the value of co-teaching courses with specialists in both ethnography and design technology.

Keywords
Human-centered Design, Ethnography, Anthropology, Convergence Education, Design Technology Education

Introduction
In design technology education, instructors value student outcomes centered on concrete design ideas and a comprehensive understanding of prototyping. However, design technology education must consider not only the general technology design process and quality but also human-technology interactions (Briller et al., 2016; Martinez, 2023; Nguyen et al., 2022; Zoltowski et al., 2012). Inevitably, designs for people are enmeshed in complex sociocultural contexts, inseparable from human needs, values, and desires (Miller, 2018).

Given this need to understand the user experience in design technology, ethnographic techniques are often used to holistically understand people, with the goal of improving their lives through human-centered design (Clarke, 2017; Drazin, 2021; Hashizume & Kurosu, 2013). A growing number of companies are hiring ethnographic researchers to gather data on how consumers use and react to existing services and products, while also informing new product development (Goffin et al., 2012). Ethnographic market research draws on qualitative methods, such as participant observation, to gain a deeper understanding of human behavior, considering opportunities and limitations on how people interact with current technologies. This immersive research approach provides insights into how to develop designs that will better satisfy people's needs and wants.

The aim of this article is to examine how ethnography can be effectively taught to aspiring designers. Through this case study of one undergraduate-level human-centered design course, Designing Technology of People, we focus on enhancing pedagogical strategies in design technology classrooms. *Designing Technology for People*, an undergraduate-level course offered at Purdue University, is co-taught by faculty from the Department of Anthropology and the Department of Technology Leadership & Innovation. This course employs a convergence educational model which aims for the "deep integration of knowledge, techniques, and expertise from multiple fields," (Herr et al., 2019, p. 228), allowing learners to apply these skills across disciplines through transdisciplinary teaching to create innovative solutions to meaningful problems (National Science & Technology Council, 2022). We also combine a learner-centered teaching approach, where the educators are responsible for "facilitating the acquisition of knowledge," while students are required to engage in the "hard and messy work of learning" by practicing content through the active engagement of skills (Weimer, 2013, pp. 10–11), with project-based, experiential learning. In this course, student-driven collaborative projects are central to the learning process, fostering problem-solving and decision-making (Chua et al., 2014; Han et al., 2024).

In this co-taught course, students are introduced to ethnographic research design, data collection, and analysis through a hands-on research project. This ethnographic process is combined with training in design thinking and is used to develop a comprehensive engineer's notebook and final design mock-up. This paper reviews how this learner-centered, convergence course is taught through a case study example, to consider a creative opportunity for engaging ethnography in teaching human-centered design.

Human-centered design

Human-centered design is an approach to building effective and useful designs for people by centering human needs and perspectives in design (Kramer et al., 2016; Still & Crane, 2017). As designers shape and reshape our material, informational, technological, and social world, humans should be central to this process. The goal of this design approach is to innovate in ways that can consciously and carefully improve the lives of people and society more broadly. As described by IDEO, "Human-centered design offers problem solvers of any stripe a chance to design with communities, to deeply understand the people they're looking to serve … and to create innovative new solutions rooted in people's actual needs" (IDEO, 2015, p. 9).

In shifting from technology-centered design to human-centered design, rather than simply imagining what will help people, designers turn to the "experts," the everyday users, who will benefit from new design ideas. By combining this expert knowledge with an analysis of broader contextual and structural factors, designers have the opportunity to systematically, effectively, and creatively produce designs in service of people (Briller et al., 2016). This approach has important implications for the long-term success of projects. As described by Zoltowski et al., human-centered design approaches have been "shown to increase productivity, improve quality, reduce errors, reduce training and support costs, improve people's acceptance of new products, enhance companies' reputations, increase user satisfaction and reduce development costs" (Zoltowski et al., 2012, p. 30).

Of course, there are many approaches to teaching human-centered design in the design technology classroom, where the goal is to encourage students to learn how to engage "humans" in the design process as "subjects" rather than "objects" (McCarthy & Wright, 2015). Cognitive psychology, often with a focus on human factors research, has been one major approach. Mixed-methods techniques common in market research such as questionnaires, pile sorts, customer surveys, consumer demographics, and purchase records have been others (IDEO, 2015; Wasson, 2000, pp. 377–378). Other qualitative and multimodal techniques such as participatory storyboarding and drawings, social media analysis, mapping, empathic modeling, naturalistic inquiry, and participative experiences are also becoming increasingly popular (IDEO, 2015; Tomitsch et al., 2020; Tomitsch & Hepburn, 2020). Several of these methods, especially those that are "immersive," are directly or indirectly inspired by ethnography and its core methods, such as participant observation. In using a case study to present how ethnography is taught in our course, our goal is to not only list how these methods can be taught but to demonstrate how ethnography and design can be creatively interwoven into the classroom experience through the ethnographic presentation of a case study.

Ethnography as methodology

The inclusion of ethnography in design has become so popular that the design anthropologist Christine Miller asserts that "young designers have never known of a world where design happened without ethnography'" (2017, p. 89; 2014, p. 63, citing Wasson, 2000, p. 382). Yet, concerns exist that the use of the term ethnography, both in design and beyond, is being so broadly applied, that it has lost its meaning (Ingold, 2014; Miller, 2017, p. 90). For this reason, before moving into an overview of how Designing for People is taught, it is critical to provide an overview of how ethnography as a methodology and ethnographic methods are framed in the context of this course.

Dating back to the 19th century, cultural anthropologists have engaged in ethnography to understand diverse human experiences, in all of their complexities (Barnard, 2000). Put simply, ethnography is a methodological approach that focuses on "learning about people by learning from them" (Roper & Shapira, 2000, p. 1). The goal of the ethnographer is to immerse themselves in the lived experience of the people they are studying (Ehn et al., 2015; Mannik & McGarry, 2017). This experiential approach provides researchers with the opportunity to engage in an embodied, experience where researchers can engage all of their senses as they seek to understand the lived realities of the people with whom they work.

Participant observation is a quintessential method ethnographers use to learn about people. In participant observation moments of "pure observation," may exist but the researcher's goal is not to act as a "neutral" or "outside" observer, watching from a distance. Rather, the ethnographer participates. As Michael Wesch explains, "We do not just observe other people in our attempts to understand them. We join in. Only then can we move closer to their experience and understand them with depth and detail" (2018, p. 12). During participant observation, the researcher not only actively engages, but also systematically records their observations, always with consent from the participants. While gathering data, it is common for the ethnographer to jot memos and, with the proper permissions, take photos and audio/video recordings. After each participant observation opportunity, the ethnographer writes detailed fieldnotes, recording their experience in as much detail as possible. The fieldnotes will ultimately serve as a primary source for data analysis.

Although participant observation is the method that sets ethnography apart, ethnographers will often aim for data triangulation, employing a variety of methods to gain a fuller understanding of the relationship between the people and the social phenomenon they are studying (Bernard, 2011; Teddlie & Tashakkori, 2008). As Fetterman explains, triangulation is at "the heart of ethnographic validity," where the ethnographer compares information sources to test the quality of the information (and the person sharing it), to understand more completely the part an actor plays in a social drama, and ultimately to put the whole situation into perspective" (1998, p. 93). Most ethnographers will combine participant observation with various types of interviews (e.g., oral histories, go-along interviews, focus groups). They may also use other qualitative and multimodal methods such as photovoice, participatory video, asset mapping, participatory GIS, social media analysis, and open-ended questionnaires (Gubrium & Harper, 2013; Snodgrass, 2014). Ethnographers can also employ quantitative and mixed methods such as surveys, pile sorts, social network analysis, cultural consensus, and cultural domain analysis (Bernard & Gravlee, 2014; Kronenfeld et al., 2015). The combination of these methods, among others, allows for a data-rich analysis, focused on the complexities of the human experience and in applied settings, critical insights into potential solutions in service of people (Negrón et al., 2024).

Ethnographers have contributed to the design of many well-known products, including Yoplait's Go-Gurt (Squires, 2021), the Xerox machine (Suchman, 2013), and MP3 players (Brown, 2012), to name a few. As Nuzzolillo highlights, anthropologists bring valuable skills to professional design, such as empathy, deep contextual understanding, cultural relativism, systems thinking, expertise in qualitative methods, and strong synthesis and storytelling abilities (2020). These skills are crucial for students pursuing careers in human-centered design. Recognizing this, companies like Intel, Meta, Universal Theme Parks, Ford, and Hewlett-Packard have hired cultural anthropologists and ethnographers to better understand the experiences, needs, and desires of their clients (Jordan, 2013; Otto & Smith, 2020). While traditional information-gathering techniques such as human factors research, user surveys, demographic surveys, focus groups, and product sales history can all be helpful for understanding clients, Jordan explains that they often "depend on past history and what the user tells the researcher." She adds, "For all of us, what we say we do and what we actually do are two very different things." (Jordan, 2013, p. 90). The inclusion of diverse ethnographic methods allows design specialists to move towards the goal of more closely understanding what people do and how new technologies might improve their lived experiences.

Today, within anthropology, "design anthropology" is a rapidly growing subfield (Miller, 2018; Otto & Smith, 2020), with minors and concentrations across universities becoming increasingly popular. For anthropology students interested in design, combining training in anthropological praxis with design courses such as UX research and design technology presents meaningful opportunities for these students to be prepared and competitive in seeking design career positions (Santee, 2019). The flip side of this would likely also be true for design students, who may benefit from formal training in ethnography, whether through anthropology or a related field in the social sciences.

Designing Technology for People is a course that acts as a bridge. Although introductory in nature, it is intended to bring both experts and students in anthropology and design technology together to collaboratively practice ethnographically-driven design. By providing a step-by-step example of how we use ethnography in combination with design technology education, we hope that other design technology educators may experiment with this approach and ultimately contribute to future scholarship on teaching ethnography to design technology students.

Why share *Designing Technology for People's* approach to teaching ethnography and design?

This article was inspired by a presentation given by the authors at the 1909 Conference, an annual design technology and engineers education conference. Presented in-person by Sarah Renkert, one of the anthropologists on the teaching team, this presentation received honorable mention for the Epsilon Pi Tau Outstanding Presentation Award, which is awarded based on votes from conference participants. Throughout the conference, Renkert was approached by several attendees, all of whom are educators in design technology and engineering, interested in learning more about the structure of the course, activities, and templates used to teach ethnography. Given the excitement generated by this presentation, the authors of this article decided to move forward with publication, recognizing that other design technology educators could benefit from this pedagogical example. This article seeks to provide a clear and applicable example of how ethnography can be taught through a learner-centered approach in the design technology classroom, informed by the expertise of both cultural anthropology and design technology.

It is also important to note that this course development relates to a larger NSF-funded research program that considers novel structures for expanding convergence education. In this broader research program, enablers and barriers for expanding convergence teaching and learning overall and for design and innovation education specifically were explored (G. J. Strimel et al., 2022, 2023). By investigating in depth, the making of a Design and Innovation minor and how Colleges of Technology, Liberal Arts, and Business collaborated on this initiative over time, much insight was gained into how programs can be launched at the intersections of multiple fields. In a variety of classes and numerous ways, the research team was able to examine cross-disciplinary and collaborative teaching and what bolstered or hindered these educational experiences. Here we will take a deeper dive into a core foundational class that marries ethnographic approaches and design education and is a springboard for students developing this kind of blended mindset and applying it as they continue in their education and out into their work lives.

The decision to focus on a single case study for this article is, in itself, ethnographic. Hyett, Kenny, and Dickson-Swift explain that "Case study research is an investigation and analysis of a single or collective case, intended to capture the complexity of the object of study" (2014, p. 2). By taking an inductive look at a single project, we are better able to elucidate the process and experiences the students moved through as they started with a user group and moved toward a design mock-up. We can tell their story not in the abstract, but with rich detail (Bronk, 2012;

Flyvbjerg, 2006). Moreover, presenting the findings through an exemplar case study framework enables us to illustrate the nuanced aspects of teaching design thinking. We believe this approach can provide educators with not just a theoretical understanding but a practical guide to replicate and adapt the process in their own teaching. By doing so, a key goal is to help foster innovation and creativity in contemporary learning environments. By sharing this case study, we hope to contribute to a broader conversation about how convergence education and project-based learning can be effectively implemented in the learner-centered classroom (Chua et al., 2014; Han et al., 2024). Additionally, although convergence education via two instructors from different fields may not always be feasible, this case study will exemplify the opportunities co-teaching can present when universities bring disciplines together. As such, this case study aligns with wider conversations about how to advance convergence education moving forward (National Science & Technology Council, 2022).

***Designing Technology for People*: An Overview**

The *Designing Technology for People* undergraduate course at Purdue University was originally designed to be co-taught between a design technology professor from Purdue Polytechnic and a cultural anthropologist from the College of Liberal Arts. The course is cross-listed across several disciplines, creating a diverse student body with students from the social sciences, engineering, UX, and technology design, among other fields. In fact, students from 65 different majors have participated in this course. In the class, students are divided into teams, where each team is tasked with developing a design aimed to benefit a specific "user group." There have been a variety of user groups, covering topics such as Climbers, People with Debilitating Menstrual Pain, Dog Owners, Disabled Athletes, Gamers, Firefighters, and Pilots, to name just some. The case study discussed in the latter part of this article will look at the "Squirrel Watchers" team, better known as the "Squirrel Squad," as they renamed themselves.

These teams are selected in the first week of class after students brainstorm potential user groups using an Online Sticky Note program (see Figure 1). Once several pages of sticky notes have been filled by students, students vote for their top choices by placing their initials on several sticky notes. Using these data, the professors will select final teams. Outside of class, students will complete a survey, ranking their top choices from the final list. The professors will combine student preferences with factors such as their majors (e.g., spreading out the social scientists, design technology, and other students) to select final teams. Students may have deep familiarity with a user group such as being a college athlete themselves- or be a complete novice. Some topics regularly come up each semester- and others, like this case study, are much more novel and surprising.

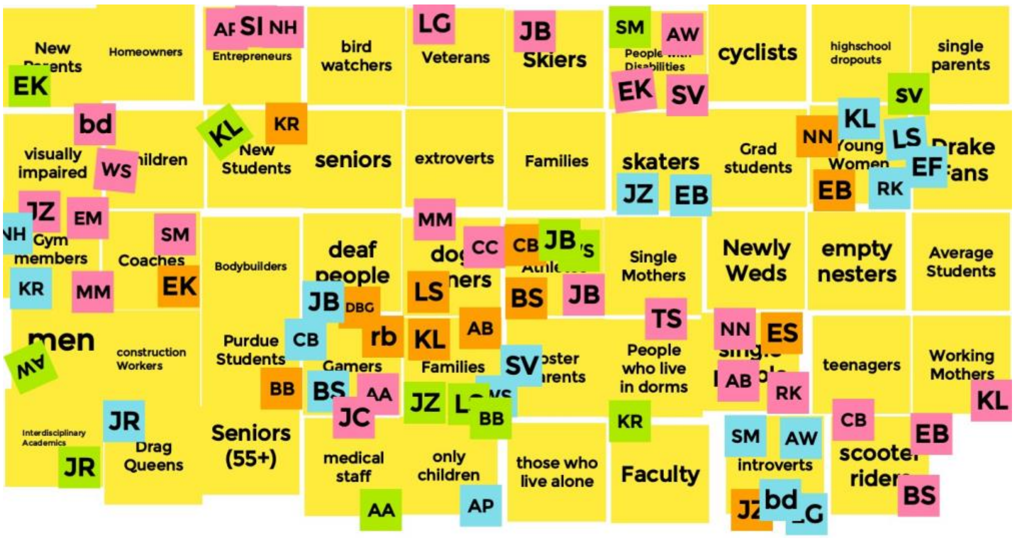

Fig. 1: Brainstorming User Groups

During the first part of the semester, students are introduced to ethnography and learn introductory ethnographic methods, with a focus on participant observation, semi-structured interviews, and the importance of triangulation in the data analysis process. Each student is then required to conduct ethnographic research using a variety of methods on three to four occasions, and submit fieldnotes that will be collectively analyzed by the team. Table 1 contains an overview of the fieldnotes templates students complete as part of the assignment. After each fieldnotes submission, teams collectively analyze patterns and differences, and reflect on their data using a separate “Team Planning Memo” template. Each team will then meet with another team, who will review their analysis and offer reflective feedback. See Tables 2 and 3 for an overview of the Team Planning Memo analysis and feedback process (the templates for Tables 1, 2, and 3 were inspired by Angrosino, 2001 and McCurdy et al., 2004).

Once students complete the data collection portion of the course, they move into the design phase, led by the design technology professor. Students are tasked with creating a final design sketch and mock-up that is informed by their ethnographic data (students will have the opportunity to turn their mock-up into a prototype in the subsequent course, *TECH 340: Prototyping Technology for People*, which is co-taught by a design technology professor and a professor from the business school). Once they have a final design sketch, students are also tasked with conducting market research (e.g., patent searches, benchmarking and collecting stakeholder feedback). At the conclusion of the semester, students are required to present a mock-up of their design.

All data and notes recorded by students throughout the semester are kept in an engineer’s notebook. Traditionally, an engineer’s notebook is intended for professional engineers to record their design thoughts and report technical information for their own use and the use of others working on similar design problems. However, there are growing calls to use engineer’s notebooks in the design technology classroom (Asunda & Hill, 2007; Hill, 2006; Kelley, 2011). For instructors, detailed documentation creates an opportunity for holistically evaluating students’ engineering design thinking, including their reflective process (Kelley, 2011, p. 32). Virtual notebooks are currently being used in *Designing Technology for People*. The students begin using the engineer’s notebook at the beginning of the semester and document the entirety of their process, including their ethnographic research, design process, and final design sketch. Reflection is also consistently built into various sections of the notebook.

Top-performing teams will have the opportunity to participate in a competition in front of a panel of expert judges. All teams selected for the final competition will win prize money, with the top team taking home $1000. Teams are selected for the final competition based not entirely on their design in itself, but on their ability to demonstrate how their design connects to their ethnographic data.

Table 1 Research Template

Participant Observation	Interviews
Setting, Date, Context: Where are you? When is this happening? What's going on?	**Interview Focus:** What is the focus of this interview? Provide a description.
Description of Participants: Who is there? Describe them.	**Setting and Context:** Where are you? How are you conducting this interview?
Chronology of Events: Document what goes on while you are there; be detailed.	**Description of the Interviewee(s):** Who are you interviewing? Describe who they are. Why are you interviewing them?
Describe technology being used: What technology is employed? How is it used?	**Interview Questions and Responses**: What questions did you ask? How did they respond? (List in order)
Conversations: What gets discussed verbally or otherwise?	**Self-Reflection:** What are your key takeaways, insights, feelings, thoughts? Keep in mind, this is your initial analysis.
Self-Reflection: What are your takeaways, insights, feelings, thoughts? Keep in mind, this is your initial analysis.	**Design Ideas**: Share ideas about how technology use is going, what may be missing, innovation possibilities, etc.
Design Ideas: Share ideas about how technology use is going, what may be missing, innovation possibilities, etc.	**Other Important Notes / Photos / Sketches:** (Optional)
Other Important Notes / Photos / Sketches: (Optional)	

Table 2 Team Memo

Team Memo Template
Patterns of Behavior: What was similar / different in what you observed? • List 3-5 things that everyone observed (backed with evidence from the fieldnotes) • List key different findings of interest (backed with evidence from the fieldnotes)
Group Reflection: What was similar / different about our fieldwork experiences? • What are we learning from doing fieldwork, individually and as a team? • What is interesting and/or surprising about our different information, insights, and ways of working? • How can we make the best use of team-based ethnography going forward?
Design Ideas: Share ideas about how technology use is going, what may be missing, innovation possibilities, etc.

Adapted from Angrosino, 2001 and McCurdy et al., 2004

Table 3 *Team Report Out*

Team Plan Report Out *Use the 5W's below to draft your plan. You will use this plan on Wednesday to get feedback from two other teams.*
OUR PLAN
Who? Who will you be working with?
What? What will you be doing and asking?
Where? Where will you be observing? Finding other information?
When and Why? When and why will you be using this strategy?
How to move forward? How will you use these activities to learn about the user group, develop design ideas, and make progress?
Team Feedback ***Wednesday in-class***: *Based on your plan, what specific feedback did you receive from other teams? Be as specific as possible to the 5W's and 'How we move forward' elements of your plan.*
Feedback – TEAM 1

Case Study: The Squirrel Squad

Purdue University is a campus known to celebrate its vibrant squirrel community (The Exponent, 2013). The squirrels are so beloved by many students that there are several social media sites dedicated to the campus squirrels. Even the *Purdue Exponent*, the student paper, features a "Squirrel of the Week" photo on their Instagram page. At one point, there was an official "Squirrel Club – Purdue University," where students would gather to watch squirrels. The city of West Lafayette, where Purdue is located, has even named a park immediately adjacent to campus "Squirrel Park," which is currently undergoing major renovations and improvements (Nair, 2023). Despite all of this excitement about squirrels in West Lafayette, team Squirrel Squad started their research by focusing on potential challenges squirrels might present to campus and others who engage with squirrels. They felt that their design needed to focus on a squirrel "problem."

To learn more about these problems, the team spent hours engaging in immersive "squirrel watching." As one student described in their fieldnotes,

> *Sitting on a very nicely placed concrete bench, I already hear the snickering of the wildlife. In campus [sic], I saw an overwhelming majority of Grey squirrels and Fox squirrels … The squirrels are borderline sedentary. They lie down on the concrete borders, strut up to people without a care in the world, and feast on their choice of nuts in the open. The Fox squirrels are most often found on the ground, and while they do*

climb trees, I never saw them actually do it. I would chase one around and it would grab onto a tree and just hide on the other side. (Fieldnotes #1, 9/18/2022, Student B[1])

They also began interviewing experts. One of these students interviewed a professor in landscape architecture, with the hope of identifying a problem they could study. Although the professor emphasized that rabbits are a more significant challenge than squirrels, he noted,

We do have to take squirrels into consideration when it comes to urban planning. Some types of trees attract squirrels way more than others, so we have to be cognizant of what and where we plant. They also dig into lawns, and do damage to turf and soil. They eat just about everything." (Fieldnotes #1, 9/16/2022, Student A)

This initial focus on looking at squirrels as a problem was reinforced in the Squirrel Squad's early conversations with class peers, during the first "Team Report Out" (see Table 3). Class peers mentioned that squirrels are a problem in several ways, including being a nuisance on the road, stealing food, and generally getting in the way of pedestrians. During this report out, it was also noted that humans contribute to squirrel problems by feeding squirrels, as students enjoyed interacting with them. The peer group explained that squirrels can be an attraction and that more trees could be strategically planted where people want squirrels (9/14/2022). Here we can see several squirrel problems, but also the first hints that their ethnographic data will not be universally negative.

During the second round of fieldnotes, the Squirrel Squad divided tasks, with some students conducting participant observation, while others continued with interviews. During the interviews, further squirrel problems were identified (e.g., eating through wires, and digging holes). However, like the Team Report Out, not all was problematic. A senior in landscape architecture who was interviewed explained,

There are a lot of pre-existing squirrel-deterring technology that [we] work with … That said, squirrels actually add to the biodiversity of an environment. Sometimes they store seeds for the winter and never dig them back up. They plant plants without even realizing it. (Fieldnotes #2, 9/24/2022, Student A)

By Fieldnote #3, the design team explored not only on squirrel problems but ideas for appropriate human interactions with squirrels. For example, one student visited "Wolf Park," a wolf conservation center in Lafayette, IN, which is open to the public. Their goal was to observe how guests were able to interact with the wolves from a safe distance. Reflecting on the experience, the student wrote in their fieldnotes:

We have to learn, observe, and educate others on animals. With our squirrel problem, we need to figure out how to live with them around and learn about them so we and the squirrels live safely. … I think that a squirrel viewing area for an obstacle course or stylized feeder would be very cool. We would need access to woodworking and a

[1] This team was made up four students, all of whom we thank in the acknowledgement section by name with their permission. However, in the article, we do not want to match specific quotes with names. Therefore, we have randomly assigned them as Student A (Animation Major), Student B (Teaching Design and Innovation Major), Student C (Anthropology Major), and Student D (Exploratory Studies Major).

constant supply of seeds and food supply for the squirrels. We could make a Purdue-related squirrel feeder. (Fieldnotes #3, 10/01/2022, Student C)

Thinking about safe interactions with squirrels was seen as important, particularly given the tendency for students to feed squirrels, as was mentioned in Team Report Out #1. Likewise, in an interview with a Purdue undergraduate, the student mentions that they find them to be "cute and entertaining," but that the public needs help with education on how to interact with squirrels. She noted that a lot of students feed them, critically noting that this encourages squirrels to approach humans. *(Fieldnotes #3, 10/02/2022, Student D)*

By Team Memo #3, the Squirrel Squad still recognized that squirrels cause problems, but that they did not seem to be an overwhelming concern when compared to other animals, such as rabbits, especially given their potential to increase biodiversity. In light of these early observations, the students decided to start shifting gears. In their words,

We have learned that squirrels are everywhere and are universally funny to watch. No matter how hard we look for problems, there is no point to trying to solve them. … By shifting our focus from "what squirrel-related problems can we solve?" to "how can we enhance squirrel-related experiences?" (Team Memo #3, 10/03/2022)

Inspired by their initial ethnographic findings, students started to creatively think of ways to enhance squirrel interactions, that were safe for both the humans and the squirrels. This idea of enhancing the squirrel-watching experience on campus was also appealing to many students they interviewed. As one team member described in their notes:

[The interviewee] said that it would be cool to see like a swing or small table hanging from the tree for the squirrels to sit on and eat. She said to make sure that the food is natural food for the squirrels. She felt that even benches with feeders would be cool and appeal to many of the visitors for that are on campus [sic] … She said that she sees a lot of squirrels in the trash cans so having a feeder for them if anything should give them a healthier diet. (Fieldnotes #4, 10/07/2022, Student C).

By the time the students wrapped up their data collection, the Squirrel Squad provided the following "Problem Statement" inspired by their ethnographic data:

Squirrels are a center of Purdue's campus life and are loved by anyone who comes to Purdue University. People find them hilarious, cute, and entertaining. There are a few exciting ways to encounter these squirrels in a safe way too. We want to find a solution to enhance the squirrel watching experience. We desire to develop Purdue themed squirrel feeders to place around campus in order that affiliates can observe, learn, and appreciate their unique presence and activity around Purdue campus. (Engineer's Notebook, Problem Statement, 10/19/2022)

By combining participant observation, interviews, and secondary sources of data (e.g., virtual research, documentaries), in combination with analysis and reflection, the Squirrel Squad was ultimately able to move away from their own perceptions of what the design should focus on (a "squirrel problem"), to a human-centered design ("enhancing squirrel interactions"), inspired by their ethnographic research.

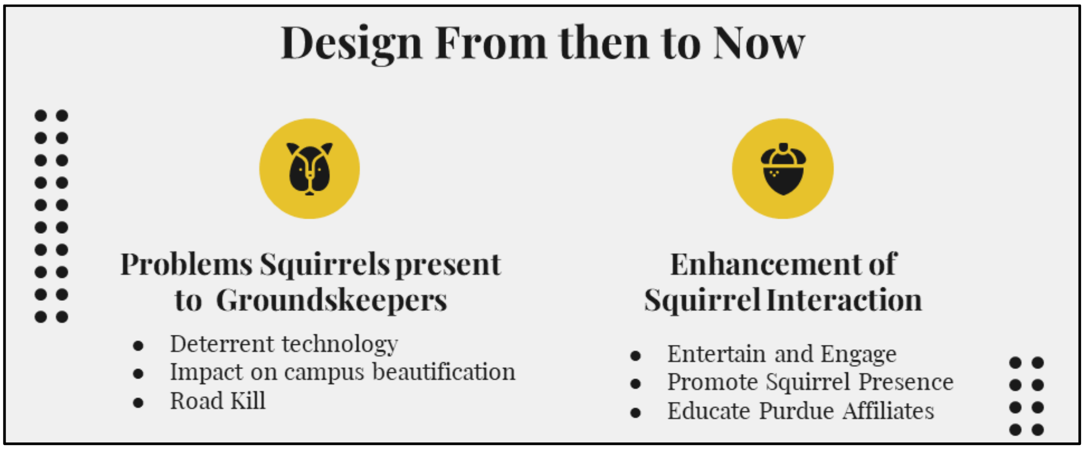

Fig. 2 "Design from Then to Now" (Squirrel Squad: Final Presentation)

Once the Squirrel Squad completed their ethnographic fieldwork and analysis, the course shifted into the design phase. This phase is when the benefits of having a co-taught course become most visible. The anthropology professor continues to support students by ensuring that their design is connected to their data and that they collect quality stakeholder feedback once they have a final design idea. Meanwhile, the design technology professor works closely with students to critically consider how to effectively create the design, while providing substantial feedback on their engineer's notebooks (see Figure 3 for a view of the Squirrel Squad's Engineer's Notebook). After completing fieldwork and the collective ethnographic analysis, the Squirrel Squad opted to move forward with a Purdue-themed squirrel feeder that could be installed at central campus locations.

They had several creative feeder designs but ultimately decided on the "Boilermaker Extra Extra Special," modeled on Purdue's Boilermaker Special, the train that serves as the university's official mascot. In addition to creating a permanent campus feeder, based on the stakeholder feedback they received, they also opted to create an "easy-to-build kit," which could be purchased for home assembly. The students put a lot of work into the mock-up process, spending extensive time in the Innovation Lab (a prototyping space managed by students within Purdue's Design and Innovation Program), where they took advantage of tools such as 3D printing and laser cutting. Ultimately, they were able to develop a functional mock-up. See Figures 4 - 6 from the Squirrel Squad's final presentation to learn more about their final design.

The Squirrel Squad was selected for the final design competition, placing third. In assessing which student team will be selected for the final competition, the professors in *Designing Technology for People* are particularly interested in designs that are inspired by the fieldwork process. Specifically, teams are encouraged to share their "story," giving the audience a cohesive understanding of how the data connects to the final design. Successful teams clearly demonstrate how their ethnographic data and analysis led them to the development of a human-centered design. One of the key reasons the Squirrel Squad was selected was because they clearly described the relationship between their ethnographic observations and analysis and their final design. They effectively described their methods (participant observations, semi-structured interviews, informal conversations, secondary literature), demonstrated how their data and analysis shifted across each of the fieldwork submissions, and then had a final mock-up that was inspired by these data.

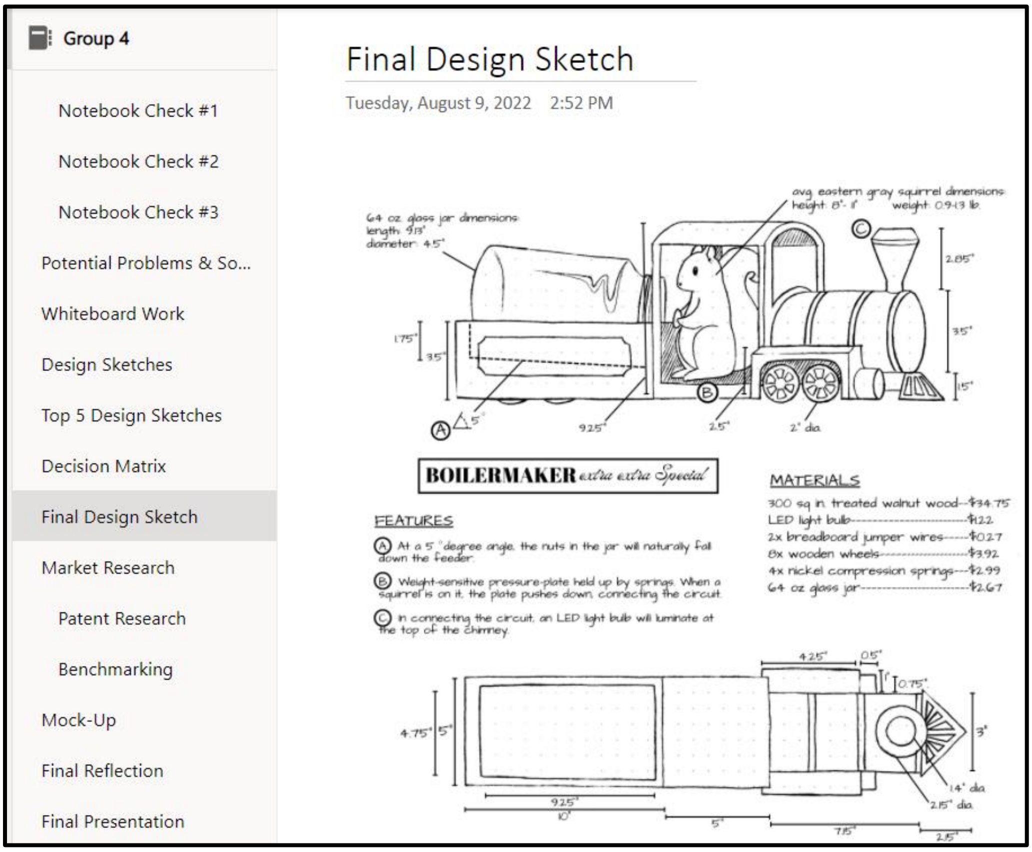

Fig. 3 **Squirrel Squad's Engineer's Notebook**

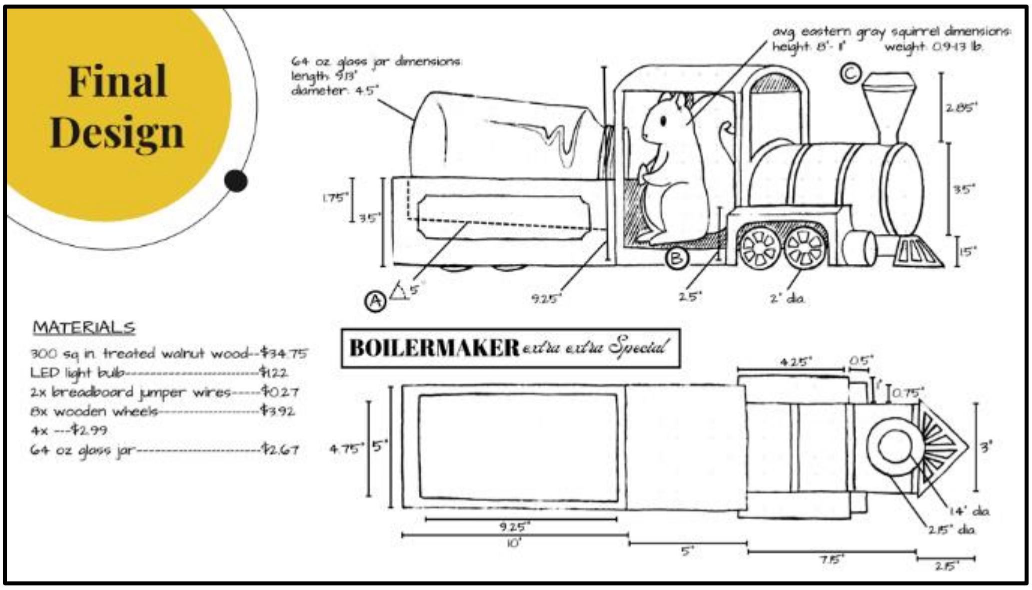

Fig. 4 Final Design

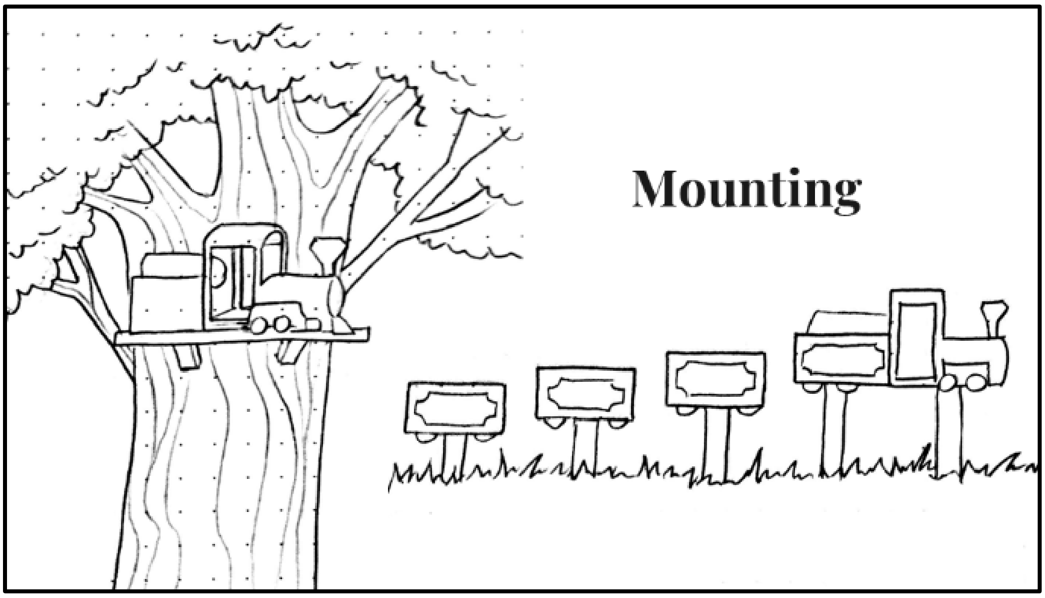

Fig. 5 Mounting

Fig. 6 Final Mock-up

The Squirrel Squad's Final Reflections

At the end of the semester, students in *Designing Technology for People* are asked to engage in an individual and group reflection process, where they consider what they learned throughout. While these evaluations are intended for student reflection, they are also critical resources for the instructors, as they provide specific insights into students' key takeaways. Overall, students on the Squirrel Squad spoke highly of the course, valuing the applied fieldwork and cross-disciplinary nature of the teaching. Among other course components, the opportunity to learn ethnography was highlighted, with a focus on how their ethnographic data shaped their final outcome.

For example, in reviewing the fieldnotes process and collective data analysis, the team's lead designer explained,

> *The format of getting each student to go into the field and create a document to share with other groups is a stroke of genius. It was quite effective at furthering our progress in developing our plan against, and eventually for, the squirrels. (Individual Reflection, 12/08/2022, Student B)*

Here we can see that this student valued fieldnotes as a tool for recording data collection and the collective review process that occurred during class. This iterative process of reviewing fieldnotes as a group was considered highly valuable. Based on each week's group analysis, they were able to determine their next steps in the project and eventually their final design.

This student's quote also highlights how conducting multiple field visits and interviews was important in shaping their design direction. When the student says that they were initially "developing our plan against, and eventually for, the squirrels," we can see the shift in the team's thinking. They began their fieldwork viewing squirrels as a problem and in turn, thought they had to design to solve this problem. However, based on the data they collected, they decided to focus on finding a way to positively enhance squirrel-human interactions. The students mused on this shift in their group reflection as well, noting, "We researched our problem to its core and found that from all of our combined efforts, our initial problem statement had gaps." The key gap they were missing is that many people enjoy the squirrels. Based on this insight, "We decided to pivot our problem statement. We want to help how squirrels are viewed and how they are interacted with". (Team Final Reflection, 12/05/2022)

One student also spoke about how learning ethnography has reshaped how they think and view problems. In their words,

> *Through making ethnographic [sic] it has made me think critically and differently in simple situations that I would not have done before. For example, finding myself intrigued in my atmosphere sometimes, looking around, seeing people read books, talking with friends, riding bikes, drinking coffee etc. From what I have learned this semester I feel that I can proceed to try fixing problems that occur to me by using the design and innovate process and ethnographic aspects. (Individual Final Reflection, 12/05/2022, Student D)*

Here, the student is reflecting on how learning ethnography, in combination with design education, has taught them to pay attention to the small, everyday details. "Fixing problems" comes from understanding and participating in the daily interactions and contexts in which problems occur. Through ethnographic engagement, and participant observation in particular, the student feels empowered to use new blended skills to try and address challenges.

Finally, one student emphasized that the convergence structure of this course changed their career trajectory. In their words,

> *I first chose this class to fulfill a requirement on my course sheet, but I was surprised to find out that I would like it so much that I would change the direction of my desired career … The Design for People class, integrating tech and anthropology and having two*

> *instructors from separate fields, was a fantastic idea … This is the only class I have ever done fieldwork in and applied demonstrations. More classes need to be like this. (Individual Student Reflection, 12/08/2022, Student C)*

Ultimately, these reflections highlight that for the Squirrel Squad team, engaging with the ethnographic process empowered them to rethink initial assumptions and observations to develop a human-centered design grounded in their research. It is also exciting that for individual students in this group, the convergent teaching and learning approach of the course has influenced their approach to everyday problem-solving while opening the door to new and exciting career possibilities.

Conclusion

Preparing both design technology and anthropology students in human-centered design is enhanced by creative pedagogical approaches, robust methodological training, and experiential, learner-centered teaching. *Designing Technology for People* is a course that is uniquely positioned to support students in developing these skills by blending ethnographic research methods and design skills while emphasizing the value of experiential education. A critical feature of this course is its co-teaching model, bringing professional ethnographers and designers together to teach students through a learner-centered, convergence model. However, co-teaching can be difficult to implement as it is resource-intensive for universities; yet, our related research and teaching experiences show that it is worthwhile (G. Strimel et al., 2022). For this reason, one of our key goals in writing this article was to demonstrate our process, using a detailed case study to elucidate how students in *Designing Technology for People* are introduced to ethnography, collect ethnographic data, and ultimately connect these data to their final design. While making the Boilermaker Extra Extra Special, a feeder to enhance human squirrel interactions, may at first glance seem like a light-hearted or frivolous activity to some, the pedagogical goal and value have a much more serious purpose. We are using convergent education, combining ethnography and design thinking, to help prepare undergraduate innovators who are comfortable, knowledgeable, and skilled in working in these vital, blended ways.

While various human-centered approaches are already common in design technology education, this article offered a focused exploration of how ethnography can be introduced from the perspective of cultural anthropology, a discipline that has relied on this methodology for over a century. By actually engaging in a hands-on ethnographic project in the classroom, students in *Designing Technology for People* are not only exposed to the value of learning ethnography for design but also putting it into practice. This learner-centered approach to teaching offers students practical experience providing them with the opportunity to materially and experientially understand how an immersive approach to learning about people will benefit their design process.

Looking ahead, future research could explore how alumni of this course apply the ethnographic skills they have acquired in their professional design roles, offering valuable insights into how early exposure to ethnography shapes long-term human-centered design thinking. By tracking how former students integrate these methodologies into their careers, we could better understand the lasting impact of ethnographic design projects and how well classroom experiences prepare students to meet the evolving demands of the design field. In the meantime, *Designing Technology for People* aspires to inspire the broader adoption of ethnographic teaching methods across design technology programs, enriching both students' educational experiences and the long-term outcomes of human-centered design. By continuing to explore the convergence possibilities between fields such as anthropology and design technology, we open up more opportunities for exploring creative approaches in the classroom and beyond that will ideally lead to creative 21st century designers and innovators.

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Conflict of Interest
The authors declare no conflict of interest.

Ethics approval
All procedures performed in studies involving human participants were in accordance with the ethical standards approved by the Institutional Review Board (IRB) at Purdue University under protocol # IRB-2021-266.

Consent to participate
Informed consent to participate was obtained from all individual participants included in the paper.

References
Angrosino, M. V. (2001). *Doing Cultural Anthropology: Projects for Ethnographic Data Collection* (1st edition). Waveland Pr Inc.

Asunda, P. A., & Hill, R. B. (2007). Critical features of Engineering Design in Technology Education. *Journal of Industrial Teacher Education*, *44*(1), 25–48.

Barnard, A. (2000). *History and Theory in Anthropology*. Cambridge University Press. https://doi.org/10.1017/CBO9780511808111

Bernard, H. R. (2011). *Research Methods in Anthropology: Qualitative and Quantitative Approaches* (5th ed.). AltaMira Press.

Bernard, H. R., & Gravlee, C. C. (Eds.). (2014). *Handbook of Methods in Cultural Anthropology*. Rowman & Littlefield.

Briller, S., Kelley, T., & Wirtz, E. (2016). Designing for People. *Anthropology News*, *57*(9), e51–e54. https://doi.org/10.1111/AN.124

Bronk, K. C. (2012). The exemplar methodology: An approach to studying the leading edge of development. *Psychology of Well-Being: Theory, Research and Practice*, *2*(1), 5. https://doi.org/10.1186/2211-1522-2-5

Brown, A. S. (2012). Designing for Technology’s Unknown Tribes. *Mechanical Engineering*, *134*(08), 30–35. https://doi.org/10.1115/1.2012-AUG-1

Chua, K. J., Yang, W. M., & Leo, H. L. (2014). Enhanced and conventional project-based learning in an engineering design module. *International Journal of Technology and Design Education*, *24*, 437–458.

Clarke, A. J. (2017). *Design Anthropology: Object Cultures in Transition*. Bloomsbury Publishing. https://doi.org/10.5040/9781474259071

Drazin, A. (2021). *Design Anthropology in Context: An Introduction to Design Materiality and Collaborative Thinking* (First Edition.). Routledge.

Ehn, B., Löfgren, O., & Wilk, R. (2015). *Exploring Everyday Life: Strategies for Ethnography and Cultural Analysis*. Rowman & Littlefield Publishers.

Fetterman, D. M. (with Internet Archive). (1998). *Ethnography: Step by Step* (2nd ed.). SAGE Publications. http://archive.org/details/ethnographystepb00fett

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Goffin, K., Varnes, C. J., van der Hoven, C., & Koners, U. (2012). Beyond the Voice of the Customer: Ethnographic Market Research. *Research Technology Management*, *55*(4), 45–53.

Gubrium, A., & Harper, K. (2013). *Participatory Visual and Digital Methods* (1st edition). Routledge.

Han, J., Kelley, T., & Lim, Y. (2024). A historical journey of US technology education leading to STEM pathways. *The International Journal for the History of Engineering & Technology*, *94*(1), 65–81. https://doi.org/10.1080/17581206.2024.2345648

Hashizume, A., & Kurosu, M. (2013). Understanding User Experience and Artifact Development through Qualitative Investigation: Ethnographic Approach for Human-Centered Design. *Human-Computer Interaction. Human-Centered Design Approaches, Methods, Tools, and Environments*, 68–76. https://doi.org/10.1007/978-3-642-39232-0_8

Herr, D. J. C., Akbar, B., Brummet, J., Flores, S., Gordon, A., Gray, B., & Murday, J. (2019). Convergence education—An international perspective. *Journal of Nanoparticle Research*, *21*(11), 229. https://doi.org/10.1007/s11051-019-4638-7

Hill, R. B. (2006). New perspectives: Technology Teacher Education and Engineering Design. *Journal of Industrial Teacher Education*, *43*(3), 45.

Hyett, N., Kenny, A., & Dickson-Swift, V. (2014). Methodology or method? A critical review of qualitative case study reports. *International Journal of Qualitative Studies on Health and Well-Being*, *9*(1), 23606–23606. https://doi.org/10.3402/qhw.v9.23606

IDEO. (2015). *The Field Guide to Human-Centered Design* (First Edition). IDEO.org / Design Kit.

Ingold, T. (2014). That's enough about ethnography! *HAU : Journal of Ethnographic Theory*, *4*(1), 383–395. https://doi.org/10.14318/hau4.1.021

Jordan, A. T. (2013). *Business Anthropology: Second Edition*. Waveland Press.

Kelley, T. (2011). Engineer's Notebook: A Design Assessment Tool. *Technology and Engineering Teacher*, *70*(7), 30.

Kramer, J., Agogino, A. M., & Roschuni, C. (2016, December 5). *Characterizing Competencies for Human-Centered Design*. ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. https://doi.org/10.1115/DETC2016-60085

Kronenfeld, D. B., Bennardo, G., De Munck, V. C., & Fischer, M. D. (Eds.). (2015). *A Companion to Cognitive Anthropology*. John Wiley & Sons.

Mannik, L., & McGarry, K. (2017). *Practicing Ethnography: A Student Guide to Method and Methodology*. University of Toronto Press, Higher Education Division.

Martinez, L. (2023). Analyzing human-centered design approaches for involving end-users throughout the design process to create user-centric interactive system. *Human-Computer Interaction Perspectives*, *3*(1), 14–28.

McCarthy, J., & Wright, P. (2015). *Taking [A]part: The Politics and Aesthetics of Participation in Experience-Centered Design*. The MIT Press. https://doi.org/10.7551/mitpress/8675.001.0001

McCurdy, D. W., Spradley, J. P., & Shandy, D. J. (2004). *The Cultural Experience: Ethnography in Complex Society* (2nd edition). Waveland Press.

Miller, C. (2014). Lost in translation? Ethics and ethnography in design research. *Journal of Business Anthropology*, 62–78.

Miller, C. (2017). Owning it: Evolving Ethics in Design and Design Research. In *Ethics in the Anthropology of Business* (pp. 87–103). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315197098-6/owning-christine-miller

Miller, C. (2018). *Design + Anthropology: Converging Pathways in Anthropology and Design*. Routledge.

Nair, M. (2023, April 3). City Council approves Squirrel Park reno, requires tenants be notified of demolition. *Purdue Exponent*. https://www. Purdue exponent.org/city_state/article_8f1618fc-d297-11ed-ba02-3301920b4740.html

National Science & Technology Council. (2022). *Convergence education: A guide to transdisciplinary STEM learning and teaching*. White House Office of Science and Technology Policy.

Negrón, R., Wutich, A., Russell Bernard, H., Brewis, A., Ruth, A., Mayfour, K., Piperata, B., Beresford, M., SturtzSreetharan, C., Mahdavi, P., Hardin, J., Zarger, R., Harper, K., Jones, J. H., Gravlee, C. C., & Brayboy, B. (2024). Ethnographic methods: Training norms and practices and the future of American anthropology. *American Anthropologist*, *126*(3), 458–469. https://doi.org/10.1111/aman.13991

Nguyen, H. N., Lasa, G., Iriarte, I., Atxa, A., Unamuno, G., & Galfarsoro, G. (2022). Human-centered design for advanced services: A multidimensional design methodology. *Advanced Engineering Informatics*, *53*, 101720. https://doi.org/10.1016/j.aei.2022.101720

Otto, T., & Smith, R. C. (2020). Design Anthropology: A Distinct Style of Knowing. In W. Gunn, T. Otto, & R. C. Smith (Eds.), *Design Anthropology: Theory and Practice* (pp. 1–29). Routledge.

Roper, J. M., & Shapira, J. (2000). *Ethnography in Nursing Research*. SAGE.

Santee, A. (2019, July 2). *10 Must-Read Books on Anthropology in Business and Design*. NAPA. https://practicinganthropology.org/blog/guest-blog/design-by-anthropologists/must-read-anthropology-books-in-business-and-design/

Snodgrass, J. G. (2014). Ethnography of Online Cultures. In H. R. Bernard & C. Gravlee (Eds.), *Handbook of Methods in Cultural Anthropology* (Vol. 2014, pp. 465–495). Rowman & Littlefield.

Squires, S. (2021). Anthropology, Technology, and Innovation. In *Oxford Research Encyclopedia of Anthropology*. https://doi.org/10.1093/acrefore/9780190854584.013.17

Still, B., & Crane, K. (2017). *Fundamentals of User-Centered Design: A Practical Approach*. CRC Press. https://doi.org/10.4324/9781315200927

Strimel, G., Briller, S., Pruim, D., Kelley, T., Sohn, J., Martinez, R., & Otto, J. (2022). Understanding the Values of, and Institutional Barriers Toward, Transforming

Undergraduate Learning in the Pursuit of Innovation. *2022 ASEE Annual Conference & Exposition*. https://peer.asee.org/understanding-the-values-of-and-institutional-barriers-toward-transforming-undergraduate-learning-in-the-pursuit-of-innovation

Strimel, G. J., Briller, S. H., Lucas, D., Kelley, T. R., & Sohn, J. J. (2023). *Moving toward transdisciplinary learning around topics of convergence: Is it really possible in higher education today?* American Society for Engineering Education.

Strimel, G. J., Briller, S. H., Pruim, D. E., Kelley, T. R., & Kim, T. J. (2022). *Understanding institutional barriers toward transforming undergraduate learning in the pursuit of innovation*. American Society for Engineering Education Annual Conference. https://peer.asee.org/42029

Suchman, L. (2013). Consuming Anthropology. In A. Barry & G. Born (Eds.), *Interdisciplinarity: Reconfigurations of the Social and Natural Sciences* (pp. 141–160). Routledge London. https://books.google.com/books?hl=en&lr=&id=BwbNLKWdBZ8C&oi=fnd&pg=PA141&dq=xerox+and+anthropology&ots=CjrrpiRSsf&sig=py8WU7y-tyZ0bucIeBUzxGHmDyI

Teddlie, C. B., & Tashakkori, A. M. (2008). *Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences* (1 edition). SAGE Publications, Inc.

The Exponent. (2013, October 14). Purdue is a college obsessed with squirrels. Purdue *Exponent*. https://www. Purdue exponent.org/opinion/article_5ab6abcd-d167-5f24-a6df-999645cf07d5.html

Tomitsch, M., & Hepburn, L.-A. (2020, April 6). Five Human-Centred Design Methods to Use in Your Projects When You Are in Isolation. *Medium*. https://medium.com/design-at-sydney/five-human-centred-design-methods-to-use-in-your-projects-when-you-are-in-isolation-420da5d06aaa

Tomitsch, M., Wrigley, C., Borthwick, M., Ahmadpour, N., Frawley, J., Kocaballi, A. B., Nunez-Pacheco, C., & Straker, K. (2020). *Design. Think. Make. Break. Repeat. A handbook of methods*. BIS Publishers. http://www.bispublishers.com/design-think-make-break-repeat.html

Wasson, C. (2000). Ethnography in the Field of Design. *Human Organization*, *59*(4), 377–388. https://doi.org/10.17730/humo.59.4.h13326628n127516

Weimer, M. (2013). *Learner-centered teaching five key changes to practice* (2nd ed.). Jossey-Bass.

Wesch, M. (2018). *The Art of Being Human: A Textbook for Cultural Anthropology*. New Prairie Press. https://open.umn.edu/opentextbooks/textbooks/656

Zoltowski, C. B., Oakes, W. C., & Cardella, M. E. (2012). Students’ Ways of Experiencing Human-Centered Design. *Journal of Engineering Education*, *101*(1), 28–59. https://doi.org/10.1002/j.2168-9830.2012.tb00040.x

Development and Evaluation of a Novel Technological Product Development Tool for Education and Industry

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Abstract

Few digital product development tools are used in industry and academia compared to their historic paper-based counterparts. This is surprising as many parts of the product development process have digitised such as communication and Computer-Aided Design. Therefore, a gap in knowledge was identified which informed the development of a novel digital product development tool which allows users to undergo the 6-3-5 ideation process to generate concepts. The digital product development tool was tested with participants to gather insights and feedback. The experiment involved focus groups using the digital product development tool alongside the paper-based equivalent to generate concepts and compare both methods. Participants were then asked to complete a survey to receive feedback on the tool. The results indicated that two-thirds of the respondents favoured the digital product development tool compared to its paper-based counterpart. This preference was influenced by the application's capability to store and export concepts, as well as its potential for enhancing learning. Moreover, the digital environment allows for easy storage and reuse of concepts post generation activity, increasing the efficiency of the design process. Additional, lessons learnt for future digital tool development has been highlighted. The use of this tool has promise to support a greater efficiency of design process and ease of learning about the tool and method.

Keywords

product development tool, product development process, 6-3-5 method, design method, concept generation, online design collaboration, brainwriting method

Introduction

Background Information

Product Development Tools (PDTs) enable design engineers and students to design new products and bring them to the market (Unger & Eppinger, 2011). These tools are particularly useful for students and educators as they provide a systematic structure to follow, guiding the designer towards a final solution (Daalhuizen, 2014; Cross, 2006). The intuitiveness of design tools, their simplicity in explanation and execution is easily achievable within a standard tutorial session, which contributes to their popularity in educational environments. Moreover, when students become graduates, they are inclined to utilise design methods in their future work after gaining practical experience with the technique through exercises or workshops (Nutzmann, et al., 2019). This applies to all levels of the educational journey with evidence that early exposure to design method and theory develops ability and skill for designing (Eder, 2013) and is preferred by students (Reddy Gudur, 2016).

While communication tools used to collaborate have progressed with technological advancements, there are fewer digital or online tools compared to their physical counterparts (Brisco, Grierson & Lynn, 2021). Using computer devices, digital design methods support the Product Development (PD) process by facilitating design ideation during the concept generation stage. There are several common examples of engineers and students favouring online or digital tools over their physical alternatives such as conducting meetings over Microsoft Teams, writing reports using Microsoft Word, using Microsoft PowerPoint to support presentations to use example from Microsoft Office. Specific engineering and design examples include creating parts, assemblies and engineering drawings using Computer-Aided Design (CAD) packages. But why not during the ideation phase of the design process? Digital design methods which aid the ideation process are not readily available, meaning physical paper-based pre-defined templates are often preferred even with their limitations. This research paper sets out to investigate if a new digital PDT for the development of physical products, which meets the requirements of engineers and students, would be preferred to traditional paper-based methods of PD and be a welcome addition to industry and academia. This research is important as the potential benefits of a novel digital PDT have not been fully realised in industry and academia and could provide students and engineers with a more effective process of PD and ideation, leading to increased productivity, creativity, and collaboration (Fucci, 2011).

Research Aim and Objectives

Research Aim

This research project aimed to develop and evaluate a novel digital PDT by capitalising on the opportunities available and addressing gaps in knowledge within the digital space, with an end goal to determine whether digital PDTs are favoured over their physical counterparts in the context of PD and ideation supporting further exploration of novel tools and best practices in their development.

Research Objectives

To achieve the above aim, the following are the Research Objectives (RO) for the research project:

(RO1) Investigate relevant research papers to ascertain the extent of prior research and identify the five most pertinent papers specifically addressing digital tools.
(RO2) Gather the requirements of the new digital PDT during the literature review based on the opportunities available, user needs and gaps in knowledge.
(RO3) Develop a prototype of a new digital PDT.
(RO4) Undergo an experiment to gather data and feedback on the digital PDT compared to its existing physical paper-based counterpart.
(RO5) Analyse results to conclude if digital PDTs should be regularly implemented as part of the PD process in education and industry.

Research Project Approach

The approach for this project will follow a similar approach to Punch’s (2009) simplified model. This framework consists of defining a topic within the research area, followed by a literature review. In the empirical stage, an experiment is then designed to collect data, which is then analysed.

Following this framework, the subsequent research procedure (Figure 1) was adopted:

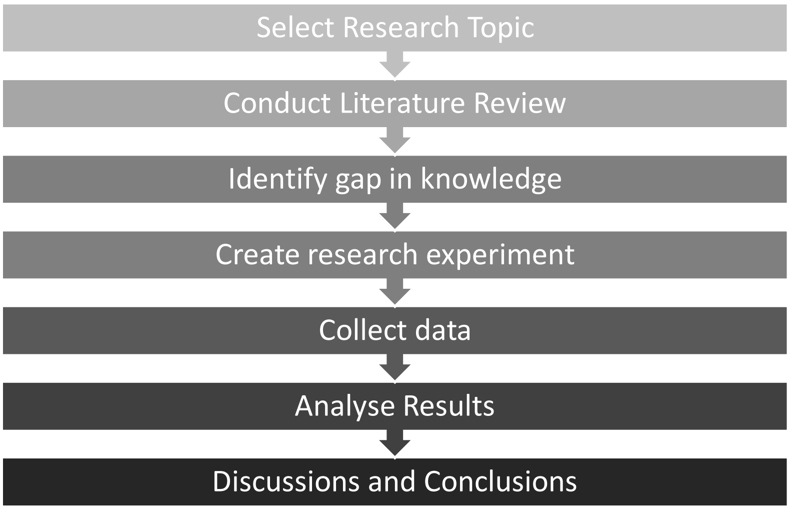

Figure 1. Research procedure

Research Paper Structure

Following the aforementioned approach, section two of this paper contains the Literature Review which provides an overview of existing PDTs and their limitations. A gap in literature will be established by comparing the current uses of digital tools. This will define the requirements of a novel digital PDT to be developed by the researcher. Section three outlines the method of gathering data during the experiment followed by section four which highlights the results of the experiment. Finally, section five provides a discussion of the key results to conclude the research findings.

Literature Review

Overview of digital product development tools

Over the past 15 years, the use of new PDT has become progressively digitised (Marion & Fixson, 2020), with digital tools such as CAD becoming increasingly popular, accessible and utilised throughout industry as well as academia during the PD process (Fixson & Marion, 2012). CAD is well established as an industry-standard tool for use within the detailed design, manufacturing, and assembly phase of product development (Vuletic et al., 2018). Packages such as Solidworks, CREO and Onshape have helped design engineers produce rapid dimensions, comments, and revisions to product designs – increasing the efficiency of the design process while reducing the effort required (Marion & Fixson, 2020). However, there have been few CAD tools developed which facilitate the conceptual design phase of PD (Tang, Lee & Gero, 2011), even though it is an important topic within design computing research (Van Dijk, 1995). Researchers such as Purcell and Gero (1998), Lawson and Loke (1997) and Verstijnen et al. (1998) believe CAD is an inappropriate means for conceptualisation although this could be attributed to the current abilities of computer-based drawing systems. Nevertheless, a more recent case study concluded that computers have materialised as an ideation tool across design realms (Jonson, 2005). Therefore, pushing for the development of computer-aided ideation tools which are utilised within the PD process.

During the concept generation stage of PD, sketches are quickly drawn, with a focus on creativity as opposed to detail (Kang Zhong et al., 2011). This helps generate a greater number of ideas that can be refined later in the PD process. Kang Zhong et al. (2011) study also noted that as CAD tools require larger amounts of precision and dimensional inputs, they are often time-consuming if used in the concept generation stage. As a result, design engineers have often been reluctant to transition to digital PDTs, with physical analogue methods often preferred despite their limitations.

Limitations of Existing Product Development Tools

To argue for the development of a new digital PDT that meets the needs of modern design engineers, the limitations of existing ideation tools and problems associated with transitioning to digital tools are presented. This also aids in defining the requirements of a new digital PDT.

The glaring limitation of physical PDTs is their lack of remote collaboration and poor support for documentation (Jensen et al., 2018). As a result, collaboration is difficult while using certain PDTs when conducted remotely. Additionally, physical files must be stored on premises which poses data loss risks, or they can be virtually scanned which therefore requires additional time, effort, and resource management (Liu, 2016).

However, often there is a learning curve associated with transitioning to digital PDTs (Wendrich et al., 2016). This means sufficient guidance or training should be incorporated into digital PDTs so they can be used effectively.

State-of-the-art Digital Product Development Tools developed and suggested improvements

Digital PDTs have been developed with the aim of tackling the limitations of their physical analogue counterparts. As technology advances, there is increasing interest in research on distributed design teams performing design activities online. Cases include the aforementioned CAD, computer-aided sketching (Company et al., 2009), Sketchy – a web-based drawing application (Wallace et al., 2020) and electronic prototyping support tools (Petrakis et al., 2022).

Shared digital whiteboard applications have emerged, including Miro (miro.com), Figma (Figma.com), Mural (mural.com) as well as others which are used by design teams during the ideation process (Vidovics et al., 2016). As an example, Jensen et al. (2018) developed an online whiteboard to conduct concept generation activities. The online tool was tested, alongside its physical counterpart, and the results were compared. The case study found that the productivity and creativity levels as well as the documentation support and visual appearance of the digital tool were superior in comparison to physical methods. However, participants generally preferred the use of physical tools due to difficulties writing on the screen. In their future work, they suggest using a hybrid approach that involves the use of physical sticky notes being converted to a digital format.

More recently, Brisco, Grierson and Lynn (2021) created a digital prototype of the 6-3-5 method. Upon testing the tool with students, it was reported that 49% of the students said the prototype did not guide them through the process. The feedback gathered during the experiment suggests that informative instructions should be implemented into the tool. Brisco, Grierson and Lynn (2021) highlighted the importance of providing instructions on how to use the system, and making the activity more enjoyable by changing the input device from a mouse to a digital pen as it has been reported mood and visual stimulus can affect the level of creativity during a 6-3-5 activity (Wallace at al., 2020).

Table 1 is comprised of the five most relevant digital design tools found within the literature. Three key questions were used to differentiate the developed tools and identify a gap. The comparison indicated that while some digital PDTs incorporate sketching capabilities, not many provide instructions or learning material – with no design tools meeting all three of the requirements as seen in Table 1.

Table 1. Comparison of digital design tools found in literature

Author(s)	Topic Focus	Project Aim	Was there a digital PDT created? (Y/N)	Does the tool use computer-aided sketching? (Y/N)	Was there learning material/ instructions provided? (Y/N)
Petrakis et al. (2022)	Digital prototyping support tool	Explore students' usage of the prototyping support tool	Y	N	Y
Wallace et al. (2020)	Web-based drawing application	Developing 'Sketchy'	N	Y	N
Vidovics et al. (2016)	Distributed collaborative	Develop of a methodology	Y	N	N
Jenson et al. (2018)	Remediating a Design Tool	Develop digitised sticky notes	Y	N	N
Brisco, Grierson and Lynn (2021)	Development of a digital 6-3-5 tool	Development of a digital 6-3-5 tool	Y	Y	N

Requirements of a new Digital Product Development Tool

Building upon the findings of Brisco, Grierson and Lynn's (2021) research, it was decided that a novel 6-3-5 digital PDT would be developed, leveraging the method's potential for application in a digital environment. The 6-3-5 design activity resembles brainstorming but offers additional advantages, such as providing participants with more time for thoughtful reflection and mitigating the influence of dominant team members (Litcanu, et al., 2015). This method has been credited with fostering the development of more creative ideas, particularly among students with expertise in extensive concept generation projects, like those in mechanical engineering (De Napoli, etal., 2020). The method traditionally involves 6 team members, drawing 3 ideas each in a time frame of 5 minutes. Following the initial 5 minutes, team members exchange drawings and proceed to refine each other's ideas for another 5 minutes, repeating this process for a total of 6 rounds (Brisco, Grierson & Lynn, 2021).

Based on the findings from the literature review, to fill the gap in the literature, the new digital PDT should:

1. Provide sufficient documentation in order to store concepts and prevent loss of data.

2. Enable designers to collaborate remotely.
3. Provide adequate instructions on how to use the chosen tool and overcome any potential learning curve.
4. Possess hybrid capabilities by facilitating the input of analogue drawings into the tool if desired by the user.
5. Be tested by students as well as industry professionals (preferably long term within a realistic industrial setting as suggested by Kurtoglu, Campbell and Linsey (2009) during their experimental study of 'effects of a computational design tool on concept generation').
6. Incorporate digital sketching capabilities to facilitate ideation.

The aforementioned points aim to create a more efficient tool that improves the quality and detail of concepts sketched and guides users with informative information.

Methods

Development of the Digital Product Development Tool

Based on the requirements determined by the Literature Review, the novel 6-3-5 digital PDT underwent development as an essential prerequisite. Over the course of three months, the researcher partnered with the Design Engineering Team at the National Manufacturing Institute Scotland (NMIS) to digitise their PD Toolkit. Following this collaboration, the researcher developed an application that facilitates the digital 6-3-5 ideation method alongside other digital PDTs. Key pages of the app, and the digital 6-3-5 PDT, which outline the user journey, are shown in Appendix A.

Research Methodology

Selected Participants

With the prototype created, the digital 6-3-5 PDT was introduced to master's students in the Department of Design, Manufacturing and Engineering Management (DMEM) at the University of Strathclyde as well as Design Engineers at NMIS. Students as well as experienced design engineers were selected as potential participants as the digital PDTs aims to be used in both industry and academia at all levels of expertise. Overall, three Design Engineers and nine DMEM students participated in the experiment. As the researcher is a university student, there was limited access to participants and available time of only one semester. Due to these limitations, 12 participants were deemed acceptable as the 6-3-5 method generates a large volume of concepts. The participants were divided into focus groups of three members each (one group of three design engineers and three groups of three DMEM students). The selected participants had a wide range of experience with the 6-3-5 ideation tool throughout their degree or career.

Experiment Procedure

During the experiment, participants were presented with an overview of a problem area to generate concepts during the 6-3-5 activity. The chosen design challenge was to redesign an extension cord for modern lifestyles. This was selected as it is a common product within individual's homes and participants can relate to many of the problem areas presented to them during the brief. Following on, an overview of the digital PD app was then presented. Participants were allocated time to study the 6-3-5 PD method within the app and read the instructions on how to use the online digital PDT. Participants were then introduced to the 6-3-5 analogue paper-based method and then given access to the new prototype 6-3-5 digital PD tool via a sketching tablet. One sketching tablet was used with two paper-based 6-3-5 templates. After each round, the paper-based templates and the sketching tablet rotated to allow each of the participants to use the digital PDT on the tablet as depicted in Figure 2. Overall, three rounds were completed per focus group.

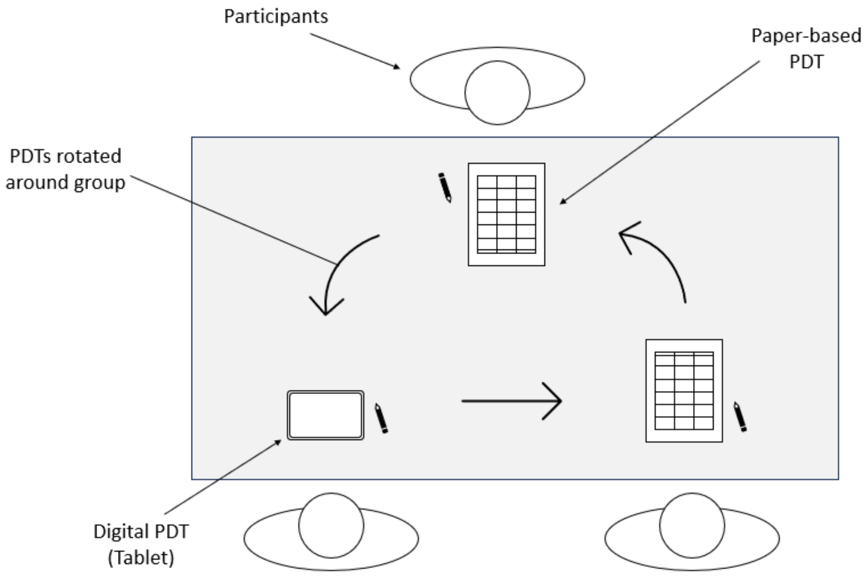

Figure 2. Experiment procedure

The workshop was completed with the *DMEM* students within the DMEM design studio, while the NMIS design engineers used one of the meeting rooms at NMIS (Figure 3). Throughout the activity, the workshop was recorded to capture any immediate feedback from the participants while they were using the tools. After the workshop concluded, the researcher and the participants discussed the concepts created and immediate thoughts of the digital PDT. Participants were then given a link to an online survey to provide further feedback.

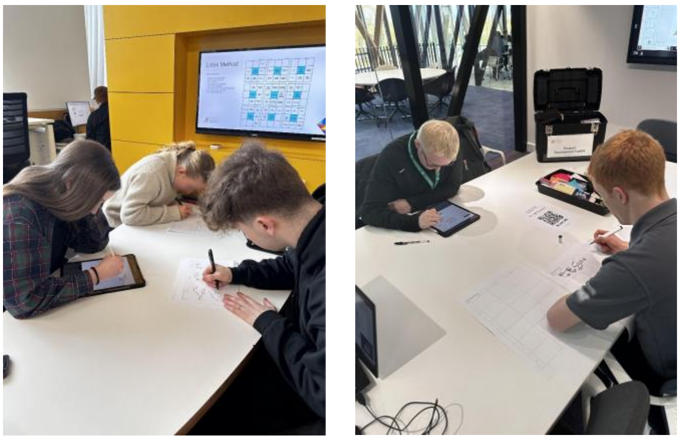

Figure 3. DMEM students (LEFT) and NMIS design engineers (RIGHT) participating in experiment

Chosen Research Instruments

To meet RO4, Table 2 outlines the chosen methods used to gather data from the participants and the purpose of using them. To facilitate a holistic approach, the chosen methods allow a mix of quantitative and qualitative data to be collected, subsequently, allowing a stronger argument and conclusive decision to be presented to achieve RO5.

Table 2. Overview of research instruments

Method	Purpose
Workshop with focus group	• Allow participants to use novel digital 6-3-5 PDT alongside physical analogue equivalent. • Observe students and design engineers use of the digital PDT. • Evaluate concepts developed from both the digital PDT and analogue PDT based on KPIs. • Record time duration elapsed per concept. • Gather immediate feedback or comments from participants on the digital and analogue PDTs.
Survey	• Collect additional intermediate feedback after the workshop has concluded from participants. • Analysis results to understand the advantages and limitations of digital and analogue PDTs and which type of tool is preferred overall.

Evaluation Procedure

To evaluate the concepts generated during the design challenge, a modified version of the Decision Tree for Originality Assessment in Design (DTOAD) was used. The DTOAD is a useful tool to identify differences in the originality of concepts (Kershaw et al. 2019; Deo et al. 2019), however, it was modified to evaluate the quality of the drawings, quality of the annotations, and drawing efficiency for this experiment. As a result, three decision trees were created to evaluate the key performance indicators (KPI), as detailed in Appendix B. Three DMEM Master's students were selected to evaluate the concepts and come to a consensus using the decision trees to reduce any bias and subjectivity when scoring the concepts generated.

Results

Results of concept evaluation

The 108 (36 digital and 72 paper-based) concepts generated by the four focus groups can be viewed in the dataset (https://doi.org/10.15129/73d02a57-dfbd-4797-a381-62af2315ad98) alongside their corresponding scores evaluated using the bespoke decision trees. Figure 4 displays the decision tree scores of the 108 concepts using the three decision trees. The average score of the digital PDT was 7.14 (2 s.f) while the average score of the paper-based PDT was 7.98 (2 s.f), which is a percentage difference of 11.76%.

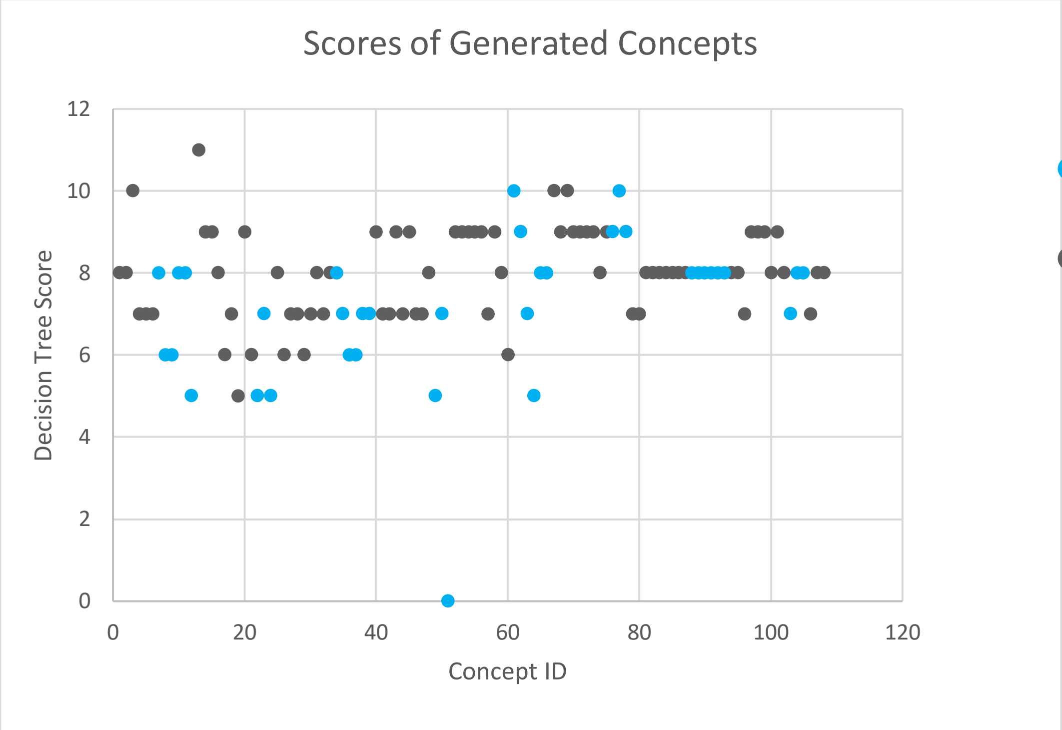

Figure 4. Score evaluated using decision trees against concept ID

During the experiment, the time elapsed to sketch each concept was recorded. Figure 5 displays the time elapsed to sketch each concept against the concept's ID number. The average time to sketch a concept on the digital PDT was 96.17 seconds (2 s.f), while the average time to sketch a concept on the paper-based PDT was 89.97 seconds (2 s.f). This is a percentage difference of 6.89%.

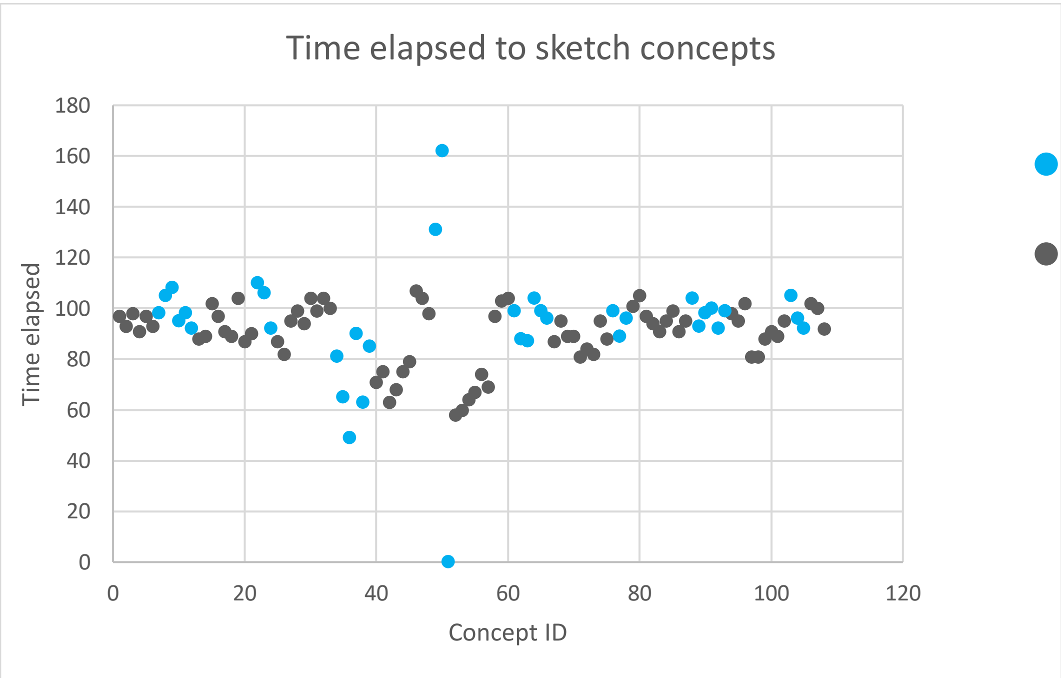

Figure 5. Time elapsed against concept ID

Four samples were identified which highlight a recurrent trend. All four samples are scatter graphs of the time elapsed to draw concepts using the digital PDT (Figures 6 and 7). Each sample result display that participants took the most amount of time to draw the first concept, and then less time for subsequent sketches.

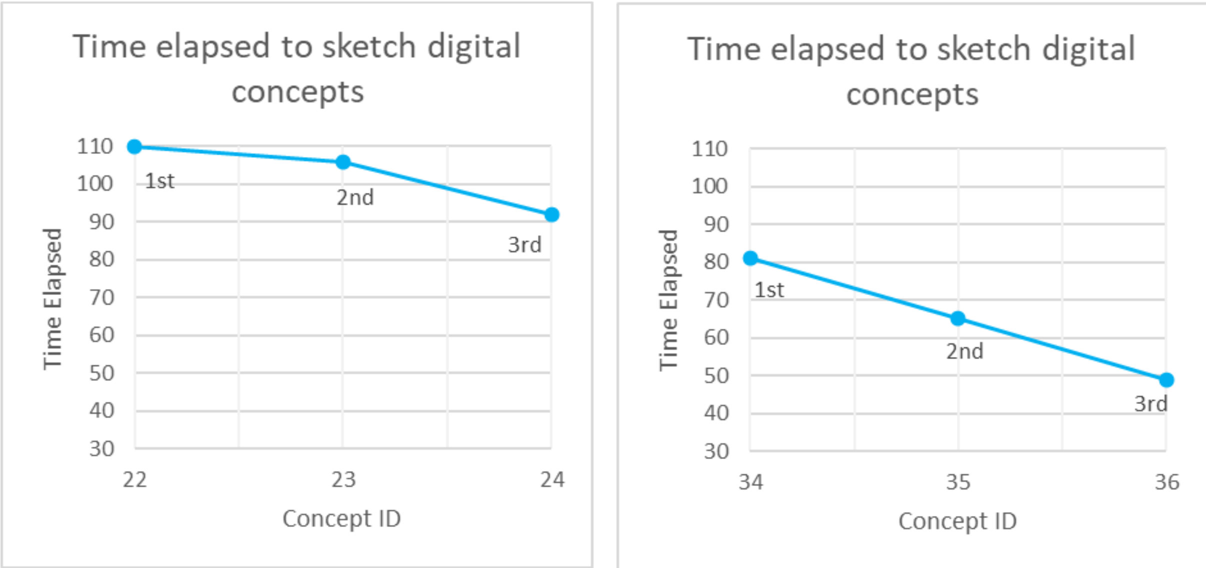

Figure 6. Time elapsed to digitally sketch concepts 22, 23 and 24 (LEFT), and 34, 35 and 36 (RIGHT)

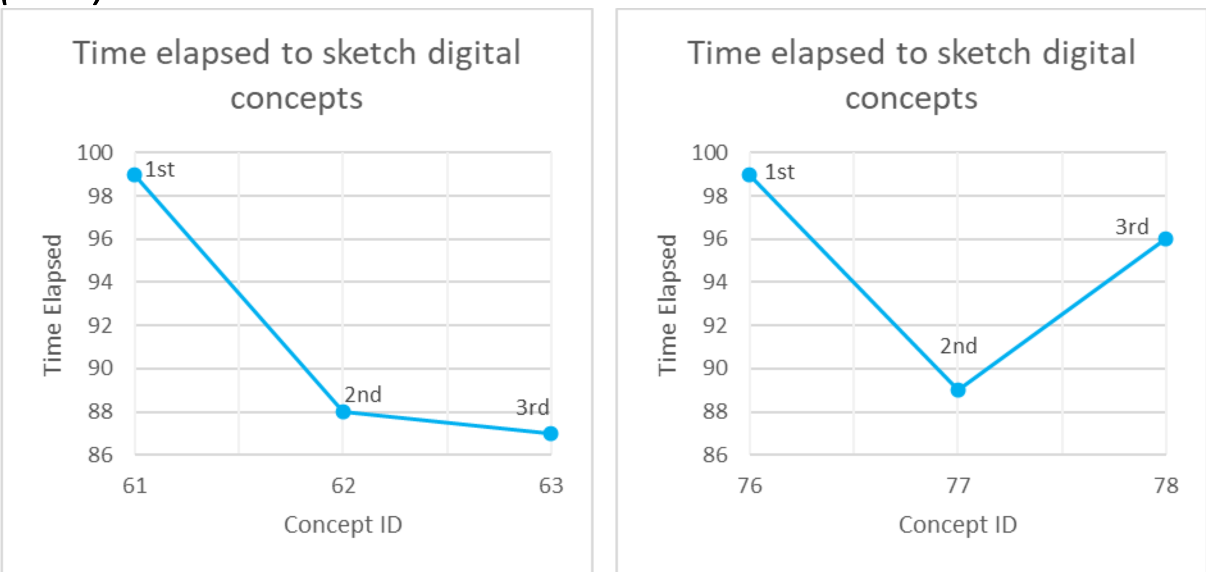

Figure 7. Time elapsed to digitally sketch concepts 61, 62 and 63 (LEFT), and 76, 77 and 78 (RIGHT)

Results of Survey

Results of Digital PDT Prototype's Functionality, Design and Usability

On a scale of 0-10, participants were asked to answer three questions: (Q1) Overall, how satisfied are you with the digital PDT's functionality? (Q2) Overall, how satisfied are you with the digital PDT's design? (Q3) Overall, how satisfied are you with the digital PDT's useability? A score of 0 represents full participant dissatisfaction while a score of 10 represents full participant satisfaction. Responses can be seen in Figure 8 including error bars. The average response for (Q1) was 8.03 (2 s.f), (Q2) 8.58 (2 s.f), and (Q3) 7.25 (2 s.f).

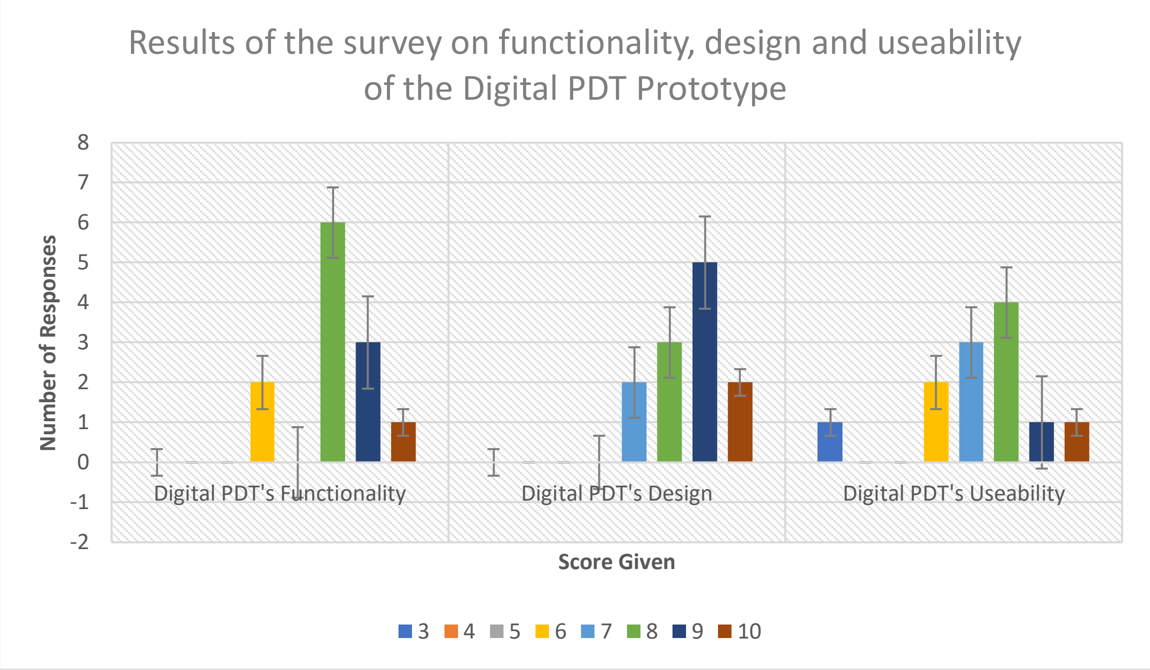

Figure 8. Results of survey on functionality, design and usability of the digital PDT prototype

Results of the participants Preference between the Digital and Physical PDT

The participants were given the option to select which PDT medium they prefer (digital or paper-based). Responses can be seen in Figure 9. 8 out of the 12 participants preferred the digital PDT, while 4 of the 8 participants who preferred the digital PDT much preferred the digital PDT.

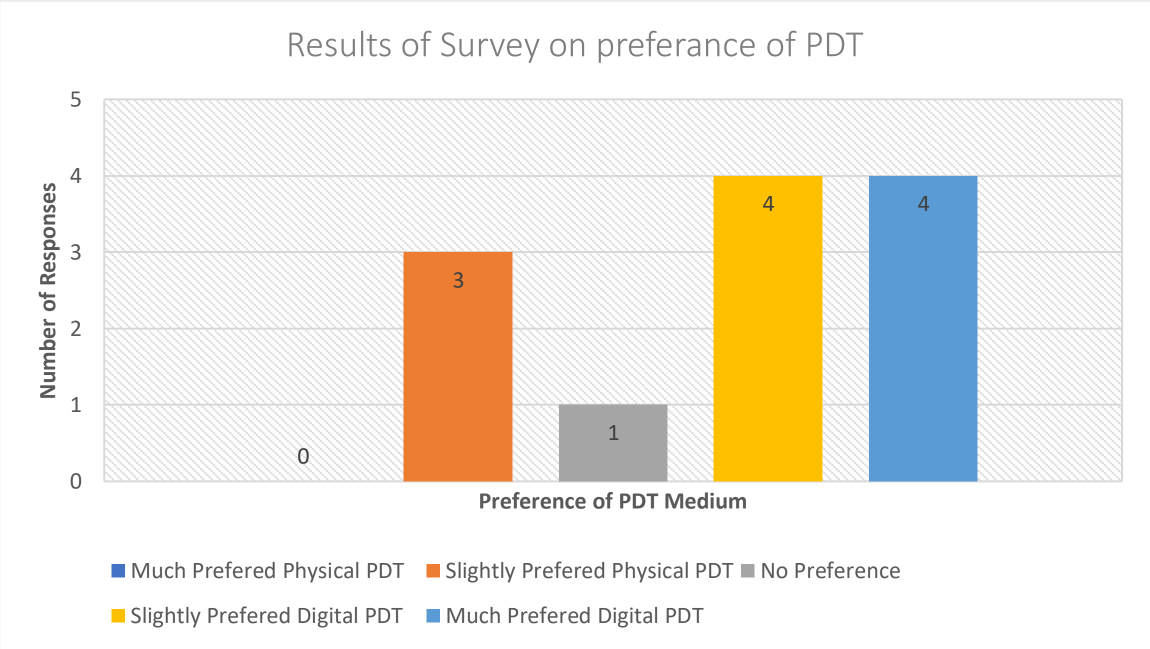

Figure 9. Results of survey on participant's preference between the digital and physical PDT

The participants were then asked to explain their choice of preference. Table 3 displays the results. To summarise, the results indicate that participants who preferred using the physical PDT did not have much experience with digital sketching which led to difficulties when using the tablet as opposed to paper. On the other hand, participants liked that the digital PDT provided storage, traceability, and a timer.

Table 3. Explanation of participants preference

Participant	Preference	Response
A	Much preferred Digital PDT	The traceability aspect of the digital tool's concept sketches and evaluation and the ability to work as distributed teams at the same time has great benefit to a 6-3-5 workshop. The ease of 'erasing' digital mistakes it easier than physical and the general 'look' of the concepts look better and more refined. "Digital homogeneity for sketching ability" The fact the digital sketching in the app makes it the same level of ability for everyone when drawing (i.e. no one is doing detailed drawings, and no person feels inadequate when drawing when compared to others as everyone is the same).
B	No preference	I liked both.
C	Slightly preferred Physical PDT	Preferred drawing on the physical tool but preferred storing on the digital tool.
D	Slightly preferred Physical PDT	Only preferred physical because of I have less experience drawing in a digital format, therefore took longer and didn't look exactly how I wanted. With practice, I think it would prefer the digital version.
E	Slightly preferred Digital PDT	Found it challenging to navigate the app.
F	Much preferred Digital PDT	It is really intuitive and easy to understand.
G	Slightly preferred Physical PDT	It was difficult to draw the concepts. It took longer and there was no eraser to remove parts of the sketch
H	Slightly preferred Digital PDT	The digital tool had the benefit of grouping together all of the concepts in a clear to understand layout. Being able to open each concept image is a good feature and having them stored digitally is a real benefit for traceability. The iPad and pencil work very well making it easy to draw concepts as you naturally would. The timer feature is also very useful to help focus your spread of time across each concept – ensuring that you are able to complete 3 concepts in the allocated 5 minutes. The drawing tools are quite basic in the digital tool and some improvements could be made to these to make it more user-friendly – such as an eraser tool. The sketch boxes are quite small on the screen and the app would be enhanced if it was possible to use the full screen of the iPad for the boxes.
I	Much preferred Digital PDT	I think this definitely streamlined the entire process and made collation of drawings so much easier to present the end sheet of 6-3-5. Only thing about the tool is it needs some refinement for the user interface as discussed during session.

J	Slightly preferred Digital PDT	I think it made it much easier to see the time left and to be able to store everything digitally rather than worrying about losing the paper. I like how it creates a full PDF of all the ideas that can be accessed online whenever and easily included in a folio. The only reason it is slightly preferred and not much preferred is I don't have an iPad, so it was the first experience of sketching digitally before.
K	Slightly preferred Digital PDT	Was good to use the digital tool to sketch and see everything clearly online but personally sometimes find it harder to sketch on a tablet.
L	Much preferred Digital PDT	Is it more time effective to generate and store the concepts digitally as opposed to scanning in the concepts once they have been sketched. This also prevents any loss of data.

Results of Perceived Usefulness of instructions

On a scale of 0-10, the participants were asked to assess the usefulness of the instructions provided on the PDT and how to use the digital version of the PDT. Participants were asked if the instructions were helpful to them (Q6), and if the participants believed the instructions would be useful for students or professionals early in their career (Q7). A score of 0 was classed as "not insightful" while a score of 10 was classed as "very insightful". Figure 10 displays the results which include error bars. On both occasions, the most common score was 8. The average response for (Q6) and (Q7) was 8.67 (2 s.f), and 8.41 (2 s.f) respectively.

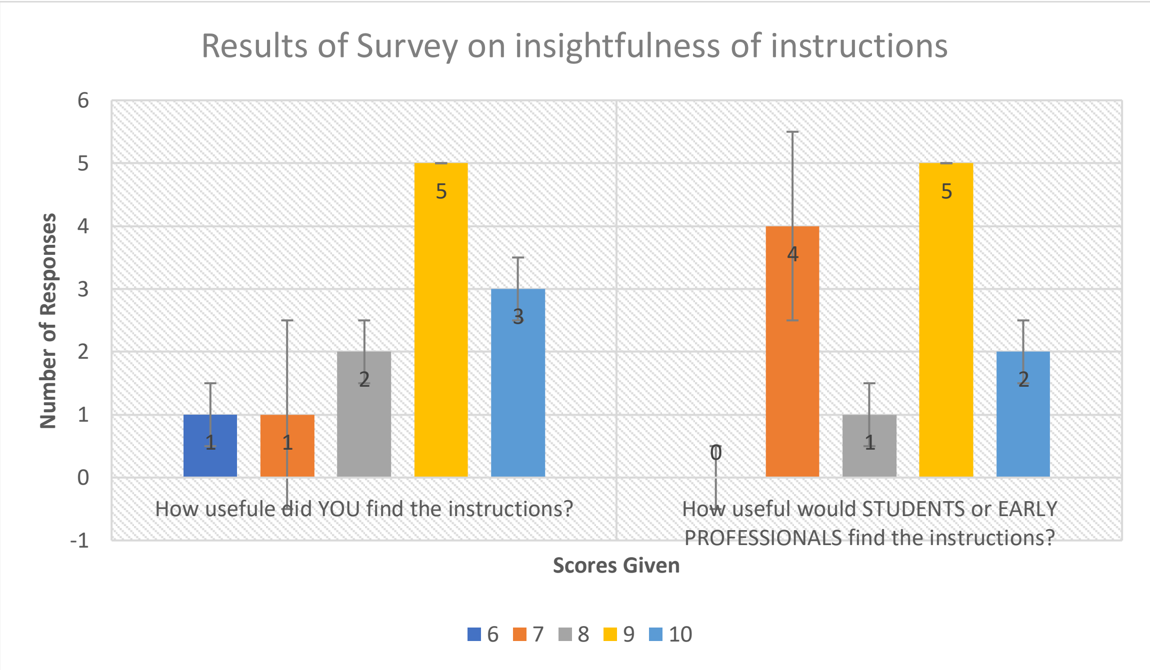

Figure 10. Results of survey on the insightfulness of instructions

Results of Participant's Experience of PDTs

Participants were asked what their current occupation was. The participants selected included nine DMEM students and three NMIS Design Engineers. The participants were then asked to judge their experience using the 6-3-5 PDT. Figure 11 displays the results. Most of the participants have 1-3 years of experience using the 6-3-5 PDT.

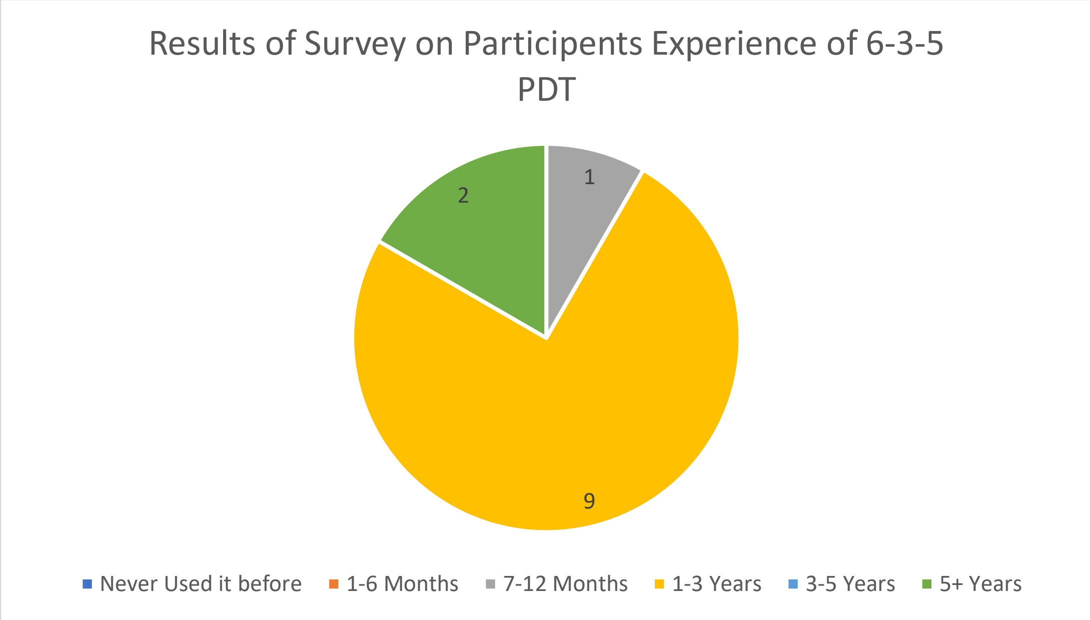

Figure 11. Results of survey on participants experience of 6-3-5 PDT

Participants were also asked to judge how well they knew and understood the 6-3-5 PDT. Using a scale of 0-10, 0 signified an amateur with no knowledge of the PDT, while 10 signified an industry expert. The results are shown in Figure 12. The most common result was seven with the average result being 7.25.

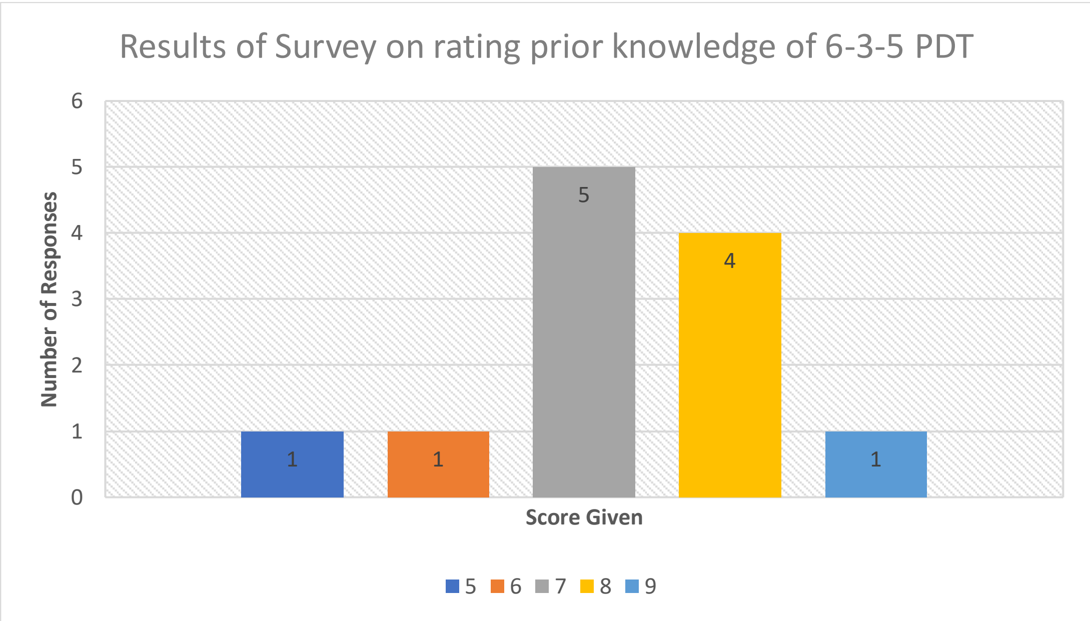

Figure 12. Results of survey on rating prior knowledge of 6-3-5 PDT

Discussion

Key findings from scoring the concepts generated

As the data within Figure 4 demonstrates, the concepts generated by the digital PDT (Figure 13) had an average score, generated by the decision trees, of 11.76% less than the concepts generated with the paper-based method. This data, in combination with the fact the concepts generated using the digital PDT took on average 6.89% longer than the paper-based method (Figure 5) indicated the presence of a learning curve when using the digital PDT. To back up this point further, four samples were highlighted (Figures 6 and 7) which illustrate the presence of a learning curve. These data samples indicate that when the participants were presented with the digital PDT for the first time, the first concept generated took longer to sketch than the remaining two concepts. This is a recurrent trend as it happened 10 out of 12 times during the experiment. In addition, one participant stated that they only preferred the paper-based PDT as they had a lack of experience in digital drawing (Table 3).

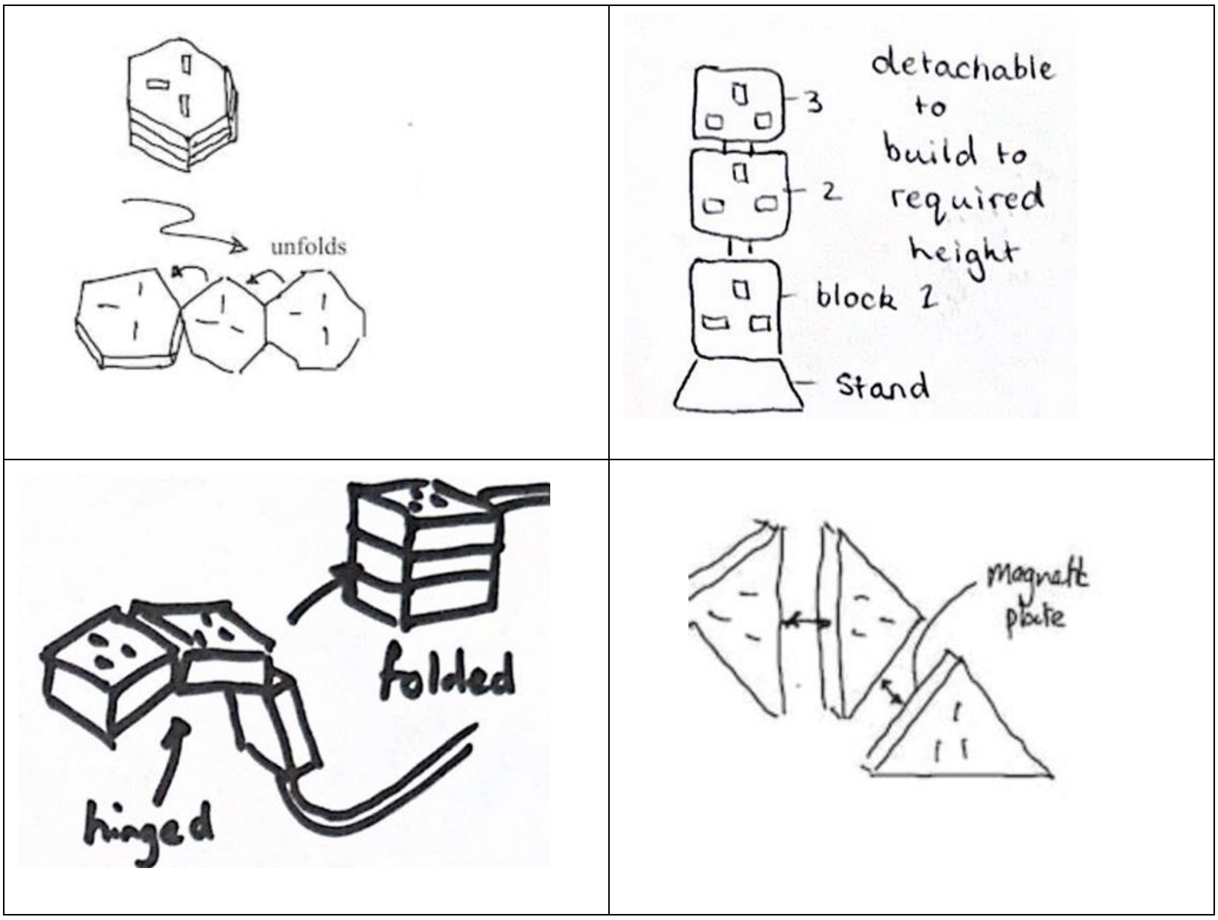

Figure 13 – Example outputs of the digital PDT (left) and paper sketching (right)

Furthermore, it is discounted that the learning curve associated with the concepts generated stemmed from a lack of experience with the 6-3-5 method as all participants had at least 7 months experience with the 6-3-5 method, with most participants having 1-3 years' experience (Figure 11). Moreover, when the participants were asked to rate their prior knowledge of the 6-3-5 PDT, the average result was 7.25. This indicates that the participants had a good level of understanding of the 6-3-5 method (Figure 12). This is expected as the participants selected were either NMIS Design Engineers or DMEM students.

As a result, it is believed that if the experiment was repeated with the same participants again, or if the participants were given additional time to explore and familiarise themselves with the digital PDT, the average time per concept would decrease and the average score of concepts generated using the digital PDT would increase. Additionally, providing specialist training to those with little experience with the PDT or digital sketching would also aid in overcoming the technology-induced learning curve which is present when using digital tools (Meneely & Danko, 2007). It is expected that participants with less experience or knowledge of PDTs may struggle to adhere to the 5-minute timeframe as per the 6-3-5 activity, but those proficient in digital tools would likely adapt to the digital PDT more easily.

Key findings from the Survey

As Brisco, Grierson and Lynn's (2021) paper found that students would find more informative instructions beneficial, there was an increased focus on providing the users of the digital PDT with informative instructions on both the generic 6-3-5 tool, and how to use the digital version itself (Figure 15 and 17). Furthermore, feedback received from Brisco, Grierson and Lynn's (2021) experiment found that the students prefer a simpler drawing module, a default drawing colour of black and an easy method of deleting parts of drawings. All of these aspects were considered during the development of the digital PDT prototype as Figure 19 in Appendix A displays.

As Figure 10 displays, participants were asked how insightful they found the instructions. The average response was 8.67 out of 10, which indicates that the participants found the provided instructions useful. As the participants were fairly experienced in the PDT, it was also asked if early professionals or students would find the provided information useful. With an average score of 8.41 out of 10, the results indicate that they would find it insightful and aid in learning how to use the PDT for the first time. However, this would need to be confirmed via further testing and feedback.

This insight is important when assessing the digital PDT prototype's functionality, design, and useability. The same survey question Brisco, Grierson and Lynn (2021) asked participants during their experience was asked on a scale of 10 instead of 5. Scaling for 10, Brisco, Grierson and Lynn's (2021) survey found that their digital PDT prototype scored, on average, 4.55 out of 10 for functionality satisfaction, 5.45 out of 10 for design satisfaction and 4.62 out of 10 for useability satisfaction. These are lower scores than the average results calculated from this experiment (Figure 8), which indicate that the features integrated to tackle the feedback and pain points identified by Brisco, Grierson and Lynn's (2021) research were successfully implemented but still have room for improvement.

Furthermore, the results from Figure 9 reveal that two-thirds of the participants preferred the digital PDT with only a minor preference for the paper-based version for two individuals and no significant preference for the paper-based option among the participants. When asked to explain their response (Table 3), participants highlighted that the digital PDT allowed "digital homogeneity for sketching ability" as well as provided informative instructions. Moreover, participants stated that they liked how concepts could be stored efficiently on the app and provided traceability. The ability to generate a PDF of the completed activity including all the concepts generated was also positively received.

This demonstrates that the majority of the students and industry professionals, which are part of this research study, welcome the use of a digital PDT. However, to confirm this insight, the experiment would need to be repeated with a larger sample size of participants. Preferably with participants that have a wider range of experience using PDTs and digital tools to compare results and confirm findings. It is recommended that the feedback received during this experiment is also implemented to encourage new findings and shift the participant's focus from the useability of the software to the digital tool's concept generation abilities.

Conclusion

This research paper documents the early development of a 6-3-5 digital PDT to use during concept generation. The novelty lies in the reporting of the digital PDT development to meet the gap in literature and the data reflecting the participant's responses to its utilisation (RO1). The need for such a digital tool stemmed from the popularity of other digital tools, current limitations in physical PDTs and the benefits digital PDTs can bring to industry and academia. The literature review established the requirements of the new digital PDT (RO2), which allowed the researcher to develop an app which hosts a variety of PDTs, serving as a valuable learning resource as well as a more efficient means of sharing, storing, and sketching concepts (RO3). To evaluate the digital PDT, nine DMEM students and three NMIS Design Engineers participated in an experiment, in focus groups, where the digital PDT was compared and used alongside the paper-based PDT (RO4). The results highlight multiple areas for improvement, but the feedback received focused on the digital PDTs useability rather than its ideation ability. It was found that features such as allowing concepts to be digitally stored and exported and introducing the user to the digital PDT with informative information were particularly beneficial which led to two-thirds of the participants preferring the digital PDT over the traditional paper-based version. Therefore, it was concluded that the participants in this study do welcome the use of digital PDT in education and industry (RO5). However, to overcome the limitations of this study, the experiment should be repeated with a larger number of participants, with a wider range of experience in both PD and digital tools to verify findings and acquire further feedback.

Acknowledgements

Thanks to the Design Engineering team at the NMIS for their collaboration in development of the digital product development toolkit, and to the students at the DMEM at the University of Strathclyde, and the Design Engineers at NMIS for their enthusiastic participation in the experiment.

References

Brisco, R., Grierson, H., & Lynn, A. (2021). 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).* https://doi.org/10.35199/epde.2021.17

Company, P., Contero, M., Varley, P., Aleixos, N., & Naya, F. (2009). Computer-aided sketching as a tool to promote innovation in the new product development process. Computers in Industry, 60(8), 592–603. https://doi.org/10.1016/j.compind.2009.05.018

Cross, N. (2006). Designerly ways of knowing (pp. 1-13). Springer London.

Daalhuizen, J. J. (2014). Method Usage in Design: How methods function as mental tools for designers.

De Napoli, L., & Rizzuti, S. (2020). Product Design Education in mechanical and management engineering master's degree programs. Analogies and differences. *Proceedings of the 22nd International Conference on Engineering and Product Design Education (E&PDE 2020)*. https://doi.org/10.35199/epde.2020.66

Deo, S., Hölttä-Otto, K., Bhalerao, Y., & Malge, A. (2019). Engineering design concept generation: The effect of concept combination and classification. *Volume 3: 21st*

International Conference on Advanced Vehicle Technologies; 16th International Conference on Design Education. https://doi.org/10.1115/detc2019-97819

Eder, W. E. (2013). Teaching and Learning Modes for Design Engineering. Proceedings of the Canadian Engineering Education Association (CEEA). https://doi.org/10.24908/pceea.v0i0.4896

Fixson, S. K., & Marion, T. J. (2012). Back-loading: A potential side effect of employing digital design tools in new product development. *Journal of Product Innovation Management*, *29*(S1), 140–156. https://doi.org/10.1111/j.1540-5885.2012.00959.x

Fucci, M. (2011). The evolution of digital tools for product design. *Innovation in Product Design*, 1–14. https://doi.org/10.1007/978-0-85729-775-4_1

Jensen, M. M., Rädle, R., Klokmose, C. N., & Bodker, S. (2018). Remediating a design tool. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3173574.3173798

Jonson, B. (2005). Design ideation: The conceptual sketch in the Digital age. *Design Studies*, *26*(6), 613–624. https://doi.org/10.1016/j.destud.2005.03.001

Kang Zhong, Kang, J., Qin, S., & Hongan Wang. (2011). Rapid 3D conceptual design based on hand gesture. *2011 3rd International Conference on Advanced Computer Control*. https://doi.org/10.1109/icacc.2011.6016395

Kershaw, T. C., Bhowmick, S., Seepersad, C. C., & Hölttä-Otto, K. (2019). A decision tree-based methodology for evaluating creativity in engineering design. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.00032

Kurtoglu, T., Campbell, M. I., & Linsey, J. S. (2009). An experimental study on the effects of a computational design tool on concept generation. *Design Studies*, *30*(6), 676–703. https://doi.org/10.1016/j.destud.2009.06.005

Lawson, B., & Loke, S. M. (1997). Computers, words and pictures. *Design Studies*, *18*(2), 171–183. https://doi.org/10.1016/s0142-694x(97)85459-2

Litcanu, M., Prostean, O., Oros, C., & Mnerie, A. V. (2015). Brain-writing vs. brainstorming case study for power engineering education. *Procedia -– Social and Behavioral Sciences*, 191, 387–390. https://doi.org/10.1016/j.sbspro.2015.04.452

Liu, B. (2016). Study on the risk and Prevention of Accounting Files Computer Management. *Proceedings of the 2016 3rd International Conference on Management, Education Technology and Sports Science (METSS 2016)*. https://doi.org/10.2991/metss-16.2016.134

Marion, T. J., & Fixson, S. K. (2020). The transformation of the innovation process: How digital tools are changing work, collaboration, and organizations in new product development. *Journal of Product Innovation Management*, *38*(1), 192–215. https://doi.org/10.1111/jpim.12547

Meneely, J., & Danko, S. (2007). Motive, mind, and media: Digital Sketching in the creative culture of Design. *Journal of Interior Design*, *32*(3), 69–90. https://doi.org/10.1111/j.1939-1668.2007.tb00541.x

Nutzmann, M., Sauer, T., Voß, M., & Bozkurt, H. (2019b). Study on learning concepts applying creativity methods in education and industry. *DS 95: Proceedings of the 21st International Conference on Engineering and Product Design Education (E&PDE 2019)*. https://doi.org/10.35199/epde2019.85

Petrakis, K., Wodehouse, A., Grierson, H., Coutts, E., Liikkanen, J., & Parkkamäki, H. (2022). The application of a prototyping support tool in a student design project. *DS 117:*

Proceedings of the 24th International Conference on Engineering and Product Design Education (E&PDE 2022). https://doi.org/10.35199/epde.2022.65
Punch, D. K. F. (2009). Introduction to Research Methods in Education. United Kingdom: SAGE Publications.
Purcell, A. T., & Gero, J. S. (1998). Drawings and the design process. Design Studies, 19(4), 389–430. https://doi.org/10.1016/s0142-694x(98)00015-5
Reddy Gudur, R. (2016). Challenges in teaching design thinking skills to novice design students. In DS 83: Proceedings of the 18th International Conference on Engineering and Product Design Education (E&PDE16), Design Education: Collaboration and Cross-Disciplinarity.
Tang, H. H., Lee, Y. Y., & Gero, J. S. (2011). 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, 32(1), 1–29. https://doi.org/10.1016/j.destud.2010.06.004
Unger, D., & Eppinger, S. (2011). Improving product development process design: A method for managing information flows, risks, and iterations. Journal of Engineering Design, 22(10), 689–699. https://doi.org/10.1080/09544828.2010.524886
van Dijk, C. G. C. (1995). New insights in computer-aided conceptual design. *Design Studies*, *16*(1), 62–80. https://doi.org/10.1016/0142-694x(95)90647-x
Verstijnen, I. M., van Leeuwen, C., Goldschmidt, G., Hamel, R., & Hennessey, J. M. (1998). Creative discovery in imagery and perception: Combining is relatively easy, restructuring takes a sketch. *Acta Psychologica*, *99*(2), 177–200. https://doi.org/10.1016/s0001-6918(98)00010-9
Vidovics, B., Vukasinovic, N., Pavkovic, N. & Kovacevic, A. (2016). Development of methodology for distributed collaborative design environment. In: Proceedings of the 18th International Conference on Engineering and Product Design Education (E&PDE16), Design Education: Collaboration and Cross-Disciplinarity.
Vuletic, T., Duffy, A., Hay, L., McTeague, C., Pidgeon, L., & Grealy, M. (2018). The challenges in computer supported Conceptual Engineering Design. *Computers in Industry*, *95*, 22–37. https://doi.org/10.1016/j.compind.2017.11.003
Wallace, S., Le, B., Leiva, L. A., Haq, A., Kintisch, A., Bufrem, G., Chang, L., & Huang, J. (2020). Sketchy: Drawing inspiration from the crowd. *Proceedings of the ACM on Human-Computer Interaction*, *4*(CSCW2), 1–27. https://doi.org/10.1145/3415243
Wendrich, R. E. (2016). Hybrid design tools for conceptual design and design engineering processes: bridging the design gap: towards an intuitive design tool. [PhD Thesis -– Research UT, graduation UT]. University of Twente. https://doi.org/10.3990/1.9789036542272

Appendix A. Key pages of the Digital Product Development Toolkit

Appendix A is comprised of the key pages of the NMIS Online Product Development Toolkit at the time of research. For context, the user journey of the NMIS Online Product Development Toolkit is illustrated below (Figure 14). Subsequent Figures will explore each of the pages in more detail and highlight the app requirements that they meet.

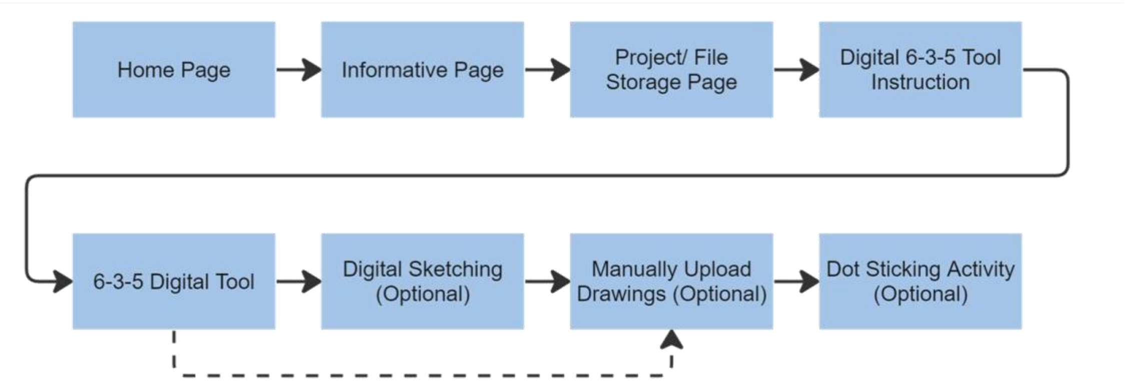

Figure 14. User Journey of the NMIS online PD toolkit app

Figure 15 below displays the home page of the NMIS Online Product Development Toolkit. Here users can learn more about the toolkit and stages of the product development process, filter the PDTs by the PD stages, and navigate to informative pages about each of the PD tools.

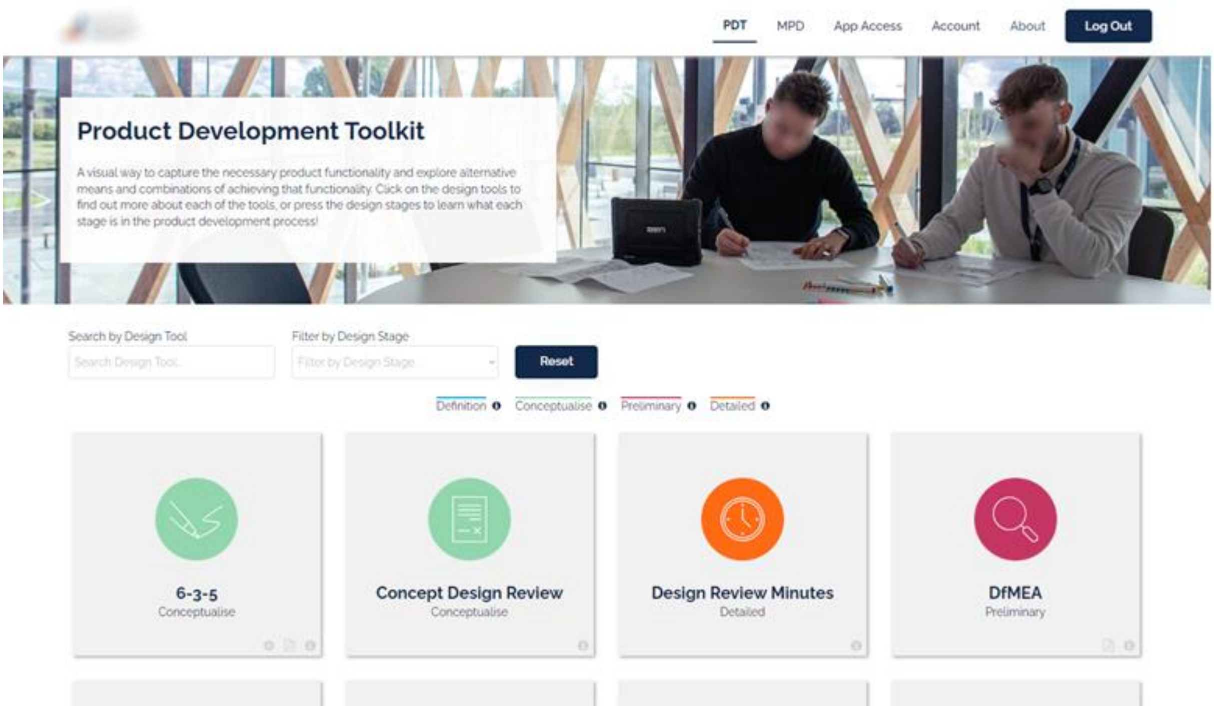

Figure 15. NMIS online PD toolkit: Home page

Figure 16 displays the 6-3-5 information pages that inform the user on what the tool is, how to use the tool, any perquisites, expected outcomes and next steps, who uses the tool, and where to use the tool in the PD process. This page is used to educate staff members, clients, and students on the tools within the PD process. Users then have the option to use the online digital tool.

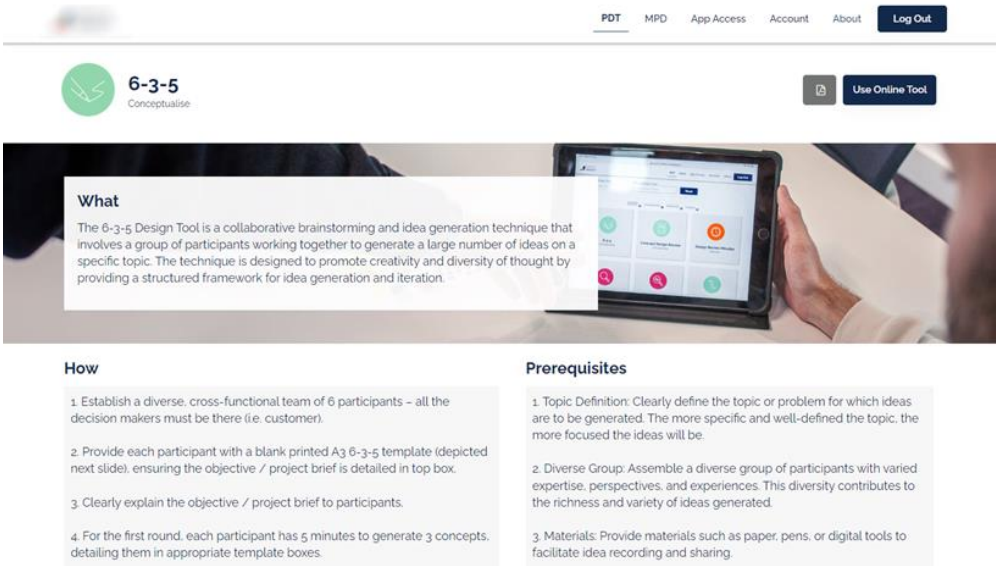

Figure 16. NMIS online PD toolkit: 6-3-5 informative page

Figure 17 displays where the projects and files are stored within the app, thus meeting requirement one of the app. Files can be added, deleted, and edited as desired. To open a file, users can click the 'Open' button.

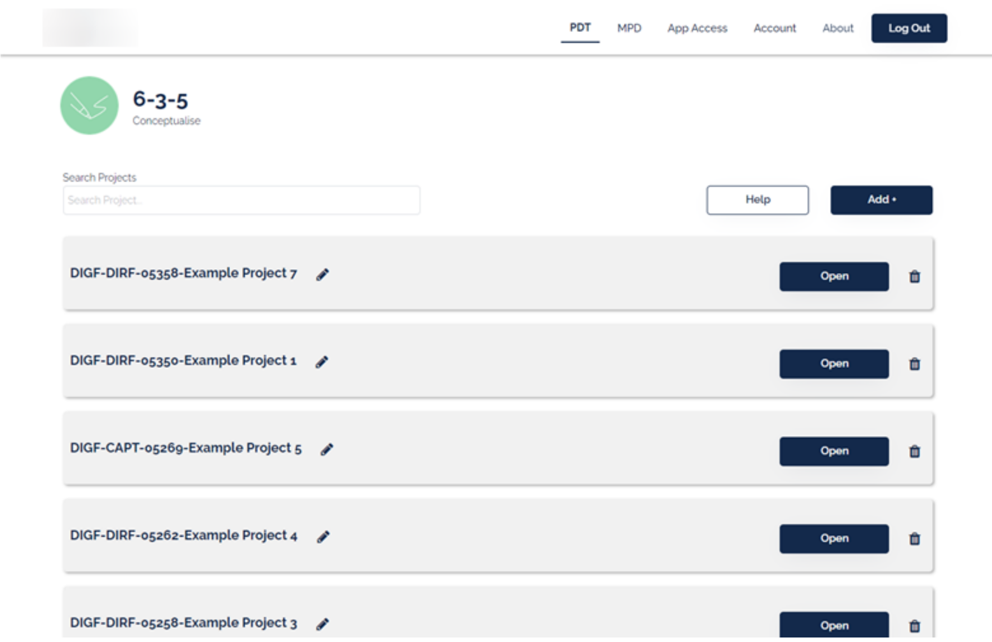

Figure 17. NMIS online PD toolkit: Project and file storage page

Users can click the 'Help' button which causes a pop-up to appear (Figure 18). The pop-up outlines how to use the digital online PDT in the app, and as a result, meets requirement three of the app.

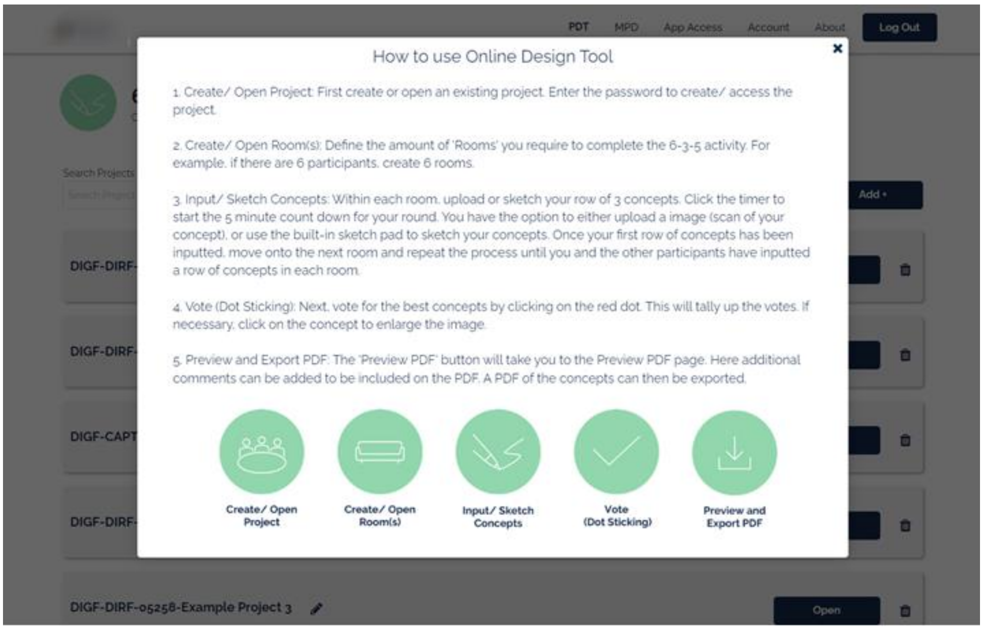

Figure 18. NMIS online PD toolkit: Digital 6-3-5 tool instructions

Within the digital 6-3-5 tool, users can add concepts to the page by clicking the 'Add' button as shown in Figure 19. This causes a pop-up to appear (Figure 20). The creator's name is also displayed for reference as multiple users can add concepts simultaneously, therefore meeting requirement two of the app. Users can delete rows of concepts as required.

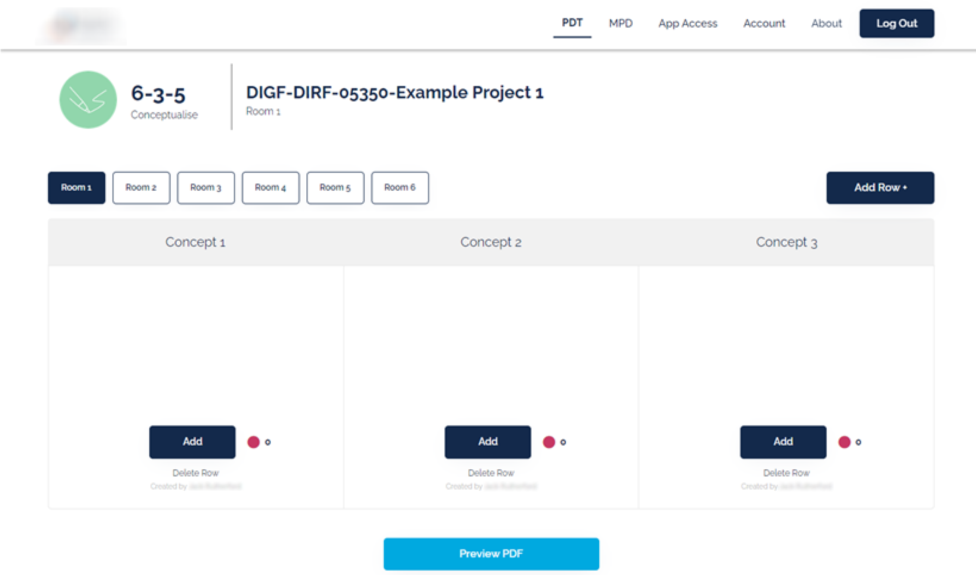

Figure 19. NMIS online PD toolkit: 6-3-5 digital tool

By clicking the 'Add' button, the following pop-up shown below appears. This allows users to start a 5-minute count down (as per the requirements of the 6-3-5 concept generation method), look at previous concepts for inspiration and use the digital sketch pad to draw concepts. Subsequently, requirement six of the app is met. The drawing module was designed to be simple, limiting the available options to select, and includes drawing, shape, and text tools. The colour can also be changed however its default option is black.

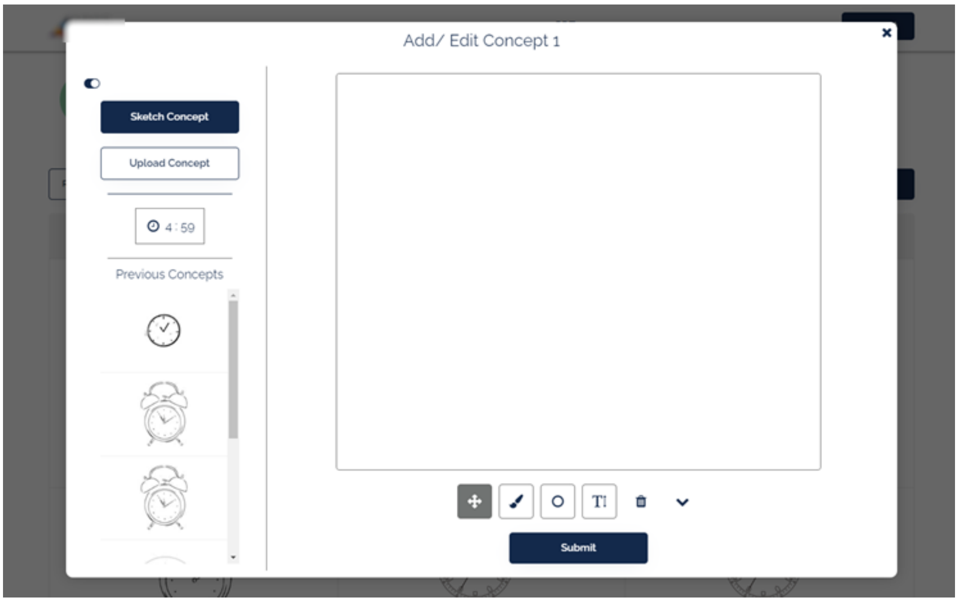

Figure 20. NMIS online PD toolkit: digital sketching

To adopt a hybrid approach, and meet requirement four of the app, users can alternatively upload concepts (Figure 21). This means users have the option to either use the digital sketch pad or use traditional methods using pen and paper and upload them to the app. Either way, the concepts are securely stored within the application.

Figure 21. NMIS online PD toolkit: Manually upload drawings

Once the 6-3-5 activity is concluded, users can undergo a digital dot-sticking activity. By clicking the red dots, users can vote on the concepts to take forward for further development (Figure 22).

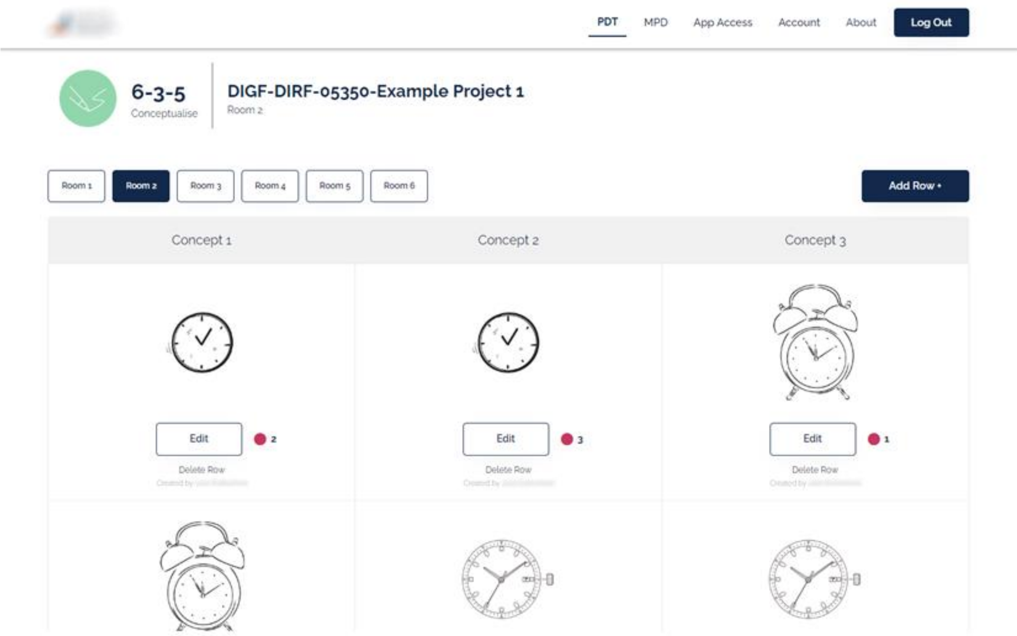

Figure 22. NMIS online PD toolkit: Dot sticking activity

Appendix B. Decision Trees

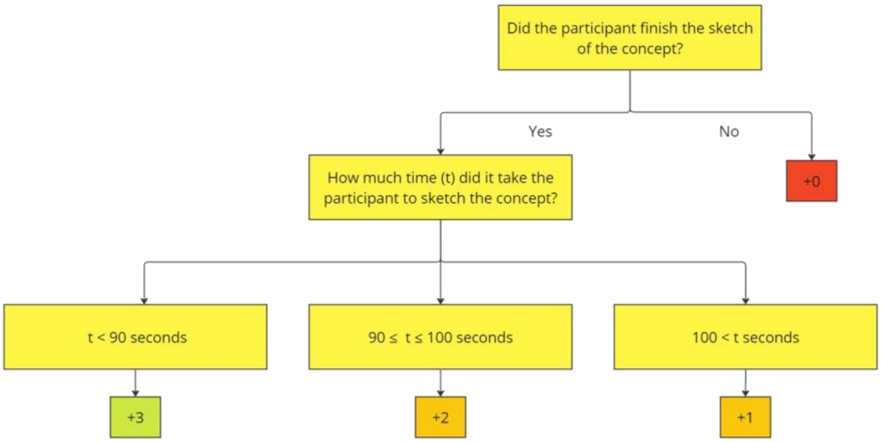

Figure 23. Decision tree to determine efficiency

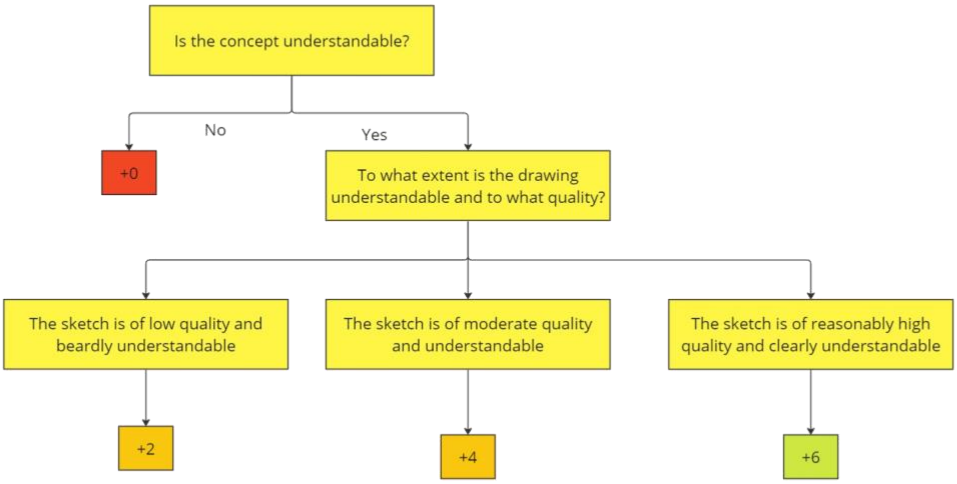

Figure 24. Decision tree to determine sketch quality

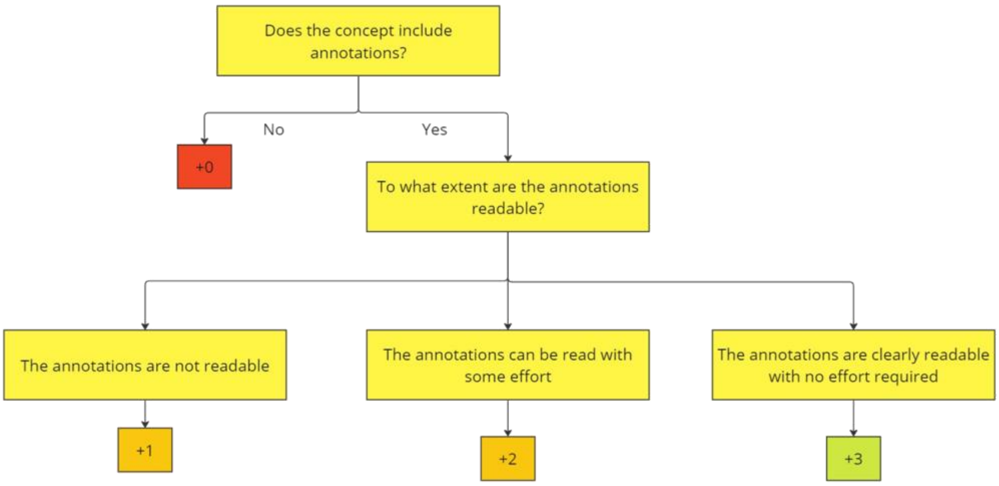

Figure 25. Decision tree to determine the detail of annotations

Design and Technology Education: An International Journal

29.3

Virtual Reality as a Supportive Tool for Design Education

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Somik Ghosh, University of Oklahoma, USA

Abstract

Immersive technologies have gained attention in design pedagogy due to their potential as effective tools for teaching and learning. Virtual reality (VR) has been extensively explored in the design discipline for tasks such as interpretation, visualization, and collaboration. However, most applications of VR have focused on replacing traditional teaching content but there is a lack of research on using VR as a supportive teaching tool. This study evaluated the effectiveness of VR as a supportive educational tool in design education. Employing a one-group pretest-posttest experimental design, the study assessed the impact of VR on learning technical and spatial knowledge among 60 sophomore students enrolled in the College of Architecture. The results showed significantly higher posttest scores following the utilization of VR content as a supportive tool supplementing traditional teaching content. This study also gathered participants' perceptions of using VR. The participants rated the quality of the VR content and the ease of use positively, while a few participants reported discomfort related to eye strain.

Keywords

Design education, Virtual Reality, VR technology, Technology integration, Immersive technology

Introduction

Immersive technologies have emerged as a topic of interest in literature related to pedagogy, particularly for their potential in teaching and learning. Since their introduction in the early twenty-first century, these technologies have been tested and applied across various fields, particularly where visualization is essential. In the design discipline, these technologies have been used and studied extensively for various applications. More specifically, virtual reality (VR), which is one such technology has been used for design interpretation and visualization, design collaboration, and design charette development (Ayer et al., 2016; Dalgarno & Lee, 2010; Zhang et al., 2020). While several studies have found VR to be beneficial for learning, other research suggests that it may not offer any significant advantages, leading to mixed perspectives (Beh et al., 2022; Jensen & Konradsen, 2018; Kim et al., 2021; Pedro et al., 2016).

In most cases, VR has been used to replace traditional content delivery (Ayer et al., 2016), substitute in-person field visits (Krakowka, 2012), and replace face-to-face design collaboration (Hong et al., 2016). In most studies, researchers compared learning outcomes between VR and traditional environments. However, many studies lacked proper controls to identify VR as the key factor behind improved learning (Lawson et al., 2024). Consequently, determining VR's true effect on learning has been challenging. In this research, the authors explored VR as a supportive tool to reinforce content taught in traditional environments. Instead of being primary instructional material, VR content can be effective supportive material after complementing the delivery of content in a traditional classroom setting (Olbina & Glick, 2022).

Supportive teaching-learning tools can be defined as additional information presented and stored in a variety of media and formats that assist in reinforcing the concepts to the learners (Mkhasibe et al., 2020).

Few digital tools such as social media, educational robotics, simulations, narrative-rich videos, and digital games have been tested as supportive tools (Kautsar & Sarno, 2019; Nikolopoulou, 2022; Stathopoulou et al., 2019) in early STEM learning, and they have been found to be beneficial. VR's effectiveness as a supportive learning tool in design education has not been investigated. Considering the effectiveness of VR in other domains, it can be expected to be an effective supportive learning tool, especially for fields such as design that heavily rely on spatial understanding.

Further, most studies have focused on the development, implementation, and usability evaluation of VR content but lacked empirical evidence based on experimental evaluation. The purpose of this study was to evaluate the effectiveness of VR as a supportive educational tool, particularly in design education, employing a one-group pretest-posttest experimental design. Given the objective of measuring the impact of VR as a supportive educational tool on students' learning in addition to traditional content delivery, the one-group pretest-posttest approach was deemed suitable for this study.

This study assessed the effectiveness of VR as a supportive educational tool for design education among 60 sophomore students enrolled in the College of Architecture at the University of Oklahoma, USA. Significantly higher posttest scores were observed following the utilization of VR content compared to pretest scores. The VR content was created by the first author of this study to align with the learning objectives of selected courses. Most of the participants positively rated the quality and the ease of use of the VR content, with a few reporting discomforts such as eye strain.

The rest of the document is structured as follows: the subsequent section presents a review of the literature concentrated on immersive learning tools, particularly those utilized in the design disciplines; the subsequent section outlines the methodology utilized in the study; followed by the results of the pretest-posttest and participant surveys, and lastly, the discussion synthesizes the findings and concludes by providing implications and suggestions for future research.

Literature Review

Digital tools and platforms like smartphones, social media, and cloud-based applications have become indispensable components of our daily routines. It is difficult to imagine life without these in the current days. In developed countries, young individuals are utilizing these technologies even before enrolling in university programs. Integrating these technologies into higher education is expected to benefit students (Lai & Hong, 2015), however available literature also points out associated issues with the use of digital media such as distraction during self-study (Ophir et al., 2009). A recent addition to these technologies is immersive environments. With projected market growth soaring, technology companies are making substantial investments in this area (De Regt et al., 2020).

Immersive Environments as Learning Tools

High-fidelity immersive environments allow users to completely immerse in the digital environment, especially using head-mounted displays (HMD). VR headsets completely replace users' natural field of view with a digital image, which creates the perception of being disconnected from actual surroundings and being immersed in the digital environment. Immersive environments have been found to have positive effects on learning (Jensen & Konradsen, 2018). Research indicates that immersive environments positively impact learning, with studies showing virtual environments as the most effective medium, followed by print media, while videos are considered the least effective (Ijaz et al., 2017). Even limited integration of VR through HMDs in classroom instruction had a positive impact on the performance of the students in comparison to those who only received traditional classroom instructions (Ray & Deb, 2016).

Research has demonstrated the effectiveness of VR in education compared to other mediums, particularly in contexts where understanding three-dimensional (3D) objects is essential (Dalgarno & Lee, 2010). For instance, healthcare educators have embraced VR technology for learning human anatomy, with the development of web-based interactive VR tools, which students found more engaging (Huang et al., 2010). These studies underscore the value of VR as both a visualization and learning tool.

Immersive Environment as Learning Tool in Design Education

Design education is traditionally imparted via design studios mainly based on a constructivist approach where educational material is not only lectured but learners have the opportunity to experience it in their own context. It also allows the learners to grasp it at their own speed. Ayer et al. (2016) stated that VR can be an effective tool for pedagogy used in design education. In design education, 3D models, whether digital or physical, are commonly utilized to enhance understanding of spatial characteristics and context. Unlike two-dimensional (2D) photographs, 3D models provide a more immersive visualization experience, although viewing them on a 2D screen may limit the level of immersion.

Alongside the recognized advantages of VR, a few drawbacks have been identified. Rashid and Asghar (2016) found that VR with HMDs was better for spatial awareness, but in-person teaching in a traditional classroom setting was better for memorizing facts. Additionally, Ijaz et al. (2017) noted that virtual environments require more time to learn compared to other mediums. Considering these limitations, instead of replacing the traditional teaching method with VR, it can be used as a supportive tool for design education. While books, prints, and videos serve as traditional supportive materials in design education, Milligan et al. (2018) suggest that textbooks have limited benefits unless learners can engage with them independently. On the other hand, young students spend a large amount of their time watching multimedia and playing video games and don't consider these activities to be boring. Considering both the advantages and limitations of VR and its potential as an effective supportive tool in education, the subsequent section explores VR's applications in learning domains within the field of design education.

Learning domains and immersive environments in AEC

In learning theories, Bloom's Taxonomy is widely recognized as one of the prominent frameworks. As per Bloom's taxonomy learning occurs in three main psychological domains: psychomotor, affective, and cognitive. The psychomotor domain relates to physical skills, the affective domain involves attitude, and the cognitive domain relates to mental skills. Several studies have evaluated the effectiveness of immersive environments as a teaching tool; Table 1 below provides a summary of studies on the effectiveness of VR across different domains of Bloom's Taxonomy for learning.

In the psychomotor domain, Chander et al. (2021) investigated the use of VR to improve postural stability while working at heights, highlighting its potential to mitigate workers' risk habituation. Albeaino et al. (2022) explored VR's effectiveness in enhancing drone navigation skills, reporting that the VR experience was stimulating. In the affective domain, Kim et al. (2021) studied the use of VR to improve vigilante behavior for onsite hazard reduction, finding VR effective in training. Similarly, Yan et al. (2022) examined VR's impact on willingness to participate in safety training, concluding that VR is effective in changing attitudes. In the cognitive domain, Beh et al. (2022) focused on building utility inspection, noting better knowledge gain and retention using VR. Lucas and Gajjar (2022) investigated VR's effectiveness in learning design and construction sequences, highlighting its positive impact on learning outcomes.

Table 1. Studies indicating the effectiveness of VR technology on learning domains per Bloom's taxonomy

Bloom's Psychological Domain for Learning	**Literature**	**Effectiveness tested for learning or improving**	**Findings**
Psychomotor	(Chander et al., 2021)	Postural stability while working at heights	Mitigates workers' risk habituation
	(Albeaino et al., 2022)	Drone navigation skills	The VR experience was found stimulating
Affective	(Kim et al., 2021)	Improving vigilante behavior for onsite hazard reduction	VR is effective in training
	(Yan et al., 2022)	Willingness to participate in safety training	VR is effective in changing the attitude
Cognitive	(Beh et al., 2022)	Building utility inspection	Better knowledge gain and retention by using VR
	(Lucas & Gajjar, 2022)	Construction sequence	The positive effect of learning

Overall, several studies suggest that VR can assist in enhancing learning across different domains of Bloom's Taxonomy, offering immersive and engaging experiences that facilitate knowledge acquisition and skill development in various contexts. It is worth noting that none of the environments in the studies discussed above were high-fidelity.

Research Objectives

Based on the literature review, it was evident that scholars have examined the effectiveness of virtual environments with varying degrees of immersive-ness. However, the existing body of literature does not support replacing the traditional methods of teaching with VR. Therefore, there is potential for VR to serve as a supplementary tool following the initial delivery of knowledge through traditional means. The current body of literature lacks evidence of VR's effectiveness as a supportive tool for design education. This study attempted to address this gap by testing the effectiveness of VR as a supportive tool in design education; the specific objectives are listed below:

Objective 1: How effective are high-fidelity virtual environments as a supportive learning tool for design education?

Objective 2: How do design students perceive the use of virtual reality as a supportive learning tool?

Methodology

The methodology adopted for this study was divided into two phases. The first phase consisted of several steps such as the selection of course topics to be used for the study, understanding the learning objectives of each selected topic, and creating VR content suitable for the identified learning objectives. Unlike previous studies that often created standalone special projects to test the effectiveness of VR, the authors integrated VR into existing courses. To identify suitable topics, the primary author collaborated with instructors teaching various courses in the College of Architecture at the University of Oklahoma, USA, focusing on areas requiring visualization, such as means and methods, and the history of contemporary architecture. The discussions with instructors also facilitated a clear understanding of the learning objectives associated with each topic, guiding the development of the VR models. Figure 1 below provides an overview of the first phase of the research methodology.

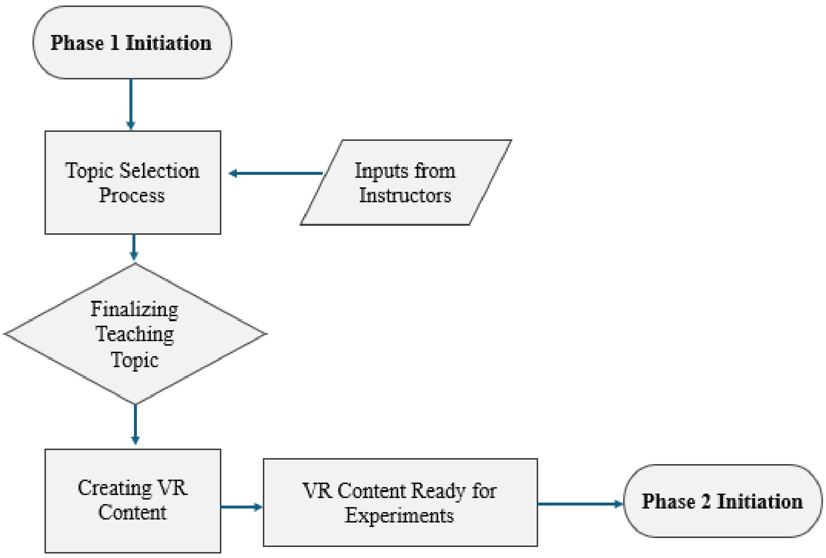

Figure 1. Overview of Phase I of the research methodology.

VR content creation (Phase I)

VR content for the selected courses was created by importing models from software such as SketchUp and Revit to Unreal Engine 5.2 (UE), a robust game design software renowned for creating AAA title games. 3D models created in modeling software such as SketchUp and Revit are not readily compatible with UE. The portability was facilitated with the help of the "Datasmith" plugin. Datasmith was installed in both the exporting and importing software (separate plugins for SketchUp and Revit). During the modeling process, careful attention was paid to segmenting elements and managing complexity to optimize rendering engine performance. Once the model was imported into UE, all the textures, lights, and sounds were added for an immersive experience. The textures from the UE library were used as they have high resolution compared to the textures from the modeling software. After the application of textures, the sound narrations and sound effects were added. All the sounds had adjusted attenuation radiuses to provide information about specific elements in the model. These narrations provided information about the model elements and navigational directions, fostering an immersive experience within the single-level environment, with no movement restrictions or teleportation constraints.

The first environment was created for the means and method course, which included the construction of several types of suspended ceilings (screenshot shown in Figure 2). Students were expected to understand the construction sequence, remember the standard dimensions and terminologies, and remember the different types of acoustic ceilings. This model showed several types of suspended ceilings with and without acoustical ceiling tiles. For a better view, the ceiling grid was lowered and kept at a height of three feet above the finished floor. An informative spot narration was added, and common terminologies and standard dimensions were visible on the walls of the room.

Figure 2. UE interface with environment #1.

The second environment, created for the history of architecture course, was the “Farnsworth House” designed by architect Mies Van Der Rohe. Farnsworth House is well known for its contribution to the modernist movement in architecture (Omneya & Fouad, 2018). From the Farnsworth House model, students were expected to learn about the spatial characteristics of the house, both from the interior and exterior. The Farnsworth House model featured all interior furniture but lacked curtains, deliberately omitted to provide the architect's intended spatial experience for students (screenshot shown in Figure 3). Students could virtually walk around, and inside the house to observe. General information about the designer and architectural style was delivered in a narration. Ambient sounds such as the crackling sound of the fireplace were added for a realistic experience. Throughout both virtual environments, students had the freedom to explore the surroundings at their own pace, walking or teleporting, thus understanding the true scale of the spaces.

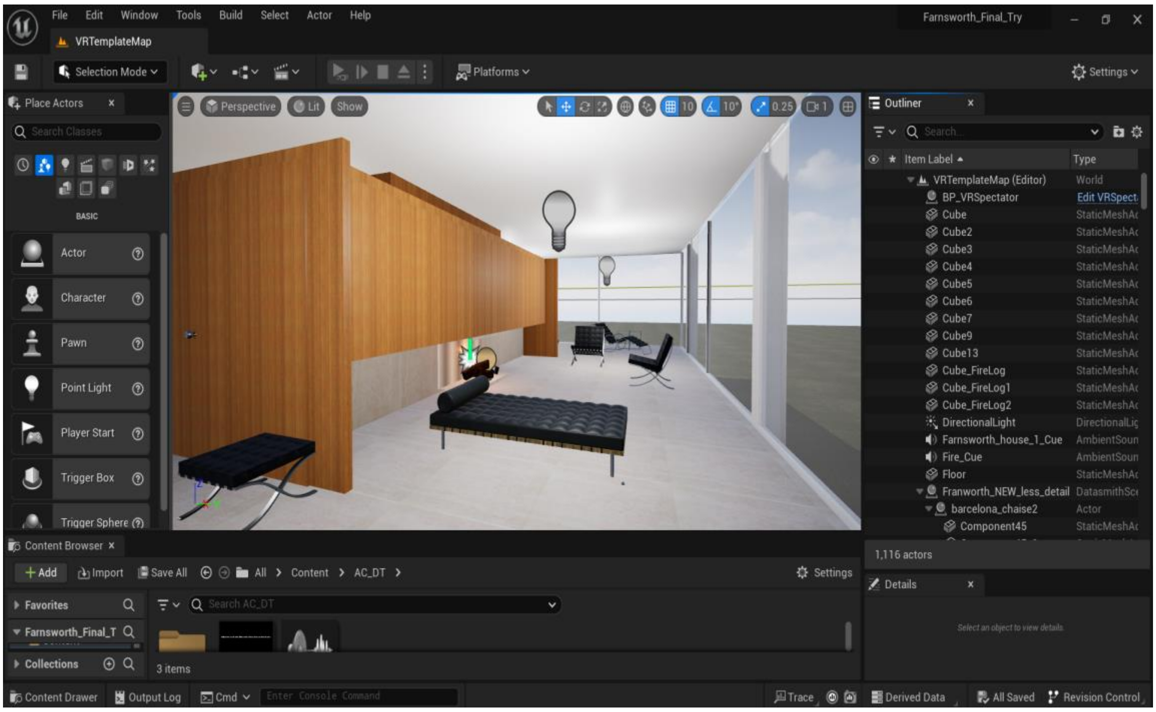

Figure 3. UE interface with environment #2.

Experiment (Phase II)

Phase II of the methodology included the recruitment of participants, setting up the experiment, and conducting the perception survey; the following section provides details of the steps undertaken.

Sample Selection

For this study, undergraduate students at the sophomore level were recruited from the College of Architecture at the University of Oklahoma, USA. When using Soper's (2020) A-priory sample calculator, with an effect size of 0.7, a statistical power level of 0.8, and a probability level of 0.05, the minimum required sample size is 68. Additionally, considering the undergraduate student population in the design disciplines at the College of Architecture to be 350, with a confidence interval of 95% and a margin of error of 10%, the required sample size was 76. A total of 115 students were invited, and 60 students agreed to participate in the study, falling short of the required sample size. A post-hoc calculation of the margin of error for the 60 responses resulted in a margin of error higher than the initially considered 10% for sample size estimation. This margin was deemed acceptable for this study since no inferential statistics were used to generalize the results.

Experiment Design

For this study, a one-group pretest-posttest design was adopted. In this experimental design, the dependent variable was measured before and after the treatment to measure the effect. If the average posttest score is better than the average pretest score, then it can be concluded that the treatment might be responsible for the improvement. Despite the inherent limitation, the authors chose the one-group pretest-posttest design for two reasons: firstly, the study aimed to explore VR's impact as a supportive educational tool rather than being the primary content; secondly, integrating VR into existing courses made it impractical to create a control group that would be deprived of the access to VR.

Participants learned the selected topics in a traditional classroom environment as per the class schedule. After the traditional lecture-based learning, the participants completed the pretest questionnaire, which was designed to capture the participants' understanding based on the traditional educational delivery. During the pretest, participants were not allowed to consult any course materials. The purpose of the test was to assess their understanding of the subject matter and their readiness to work on subsequent assignments that required this foundational knowledge. After a week from the pretest, the participants used the virtual environments as supportive educational tools. Participants accessed the VR content for 10 minutes using Meta Quest 2. Participants were able to walk a few steps, rotate, and look around 360 degrees freely. After accessing the VR content, the posttest was conducted. Along with posttest questions, perceptions of participants about the VR environment were recorded using a separate questionnaire. Figure 4 below depicts the overall research methodology adopted in this study.

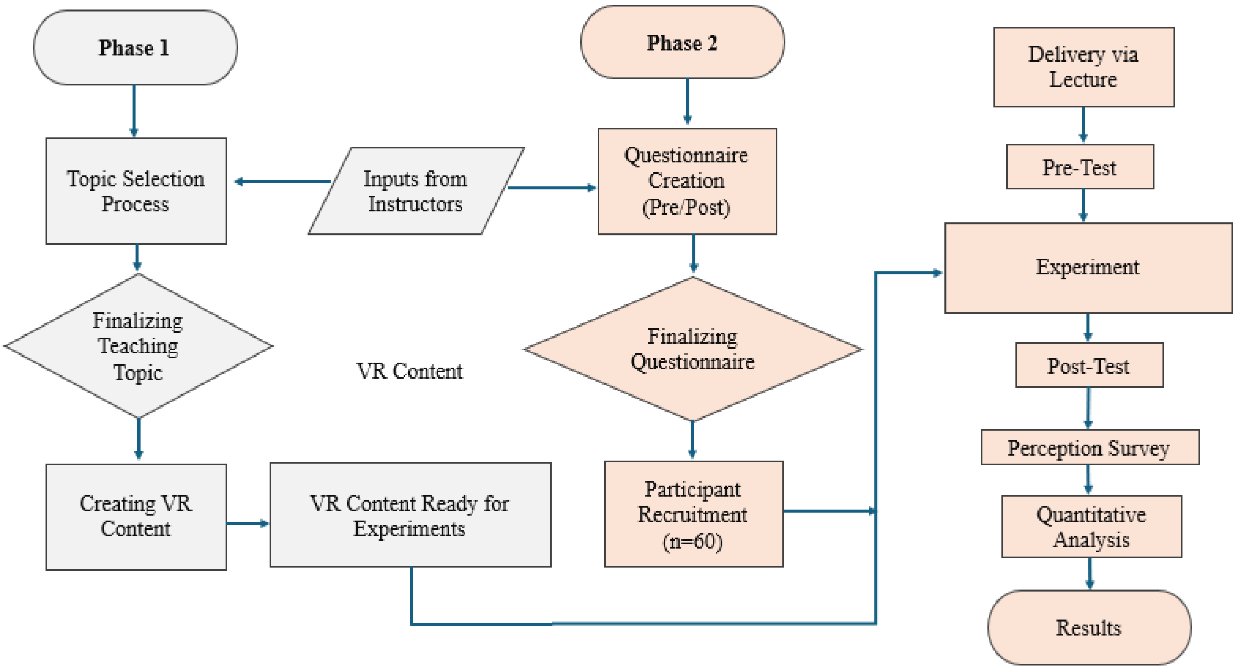

Figure 4. Flowchart depicting the research methodology.

Test instrument:

The pre-test and post-test instruments were designed to assess various aspects of the topical content. For the content on interior ceiling construction, the first question evaluated students' knowledge of the major classification of ceiling systems. The second question focused on recalling technical terminologies by asking for the technical names of the spaces above the suspended ceiling. The third question required students to identify three key components of a suspended ceiling system. The fourth question tested their ability to arrange these components in the correct construction sequence. Finally, the fifth question assessed their retention of technical specifications by asking for the maximum allowable spacing between ceiling hangers.

For the second environment, students were asked the following true or false questions: (1) Do all interior walls of the Farnsworth House touch the ceiling? (2) Is there one flight of stairs to the main floor? (3) Does the Farnsworth House have a fireplace? These questions aimed to assess the student's observational skills regarding key architectural elements, as images of both the interior and exterior of the house were shown in lecture slides. In contrast, the final two questions were designed to assess spatial perception. Students were asked if they felt the house provided a sense of protection and if it appeared stable, heavy, and firmly attached to the ground. This line of questioning followed a class discussion comparing the Farnsworth House with Adolf Loos's Steiner House, where the lack of comfort and security in the Farnsworth House was highlighted.

Results & Analysis

Pretest and posttest data were collected from the participants (n=60) who engaged with VR content as a supportive educational tool. Statistical analysis was conducted using SPSS software. Descriptive statistics including mean and standard deviation were calculated; the average of the pretest scores was 2.37 out of 5 (standard deviation = 0.91, median = 2) and the average of the posttest scores was 3.51 out of 5 (standard deviation = 1.35, median =4). The students completed the pretest immediately after the topics were introduced in the lectures. They could access the VR content as supplementary material before taking the posttests. Both the pretests and posttests were evaluated by the respective course instructors to ensure that the questions aligned with the topics covered in lectures. Table 2 below presents the distribution of scores among the students who participated in the experiment. The results indicate a significant increase in the number of students achieving 90% or higher on the posttest compared to the pretest. Additionally, the proportion of students scoring below 60% decreased considerably in the posttest compared to the pretest.

Table 2. Comparison of students' scores in pretest and posttest

Students' Score	Pretest Number of Students (%)	Posttest Number of Students (%)
≥ 90%	0	18 (29%)
80% - 89%	7 (11%)	17 (28%)
70% - 79%	0	0
60% - 69%	19 (31%)	12 (20%)
≤ 60%	34 (57%)	13 (22%)

A paired sample t-test was performed to determine the significance of improvement in post-test scores compared to pretest scores. Paired sample t-test showed a significant improvement in posttest scores compared to pretest scores [$t(60)=6.211$, $p<.001$]. Refer to Table 3.

Table 3. Results of paired sample t-test

Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Significance p
			Lower	Upper			
1.143	1.09	.184	.769	1.517	6.211	59	<.001

Responses of the participants to the survey about the use of VR were analyzed to check for any correlation with their performances. A non-significant positive correlation was found between motivation to use VR and improvement in performance.

Perceptions of the Participants on the Use of VR

The participants were surveyed to assess their perceptions regarding satisfaction and discomfort associated with VR usage. Perception was measured through four questions, covering aspects such as familiarity with VR, level of immersion, attitude towards VR usage, and discomfort experienced during VR use (Appendix I). Out of 60 participants, 14 (23%) had no prior exposure to VR, while 25 (41.6%) had used it once, and 3 participants (5%) indicated regular weekly VR usage. None of the participants reported daily VR engagement. Regarding attitudes towards VR usage, more than half of the respondents (53%) expressed excitement about utilizing VR technology. In response to the question regarding the perceived value of VR content, 17 participants (28%) affirmed its value-addition, with another 18 respondents (20%) expressing curiosity about the technology's potential. No participant mentioned rushing through the activity or finding it boring. Very few of the participants (11%) reported experiencing dizziness and discomfort while using VR, highlighting potential concerns regarding the adverse effects associated with prolonged VR usage. Table 4 below summarizes the responses of the participants regarding ease of use, clarity of the VR environment, strain on eyes, dizziness, and any facial discomfort.

Table 4. Summary of Responses (Scale 1 = min, 5 = max.)

N=60	**Ease of Use**	**Clarity & Quality**	**Strain on Eyes**	**Dizziness**	**Facial Discomfort**
Mean (SD)	4.25 (1.84)	4.46 (0.78)	2.13 (1.25)	2.00 (1.26)	2.41 (1.28)
Median	4	5	2	2	2
Mode	5	5	1	1	2

Discussion

The objective of this study was to explore whether VR fits into the role of being a supportive tool in design education, especially for topics requiring 3D visualization or special understanding of buildings and building elements. Digital technology-friendly students and the prevalence of advanced HMDs at an accessible price have created a conducive environment for integrating immersive technologies in education. While most prior studies have assessed the effectiveness of VR as a substitute for conventional teaching, its potential as a supportive educational tool remains largely unexplored. Design education typically relies on traditional supportive tools such as books, drawings, notes, and diagrams. This gap in the current literature prompted the need to examine the efficacy of VR as a supportive tool in enhancing design education.

A pretest-posttest experiment was used to measure the effect of VR on participants' improvement in learning both spatial and technical knowledge. Participants in the study received instruction on both topics through conventional methods, including slide presentations featuring text, drawings, and photographs. While instructors did not integrate VR into their teaching methods, participants were provided with VR materials as supplementary resources. The improvement in the posttest scores (average of 3.51 out of 5 compared to 2.37 out of 5 in the pretest) could be largely due to the use of VR supplemental content. The improvement in test scores aligns with previous studies highlighting the benefits of immersive environments in design education that involve viewing 3D content, and VR has been claimed as a better way of learning 3D content based on visual memory (Schurgin, 2018; Lindner et al., 2009). The results of this study demonstrate the impact of supplemental materials delivered through VR. While the findings suggest that VR contributed positively, the exact extent of its effect cannot be definitively determined due to the absence of a control group in the pretest-posttest experimental design.

Previous studies have indicated VR's efficacy across various domains of Bloom's taxonomy (Chander et al., 2021; Albeaino et al., 2022; Kim et al., 2021; Lucas & Gajjar, 2022). The finding of this study provides additional evidence of VR's effectiveness not only in enhancing spatial comprehension but also in learning and retaining technical knowledge pertinent to construction, including the sequencing of construction processes, terminology, and dimensional aspects. Furthermore, visuospatial memory, as posited by Lindner, Blosser, and Cunigan (2009), emerges as a pivotal cognitive mechanism over visual memory alone. This suggests that the integration of VR technology not only enhances learners' understanding but also promotes deeper retention of learned concepts compared to traditional methods of teaching relying solely on visual or auditory stimuli.

This study also gathered participants' perceptions of using VR. The user experience of a virtual environment is dependent on the quality of telepresence, ease of use, and discomfort faced by the users (Kim et al., 2021). The participants rated the quality of the VR content and the ease of use positively. Discomfort, mainly eye strain was mentioned by a few participants. For this study, the participants were viewing the VR content for around 10 minutes only. Instructors need to be mindful of the discomfort to the eyes as it can aggravate if the students are expected to view the content for a longer duration. On the other hand, much more complex information can be imparted through VR content in considerably less time than other supportive material such as books, prints, and videos. The use of visuospatial stimuli and motivation to use the VR content can be the responsible factors for this improved effectiveness. During experiments, participants who had used the VR headsets previously were found to be more confident in using the technology, and they also explored the VR content for a longer time. This infers that familiarity doesn't lower the motivation to use the technology.

Though the VR content was found to be effective and the technology easy to use, there are several challenges. Firstly, VR seems useful for topics where spatial and 3D understanding is required, which limits its application. Secondly, VR shows content on a real scale, which means viewers view content in perspective. For a few complex topics, drawings such as isometric and axonometric are used because they simplify the perspective and help to understand the dimensional scale better. This makes it inevitable to use other supportive materials or to include technical drawings, such as isometric, in VR content. In addition, the VR content creation process is time-consuming making it challenging for instructors to create VR content by themselves. Also, if the content is not created by a professional, it becomes difficult to handle the graphics by the HMD without the help of a computer with a graphics processing unit (GPU). For this study, the VR content was created and projected using a laptop with 12th generation i7 with RTX3070 GPU (6 GB). Even with this configuration, the laptop's temperature rose to 95 degrees Celsius after using the VR content for 20-30 minutes. However, none of these challenges seem impossible to overcome.

Conclusion

This research explored the pedagogical value of using immersive technology as a supportive learning tool for architectural educational content. To understand its effectiveness, two learning environments focusing on two different topics were developed. After testing it with 60 students several noteworthy conclusions were drawn. Analysis of pretest and post-test data suggested that VR is effective as a supportive learning tool for architectural educational content. Students showed improvement in retaining technical information after using VR, this information includes the sequence of construction, trade-specific terminologies, standard dimensions, and names of the construction materials. The perception survey expressed minimal issues with discomfort, mainly strain on the eye, during the use of VR. A positive correlation between motivation to use VR and improvement on post-test reveals one of the reasons for the effectiveness of VR as a supportive tool. Overall, motivation to use VR helped in better observation prompting improved knowledge gaining. This is in line with the findings of the literature review, where VR is found to be beneficial in two main learning domains of Bloom's Taxonomy. Overall, this study contributes by addressing a gap in current literature by testing the effectiveness of immersive technologies as a supportive tool in education, particularly in the field of design. The results suggest that VR has the potential to enhance learning outcomes and student engagement. Future research could explore additional factors influencing the effectiveness of VR, such as different pedagogical approaches in the design of VR environments and interactivity levels. Additionally, further investigation into user comfort and VR content creation techniques will be essential for the implementation of VR as a supportive tool in education.

Acknowledgment

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References

Albeaino, G., Eiris, R., Gheisari, M., & Issa, R. R. (2022). DroneSim: A VR-based flight training simulator for drone-mediated building inspections. Construction Innovation, 22(4), 831-848.

Ayer, S. K., Messner, J. I., & Anumba, C. J. (2016). Augmented Reality Gaming in Sustainable Design Education. Journal of Architectural Engineering, 22(1), 04015012. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000195

Beh, H. J., Rashidi, A., Talei, A., & Lee, Y. S. (2022). Developing engineering students' capabilities through game-based virtual reality technology for building utility inspection.

Engineering, Construction and Architectural Management, 29(7), 2854–2877. https://doi.org/10.1108/ECAM-02-2021-0174

Chander, H., Shojaei, A., Deb, S., Kodithuwakku Arachchige, S. N. K., Hudson, C., Knight, A. C., & Carruth, D. W. (2021). Impact of Virtual Reality–Generated Construction Environments at Different Heights on Postural Stability and Fall Risk. Workplace Health & Safety, 69(1), 32–40. https://doi.org/10.1177/2165079920934000

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? British Journal of Educational Technology, 41(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.

De Regt, A., Barnes, S. J., & Plangger, K. (2020). The virtual reality value chain. Business Horizons, 63(6), 737–748. https://doi.org/10.1016/j.bushor.2020.08.002

Hong, S. W., Jeong, Y., Kalay, Y. E., Jung, S., & Lee, J. (2016). Enablers and barriers of the multi-user virtual environment for exploratory creativity in architectural design collaboration. CoDesign, 12(3), 151–170. https://doi.org/10.1080/15710882.2015.1081239

Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, *55*(3), 1171–1182. https://doi.org/10.1016/j.compedu.2010.05.014

Ijaz, K., Bogdanovych, A., & Trescak, T. (2017). Virtual worlds vs books and videos in history education. *Interactive Learning Environments*, *25*(7), 904–929. https://doi.org/10.1080/10494820.2016.1225099

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. Education and Information Technologies, 23(4), 1515–1529. https://doi.org/10.1007/s10639-017-9676-0

Kautsar, I. A., & Sarno, R. (2019). A Supportive Tool for Project Based Learning and Laboratory Based Education. International Journal on Advanced Science, Engineering and Information Technology, 9(2), 630–639. https://doi.org/10.18517/ijaseit.9.2.7067

Kim, N., S. M., & Anderson, B. A. (2021). Reducing Risk Habituation to Struck-By Hazards in a Road Construction Environment Using Virtual Reality Behavioral Intervention. J. Constr. Eng. Manage.

Krakowka, A. R. (2012). Field Trips as Valuable Learning Experiences in Geography Courses. Journal of Geography, 111(6), 236–244. https://doi.org/10.1080/00221341.2012.707674

Lai, K., & Hong, K. (2015). Technology use and learning characteristics of students in higher education: Do generational differences exist? British Journal of Educational Technology, 46(4), 725–738. https://doi.org/10.1111/bjet.12161

Lawson, A. P., Martella, A. M., LaBonte, K., Delgado, C. Y., Zhao, F., Gluck, J. A., ... & Mayer, R. E. (2024). Confounded or controlled? A systematic review of media comparison studies involving immersive virtual reality for STEM education. *Educational Psychology Review*, *36*(3), 69.

Lindner, K., Blosser, G., & Cunigan, K. (n.d.). Visual versus auditory learning and memory recall performance on short-term versus long-term tests. 8.

Lucas, J., & Gajjar, D. (2022). Influence of virtual reality on student learning in undergraduate construction education. International Journal of Construction Education and Research, 18(4), 374–387. https://doi.org/10.1080/15578771.2021.1931570

Milligan, L. O., Koornhof, H., Sapire, I., & Tikly, L. (2018). Understanding the role of learning and teaching support materials in enabling learning for all. *Compare: A Journal of*

Comparative and International Education, 1–19. https://doi.org/10.1080/03057925.2018.1431107

Mkhasibe, R. G., Khumatake, M. R., Olaniran, S. O., & Maphalala, M. C. (2020). Availability of and access to learning and teaching support materials in teaching the accounting component of economic and management sciences. *PONTE International Journal of Science and Research*, *76*(12)

Nikolopoulou, K. (2022). Digital Technology in Early STEM Education: Exploring Its Supportive Role. In S. Papadakis & M. Kalogiannakis (Eds.), STEM, Robotics, Mobile Apps in Early Childhood and Primary Education: Technology to Promote Teaching and Learning (pp. 103–115). Springer Nature. https://doi.org/10.1007/978-981-19-0568-1_6

Olbina, S., & Glick, S. (2022). Using Integrated Hands-on and Virtual Reality (VR) or Augmented Reality (AR) Approaches in Construction Management Education. International Journal of Construction Education and Research, 1–20. https://doi.org/10.1080/15578771.2022.2115173

Omneya M, & Fouad, S. S. (2018). Modernism'S Influence On Architect-Client Relationship: Comparative Case Studies Of Schroder And Farnsworth Houses. https://doi.org/10.5281/ZENODO.1475018

Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences*, *106*(37), 15583–15587. https://doi.org/10.1073/pnas.0903620106

Pedro, A., Le, Q. T., & Park, C. S. (2016). Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality. Journal of Professional Issues in Engineering Education and Practice, 142(2), 04015011. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000261

Rashid, T., & Asghar, H. M. (2016). Technology use, self-directed learning, student engagement and academic performance: Examining the interrelations. *Computers in human behavior*, *63*, 604-612.

Ray, A. B., & Deb, S. (2016). Smartphone Based Virtual Reality Systems in Classroom Teaching—A Study on the Effects of Learning Outcome. *2016 IEEE Eighth International Conference on Technology for Education (T4E)*, 68–71. https://doi.org/10.1109/T4E.2016.022

Schurgin, M. W. (2018). Visual memory, the long and the short of it: A review of visual working memory and long-term memory. Attention, Perception, & Psychophysics, 80(5), 1035–1056. https://doi.org/10.3758/s13414-018-1522-y

Soper. (2020). *Soper, D.S. (2020) A-Priori Sample Size Calculator for Structural Equation Models [Software]. - References—Scientific Research Publishing*. Soper's A-Priori Sample Size Calculator. https://www.scirp.org/reference/referencespapers?referenceid=2697958

Stathopoulou, A., Siamagka, N.-T., & Christodoulides, G. (2019). A multi-stakeholder view of social media as a supporting tool in higher education: An educator–student perspective. European Management Journal, 37(4), 421–431. https://doi.org/10.1016/j.emj.2019.01.008

Yan, X., Li, T., & Zhou, Y. (2022). Virtual Reality's Influence on Construction Workers' Willingness to Participate in Safety Education and Training in China. Journal of Management in Engineering, 38(2), 04021095. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001002

Zhang, Y., Liu, H., Kang, S.-C., & Al-Hussein, M. (2020). Virtual reality applications for the built environment: Research trends and opportunities. Automation in Construction, 118, 103311. https://doi.org/10.1016/j.autcon.2020.103311

Appendix I

Q: How familiar are you with virtual reality (VR)?

Never used it
Used it once
Used it several times
Use it every week
Use it every day

Q: Answer the following questions related to the level of immersion in the VR environment on a scale of 1 to 5 (1 = minimum, 5 = maximum)

Items	**1**	**2**	**3**	**4**	**5**
How clearly could you visualize the building elements?					
How real was the feeling of being in the space?					

Q: Rate your experience of using the VR environment on a scale of 1 to 5 (1 = minimum, 5 = maximum)

Items	**1**	**2**	**3**	**4**	**5**
Ease of navigation in the VR environment					
Visual clarity and rendering quality of the VR environment					

Q: Rate your experience related to discomfort while using the VR environment on a scale of 1 to 5 (1 = minimum, 5 = maximum)

Items	**1**	**2**	**3**	**4**	**5**
Strain felt on your eyes when in the VR environment					
Dizziness felt during navigating the VR environment					
Discomfort on your face when using the headset to navigate the VR environment					

Book Review

Remke M. Klapwijk, Jianjun Gu, Qiuyue Yang and Marc J. de Vries (Eds.) (2003). Maker Education meets Technology Education: Reflections on Good Practice. Brill Academic Publishers

Reviewed by Marion Rutland, UK

This book brings together Maker Education and Technology Education through the reflections and presentations of good practice by a range of authors from around the world.

Part 1: The rise of Maker Education across the world

1 Introduction

Remke M. Klapwijk and Marc J. de Vries

This very interesting and thoughtful book begins by noting that *learning by making* has 'swung like a pendulum back and forth through history but argues that recently it has gained momentum through the Maker Movement. This has re-evaluated 'making' so that it enables the learning of a variety of skills, as well as scientific concepts in informal formal concepts contexts. Signature pedagogies, including 'playful pedagogies' focusing on collaboration and the celebration of learning through productive mistakes provide new opportunities and inspiration. The book including case studies from around the world that outline different themes associated with Maker Education in relation with Technology Education with reflections and thematic comparisons of actual practice by a number of authors.

2 The Development and Evolution of Maker Education in China

Jian Gu and Qiuyue

This chapter considers that Maker Education is an increasingly important aspect of a universal education. It is an effective way of cultivating students' communication, cooperation, innovative ability and crucial thinking in the 21st century. The chapter describes the emergence, evolution and development of Maker education in China. Chinese Maker education has a long history from Xingzhi Tao, the pioneer of modern Chinese education in the early 20th century. In 1927 he gave a speech in Shanghai called 'Creative education', arguing that 'doing' is the beginning and 'creation' and completion of Chinese education.

The chapter traces developments in the Chinese educational system to the national education reforms of the 1990s when Maker education took root and gradually developed in the 21st century and a move from factor and investment to innovation-driven, innovative education. Maker education became the source of economic development. The chapter goes on to describe reforms in 2013 and 2014 to the curriculum reforms for senior high schools and various disciples that resulted in *The General Technology Curriculum Standards for Senior High schools* (2017) and further developments through to the present day.

Reference: Ministry of Education China (2017) *General Senior High School Curriculum Program and Standards* 1st Edition.

3 A Participatory Design Approach to Sustaining Makerspace Initiatives

Katrine Holm Kanstrup, Ole Sejer Iversen, Maarten Van Mechelen, Christian Dindler and Marie-Louise Wagner

The chapter outlines a six-step framework developed by eleven Danish municipalities and a private foundation for sustaining makerspace initiatives by means of a participatory process. The aim was to create sustainable infrastructures the initiatives that provided makerspaces with a shared vision, considering the individual ambitions and circumstances of the municipality.

A six-step framework was developed based on research into Participatory Design (PD). The infrastructure included the technical structures, organisational, political and personal structures needed for long term success. All eleven initiatives makerspace initiatives were in formal educational settings and included schools, municipality libraries and educational institutions. The PD design tradition, originating in Scandinavia emphasises the direct and continuous involvement of future users and stakeholder in the design process and integrates concerns for designing physical and digital spaces, educating and creating organisational commitment. The participatory approach for sustaining maker initiatives derives from Danish research from 2019 to 2021.

Funding was provided from a private foundation for a period of three to five years, with two-to-three-day workshops of 12-30 participants run in the eleven municipalities. There was a director of education, project lead, makerspace manager, school principal, teachers, project partners, funding agency and university researcher. Six steps towards Sustaining Makerspace Initiatives were identified from the eleven makerspace workshops. These were understanding the complexity of the initiative; hands-on introductions to makerspace education; establishing a grand narrative for a makerspace initiative; developing a makerspace initiative within an existing municipality landscape; confirming and articulating management support and then choosing and purchasing technologies for the makerspace.

As a result, the funding agencies decided that six new municipalities would follow the steps in 2021, and 2022. It was emphasised that school systems, funding agencies have different approaches and requirements, and the willingness and culture of collaboration would be different across countries. Finally, that the six-stage framework requires substantial funding in relation to planning time, stakeholders' participation, expert engagement and access to existing makerspace initiatives.

Part 2 Case studies on Maker Education

4 Informal Learning in a Public Library Makerspace for Youth in the Netherlands

Monique Pijls, Tom van Eijck and Bert Bredeweg

This chapter focused on how informal learning spaces create opportunities for children to develop their talents, experience new social roles and where former librarians or other professionals provided informal learning of children in makerspaces for children aged 8-12 years. In recent years, museums and libraries in the Netherlands have established makerspaces in various urban areas to enable young people, sometimes from lower socio-economic status and little access to technology or creative resources at home, to develop their digital skills in conjunction with their creativity. The Amsterdam Public Library created a network of ten makerspaces where children could attend school and after-school programmes and provided training for the makerspace coaches.

The project Maakplaats2 was monitored through a formal research project and 123,826 children visited the after-school programme between 2017 -2020 with a gender balance of 50/50. 27 interviews with children and 12 makerspace coaches were analysed. All after-school activities took place on weekday-afternoons for 15 children guided by two to three makerspace coaches, often recruited from library staff and sometimes student teachers. The programmes consisted of ten weekly classes comprising digital fabrication and tinkering, designing, community art programming/coding often based on a theme.

Eight examples described typical examples of learning in the public library makerspace. In *Developing Skills by creating Creatures* nine children learnt to work with a laser-cutter and sewing machine, Tinkercad software for the 3D printer, Inkscape and a sticker cutter. They designed their own animal, cutting the fabric with a laser cutter and designing small accessories such as eyes. The children were motivated, developed technical skills and creativity, were in a safe place and the activities were structured and focused on individual development.

Another example 'Codeteam', was an activity for eight children working in groups of two or three and called *Making a Robot to help Granma'*. It was a ten-week programme about coding and programming. In 'The Beach' there was collaborative community programme led by the cultural foundation. Some clothing and accessories made by the children were sold at the local market. The tasks were open, and the children had the freedom to come up with ideas and multiple solutions instead of only one *correct* answer.

Essentially, the maker space provided opportunities for children to learn and get acquainted with creativity and technology. The after-school programmes helped motivate, improve confidence and stimulate the children. The makerspace was embedded in the community and needed continuous professional development and cooperation with local organisations, institutions and universities. After-school programmes fulfilled an important role in motivation and the development of talents. It was acknowledged that after school makerspaces put high demands on staff and require time, training and support. Challenges included continuity, finances, keeping children in contact with the makerspace as they grow older and maintaining the service free to children.

5 Using 'EcoMakerKits' to stimulate Maker Mindset and Circular Thinking in Mexico

Alvaro Nunez-Solis, Suneel Madahar, Nathan Eskue and Miroslava Silva-Ordaz

In this chapter Maker Education focused on using e-waste to stimulate the Maker Mindset and Circular Thinking of primary children in a Mexican context. The use of 'Eco-Maker Kits' was explored to see if they enabled or hindered the learning concept of Circular Thinking and Maker Mindset through basic electronics hands-on experiences with waste materials. 'The EcoMakerKits' helped expand the Maker Mindset of the children through assembling artefacts and electronic circuits. They built on their technical skills and motivation to tackle global issues such as electronics waste and the importance of reusing, repairing and repurposing.

The Circular Economy thinking was based on the principles of design, repair and reuse to keep products and materials in use. In recent years there had been a rise in the purchase and waste of electronic and Circular Thinking and Maker aimed to address this issue by developing more sustainable products. The Maker Education mindset was based on the skills, attitudes and knowledge that fosters active learning, curiosity, engagement, playfulness and resourcefulness to transfer their ideas into tangible artefacts.

How sustainability and especially Circular Thinking approach, can be added to STEAM renamed as STEAMS was explored. STEAMS is a project-based approach to create artefacts made from reused, repurposed or repaired objects. Young children were given the opportunity to wonder and explore technological skills such as electric circuits, multimedia, tinkering and engineering computational thinking, creativity, communication, collaboration and critical skills. The aim was to make the new generation in Mexico curious about Circular Thinking by using Maker Mindset and e-waste to recycle and turn it into profitable products. An 'Innovation Lab', a team of engineers and mechatronic based on the maker principles, worked collaboratively to reuse different parts of the e-waste. The Eco-Maker store developed 'EcoMakerKits' from e-waste parts to build a range of products. These were shared with the educational community through donations campaigns, students, teachers and the extended community. Fan Maker Kits' were donated to teachers interested in STEAMS education and have been used for activities in 147 schools with 219 kits in 24 of the 32 states across Mexico. The focus was on a range of hands-on learning activities and workshops, where children fostered their curiosity and expanded their Maker Mindset through hands-on learning based on the concept of reusing e-waste materials and Circular Thinking.

6 Playful Learning by Design in Kenya: Remote Development of Design Education for Rural Kenya

Marten B. Westerhof, Mathieu Gielen, Annemiek G. C. van Boeijen and James Otieno Jowi

The chapter recounts the development of design-related skills for primary children in in non-formal contexts of community centres in Rural Kenya. This was in collaboration with the Dutch Design School (IDE) at Delf University and a local Kenyan non-profit organisation. It required rethinking design education in specific cultural and economic contexts. Travel restrictions due to the Covid-19 pandemic enforced a remote development process. In West Kenya, a local community centre run by Sustainable Rural Initiatives (SRI) developed the programme.

The community centre had workshop facilities for craft for woodworking and tailoring and a facilitator was available to support the children's learning. Workshop instruction guides and supporting videos were developed the initiative and a Masters student was available to develop a design education format, focusing on creative problem solving and communication. Designing and making toys their own toys would motivate the children to replace their current imported toys with ones that reflected their own cultural identity and individual play preferences. Plastic was replaced by more sustainable locally sourced materials and the project ran for five months.

A rather different approach was taken later, and the workshops were divided into three distinct phases of exploring, building and presenting. In the first a topic was introduced and explored through questioning to develop conversation between the children. In the second phase the children gathered the materials they wanted to use to build their final product by testing and iterating their ideas. In the final stage the children presented their designs to each other and explored the diversity of the possible solutions. A further sequence of several workshops was developed where the children expanded their activities to explore different approaches, tools and materials that they could use in different contexts and circumstances.

7 Connecting Maker Education in Secondary School Technology Education in Korea: A case of the Technology Teachers' Learning Community in Republic of Korea

Hyuksoo Kwon

The chapter described trends and examples for maker education in South Korean technology education with specific reference to technology teachers' professional learning communities. Four themes were drawn from the qualitative analysis of interviews with four technology teachers, sharing and communication; being makers; technology teachers as practitioners for maker education and diffusion and movement. MAKERS, a technology teachers' professional community focused on sharing and communicating to share experiences in both hardware and software.

The core idea of the innovation was learner centred participation. The Korean government had introduced the philosophy of maker education into the school curriculum and teachers had shown great interest in a problem-solving approach centred on hands-on activities. Technology education was one of the national curriculum subjects in elementary and middle school and each provincial office of education had various types of school maker spaces with student-centred activities. 3D printers and software were introduced.

Case studies of maker education included a professional learning community (MAKERS) run by technology teachers in Seoul, the capital of South Korea. Teacher community meetings helped spread the making culture though research, workshops, seminars and MAKER websites. Four themes evolved *Sharing and communicating* through regular sharing meetings and workshops; *We are makers* where technology teachers have developed community meeting and workshops with project-based activities such as a Maker-A-Thon; *Teachnology Teachers as Practitioners of Maker Education* where technology teachers base their activities on design thinking and problem solving from real life and *Diffusion and Movement* based on the concept that Maker education is a good opportunity to promote the value of technology education in schools.

8 Case Studies of Maker Education in China

Jianjun and Qiuyue Yang

Maker Education and the promotion of lifelong learning for all people in China had recent extended and developed due to the vision of the government, society and educational reform. A new educational model that integrated the spirit of creativity into teaching practice had been developed by the Tsinghua University iCentre. The chapter described the implementation of maker education at the higher educational level and at the basic education level. It explored and formed a new teaching model based on 'student-orientated, creator-driven, project guided teamwork and cross fertilisation'. The 'Manufacturer + Internet +Creative Space had built an open service platform and teaching system for creative, providing support in terms of incubation sites, technical training, product development, processing and production and management consultancy. It provided a more creative learning space for teachers, students and domestic and international entrepreneurs.

It was argued that Maker education is a life-long, whole person development that fosters individual DIY, sharing spirt and creativity to promote the cultivation of innovative talents. It is the ability to use creatively various technical and non-technical means to identify problems, deconstruct then, find solutions through teamwork and form creative artefacts. Inspired by the iCentre activities students at Tsinghua University, Tsinghua Makerspace launched club activities and DIY assemble kits suitable for children education's maker education. In this programme the children's practical imagination, co-operation and communication and other aspects of innovative qualities were fully practiced and improved.

9 Maker Education in the Applied Physics Bachelor Programme at Delft University of Technology

Freek Pols and Rolf Hut

Two mandatory courses based on Make Education as learning activities were included in the applied physics bachelor programme at Delf University of Technology. This chapter included a rationale for their inclusion, the associated learning goals and the need for a makerspace with readily available makertools. The design of the makerspaces was outlined, how this affected education and become part of the final project.

Creating Engineers was an objective at Delft University of Technology. Students may become scientist or engineers, but design skills are essential for physicists as though they may not build instruments themselves, they need to need to understand and know about what will be needed and how the final design or outcome will be evolved. The first- and second-year courses in Design Engineering for Physics Students (DEPS) aimed at teaching students the skills to combine and apply their content knowledge in designing solutions.

In the first-year course students gained experience in design approaches and in the second year the focus was on designing and building an instrument that measures a physical quality. The gained insights and learning were applied in a final project. It was discovered that there was an urgent need for dedicated rooms or makerspaces with tools and equipment for the students to develop their designs. One room, the Maker room was used for quick production of prototypes, another to the use of more conventional and heavy machinery such as CNC's and drills. The Assemble room was equipped with a single60W laser cutter, two tables with three workstations for soldering and general tools and equipment such as electronic test equipment. The introduction of a Makerspace offered chances to streamline design assignments before handling them in. Students were introduced to the final project, expected to pick one of their ideas and present it to a physics teacher and make any changes before finally beginning work on their project. They also have meetings with a teaching assistant. This clarified that *they* are working towards and building a project *they* choose themselves. Working in the Makerspace had allowed students to work with proper tools throughout and develop a greater sense of ownership. The students presented their demonstrations during a science fair to former physics teachers and university staff.

Part 3 Thematic Reflections

In the following chapters Maker Education was viewed from a range of perceptions by authors from around the world.

10 Maker Pedagogy

P. John Williams

This chapter examined and discussed the pedagogy of the makerspace case studies though a framework of rationale, aims, content activities, resources, teachers' role, collaboration, where and when and assessment. It concluded that there was significant diversity, and it is 'concrete action learning' that fundamentally unities them.

11 Dynamitic Roles of Materiality in Maker Education

Varpu Mehto and Kaiju Kangas

The perspective of materiality was explored in this chapter. It was believed that the maker not only learns about the material world but is also taught by it and that material perspectives enrich what matters in learning and how to live well within the world.

12 Social Learning: Does Cooperation Contribute to the Learning of Makers?

Wendy Fox-Turnbull

This chapter explored the scope and nature of social learning found in the case studies and Makerspace learning, where the learner is central in constructing artefacts. It argued that its collaborative nature and the need for learners to become critical thinkers and makers, ensures that learners today are equipped with the necessary skills and dispositions essential for life in the 21st Century.

13 Reflections on Maker Education as a Potential Context for the Development of Spatial Ability

Jeffrey Buckley

In this chapter the case studies were reflected upon through the lens of their ability to increase learners' level of spatial ability. It was argued that shared discourse between maker education stakeholders, can lead to significantly improved practice in terms of individual learner's spatial and societal outcomes.

14 Making in Informal and Formal Settings

Gerald van Dijk and Elwin Savelsbergh

This chapter welcomed the fact that maker education is increasingly finding its way into informal and formal educational settings. It reflected on the case studies through five lenses, the development of maker identity; what is being learnt; what drives learners, what is motivating; the value of working with tangible objects and different materials and ways of sustaining making in education. The crucial role of the teacher as a maker in creating and inspiring high-quality learning experiences was noted across all the settings.

15 Sustainability of the Case Study Maker Education Initiatives

HildaRuth Beaumont (formerly known as David Barlex)

The chapter began by providing examples of educational reform in the UK that were used as a framework to examine and explore the sustainability of the case studies. Following a scrutiny of each of the case studies, it identified three requirements that need to be meet if these and future initiatives were to become sustainable. These requirements were continued perceptions of worth by key stakeholders, continued funding and professional development for those responsible for implementation.

16 Conclusions

Marc de Vries and Remke Klapwijk

This final chapter drew together the insights from all the previous chapters. It discussed how the appreciation of making is related to a worldview in which the materiality of reality and a certain view on mature and human features. It was concluded that there was a need for further research into maker Pedagogical Content Knowledge with teachers. With teachers being well equipped to do making activities, there is lasting value of Maker Education, both in schools and elsewhere.

Book Review

Dakers, J.R. (2023). A Nomadic Pedagogy about Technology: Teaching the Ongoing Process of Becoming Ethnictechnologically Literate. Brill Academic Publishers

Reviewed by Matt McLain, Liverpool John Moores University, UK

Introduction

John Dakers always provides challenging and thought-provoking narratives on the field of technology education, and this book is no exception. Read this book and you might be caused to rethink your preconceived ideas about design and technology education, and its related subjects around the world! Before I go any further with reviewing the book, it might be useful to define a number of terms that are used, which might not be in many teachers', let alone academics', lexicon.

To begin with the title, Dakers introduces two terms that were new to me, and I imagine many other readers. The first is nomadic pedagogy, which emphasises flexibility, adaptability, and a willingness to explore and experiment with approaches to teaching and learning. This stands in contrast to signature pedagogies, which describe common approaches used across a discipline (Shulman, 2005). A nomadic approach contrasts with traditional and established pedagogies, which Dakers proposes can present rigid educational models. The aim of nomadic pedagogies being to foster independent thinking and creativity in students, as opposed to following more teacher led approaches where the design and technology outcomes are largely determined in advance.

Secondly, Dakers introduces the concept of *ethnotechnological literacy*, which goes beyond mere technological proficiency, with the standard approach of developing conceptual (knowing that) and procedural (knowing how) knowledge. An *ethnotechnological* approach involves understanding technology within its sociocultural context, recognising the impact that it has on society (and vice versa), and developing a critical perspective on its use. In times of environmental and societal change, Dakers argues that children and young people need to become more literate in technology as a fundamentally human activity. Furthermore, the traditional craft-based approach to technology is judged to be deficient in its ability to achieve these aims.

The book draws on the philosophies of thinkers like Deleuze, Guattari, and Simondon to build a framework for this new pedagogy. Dakers uses these philosophical insights to challenge readers to rethink the relationship between humans and technology.

Content

The book is organised into eight chapters, each building on the previous to develop a comprehensive argument for nomadic pedagogy and the rationale for ethnotechnological literacy. *Chapter 1* sets the stage by outlining the book's main themes and objectives, which are followed up in *Chapter 2* with an exploration of current definitions of technology, technique and technological literacy, going back to the ideas of Aristote and the evolving interpretations and highlighting their limitations. In *Chapter 3*, Dakers delves further into the philosophical concepts that inform and underpin his approach, and in *Chapter 4* his examines the extent to which being human inherently involves being technological.

In the next chapters, his begins to outline the implications for education in *Chapter 5*, discussing how current educational systems around the world fail to adequately teach technological literacy. Developing on this, *Chapter 6* further defines the characteristics and benefits of nomadic pedagogy, with *Chapter 7* providing examples of how this approach can be implemented in educational settings. In conclusion, *Chapter 8* summarises Daker's arguments and calls for a shift towards this new educational paradigm.

Critique

Dakers' book is a compelling call to action for educators and policymakers. His critique of current educational practices is well-argued from theoretical perspectives, and his proposed solutions provide innovative and practical ways to address his perceived shortfalls in the current paradigms in technology education. The use of philosophical concepts to underpin his arguments adds depth and rigor to the discussion. However, the book is heavy on theoretical content and may be challenging for readers without a background in philosophy or education theory. Whilst Dakers provides some practical examples, more concrete case studies could help illustrate how this relatively untested nomadic pedagogy could be effectively implemented in diverse educational contexts. Furthermore, the idea that craft-based and ethnotechnological literacy technology education are mutually exclusive is open to question. No doubt, this mode of critiquing the role and impact of technology and society on each other is underrepresented in, if not wholly absence from, most technology education classrooms. But I would argue that there is a place for both approaches in a contemporary and pluralistic technology education curriculum.

As I read through the book, I found myself both fundamental agreeing AND fundamentally disagreeing with Daker's analysis of both the need for ethnotechnological literacy technology education and the current problems with craft-based technology education. Taking an ethnotechnological look at technology and society is something that has been long needed and hard to achieve in design and technology education. The fundamental human activities of technology and society are something that I have previously written about in McLain et al (2019a; 2019b). There were glimmers of the ideas in the reports written before the launch of the national curriculum in 1990 in England (cf. DES/WO, 1989). However, the legacy of craft-based technology and the dominance of making over designing in the D&T classroom in England has been handed down from generation to generation of teachers and attempts to remedy this issue – initial identified by Ofsted (e.g. 2002) and address in the National Strategies (e.g. DfES, 2004) have ultimately failed to turn the direction of curriculum practice. The most recent attempt to change this on a national scale was in the new GCSE launched in 2017 (DfE, 2015), but those who were unwilling to change found it easier to switch to vocational options or the Art and Design Textiles or 3D Design specifications, which provided more flexibility, easier wins in terms of grades, and less prescription.

Where I find myself disagreeing with Daker's analysis is in the proposition that craft-based technology education is unable to accommodate (or too broken to change) an ethnotechnological literacy approach. Having watched the rise and fall of D&T over the last three decades, I have come to conclusion that no change happens in isolation, and sometimes with no direct intention. And the sudden switch from one form of technology education to another is likely to result in the same issues as have beset D&T in England (i.e. the power of legacy policies and practices). It might be that creating a parallel subject could be an option, like happened in Sweden with Teknologi (technology) being introduced alongside Sloyd (crafts). However, there remain tensions between the two and time will tell on the success of this approach. Moreover, we already have a curriculum on England that is bursting at the seams.

Where there may be hope (in England at least) is in the current four-fold pedagogy that was initial proposed by the likes of Hildaruth Beaumont (formerly as David Barlex), and Alison Hardy and Sarah Davies at Nottingham Trent University. This is something that I have written about in Hardy (2021; 2022) and is illustrated in Figure 1. However, where I differ from other commentator is that I disagree that the fourth approach be called 'design and technology in society', favouring 'exploring technology and society' – avoiding putting the cart before the horse and putting technology and society side-by-side.

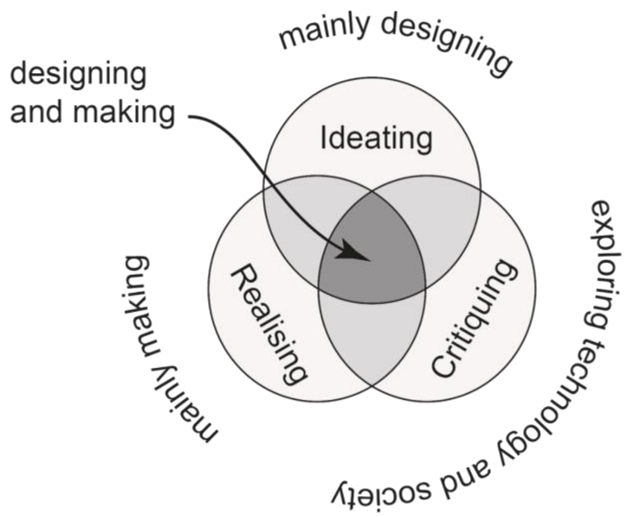

Figure 1 Four-fold Model of D&T Pedagogy Related to D&T Fundamental Activities (McLain, 2022)

Figure 1 shows how the four pedagogical approaches, developed and expanded from the previous model of the design and make assignment and focussed practical tasks, add activities called 'mainly designing' (recognising that designing does not stand alone from making, and vice versa) and 'exploring technology and society' (ETS). Both of these relatively new approaches are somewhat underdeveloped, but the ETS pedagogy is significantly less so and is ready for developing the more humanities informed approach expounded by Dakers as ethnotechnological literacy. My proposition is that to strengthen the broader approach encouraged by the four-fold model, the adoption an ethnotechnological inspired approach could lead to more sophisticated and authentic learning, without separating it from the body of D&T education.

Conclusion

In my view “A Nomadic Pedagogy About Technology” is an essential read for anyone interested in the future of technology education, particularly educators undertaking postgraduate study and research in the field, and those involved with curriculum policy at national and regional levels. However, it may prove to be a somewhat challenging and apparently irrelevant to the average classroom teacher working in isolation and without the opportunity to discuss difficult concepts with their peers. Dakers’ vision of ethnotechnological literacy and nomadic pedagogy offers a promising path forward, encouraging educators to embrace flexibility, critical thinking, and a deeper understanding of technology’s role in society. This, in my opinion, is an underdeveloped aspect of the design and technology curriculum, but there is a place for it within the ‘broad church’ of the subject, and this might be a spark to ignite a change in and evolution of the subject. At a time when a curriculum and assessment review, led by Professor Becky Francis, is taking a close look the national curriculum in England, Dakers brings an important perspective and approach that could (and should) be used to examine and question the way things are, and could be. This is a highly recommended read for all those developing D&T curriculum from the school to the national level, with a good philosophy dictionary to hand, such as Julian Baggini’s ‘The Philosopher’s Toolbox’ (2020).

References

Baggini, J. (2020). *The Philosopher's Toolkit: A Compendium of Philosophical Concepts and Methods* (3rd ed.). Wiley Blackwell.

DES/WO (1989). *Design and Technology for Ages 5 to 16: Proposals of the Secretary of State for Education and Science and the Secretary of State for Wales*. HMSO

DfE (2015). *Design and technology GCSE subject content*. (DFE-00283-2015). Retrieved from https://www.gov.uk/government/publications/gcse-design-and-technology [accessed 29/11/2025]

DfES (2004a). *Module 4: Teaching the subskills of designing.* (0971-2004 G). Retrieved from https://webarchive.nationalarchives.gov.uk/20081231051338/http://www.standards.dfes.gov.uk/secondary/keystage3/respub/design/downloads/ [accessed 29/11/2025]

McLain, M. (2022). What’s so special about design and technology anyway? Exploring contemporary and future teaching using a signature pedagogies discursive framework. In A. Hardy (ed.), *Debates in Design and Technology Education* (2nd Edition). Routledge.

McLain, M. (2021). Key pedagogies in design and technology. In A. Hardy (Ed.), *Learning to teach design and technology in the secondary school: a companion to school experience* (4th Edition). Routledge.

McLain, M., Bell, D., Wooff, D. and Morrison-Love, D. (2019a). How technology makes us human: cultural and historical roots for design and technology education. *Curriculum Journal, 30*(4), 464-483. https://doi.org/10.1080/09585176.2019.1649163

McLain, M., Bell, D., Wooff, D. and Morrison-Love, D. (2019b). Humanising the design and technology curriculum: Why technology education makes us human. *Design and Technology Education: An International Journal, 24*(2), 8-19. Available at ojs.lboro.ac.uk/DATE/article/view/2610

Ofsted (2002). *Secondary Subject Reports 2000/01: Design and technology* [report]. HMSO.

Shulman, L.S. (2005). Signature Pedagogies in the Professions. *Daedalus, 134*(3), 52-59. https://doi.org/10.1162/0011526054622015

Book Review
Center of Excellence for Technology Education (CETE) Vol. 4: Future Prospects of Technology Education

Editors: Marc J. de Vries, Stefan Fletcher, Stefan Kruse, Peter Labudde, Martin Lang, Ingelore Mammes, Charles Max, Dieter Münk, Bill Nicholl, Johannes Strobel, Mark Winterbottom (2024). Published by Waxmann

Reviewed by David Gill, Memorial University of Newfoundland, Canada and Alexander Taylor, Newfoundland and Labrador Schools, Canada

Future Prospects of Technology Education is the fourth and final volume of the Center of Excellence for Technology Education's (CETE) series on technology education from an international context. The first three volumes of the series focused on defining the discipline and its research methodologies, agendas, and impact. As the editors indicated, this final volume aimed to focus on the potential future pathways that may unfold within the context of technology education. As *de Vries* mentioned in the last chapter, trying to predict the future is no easy task and is fraught with speculation. After reading and reviewing the text, we would agree with *de Vries'* assessment as the volume is very much grounded in current and past issues and trends with very little in the way of a vision for the future.

The organization and structure of the book are also weak as there is no thread or theme that winds its way through the entire book, even though the title and preface would suggest otherwise. Rather, the book really is a collection of disconnected chapters that struggle to meet the stated aim of the volume. While there is an attempt to group similar chapters together there is no balance as some sections only contain a single chapter and others carry much of the text. Overall, there are issues with grammar and a lack of English translations for multiple figures. While the editors do reflect on the German context of much of the book's content, if this is meant for an international audience more care should have been taken during the final copy edits. That being said there is a fair amount of merit in the individual chapters in relation to some current and long-standing issues and trends within the discipline. We will next turn our attention to commenting and critiquing the main text in relation to the purported aim of the book.

The volume started with a single chapter under the digitization section. In *Gabriele Graube's* chapter entitled: **The nature of digitalisation and challenges for education systems and technology education** she explored the phases of industrial revolutions in relation to automation and digitization, focusing primarily on technological developments rather than their educational implications. She traced the progression from manual to mechanical labor, mass production enabled by electrical energy, and the rise of binary systems and computers. *Graube* highlighted the increasing complexity and autonomy of technical systems and their interactions with human users, culminating in the advent of Cyber-Physical Systems (CPS). These systems integrate networked, cloud-based interactions, responding to user input, past data, and contextual analysis - essentially describing modern Artificial Intelligence (AI) without explicitly naming it.

However, *Graube's* discussion of digitization's effects on education is limited. She briefly emphasized the need for adequate IT infrastructure, staff training, and digital learning media but did not explore these areas in depth. While she advocated for students to develop systems linking digital and physical realms, she overlooked existing technology education curricula that already incorporated CPS, input-processing-output (IPO), and monitoring, control, and regulation concepts. Despite these shortcomings, *Graube's* chapter provided a thorough overview of digital systems development, making it a useful resource for understanding the sociotechnical landscape. It holds particular value for policymakers, who often lack technical expertise and may fail to consider the complexities *Graube* outlined when designing educational policies related to digitization.

The next section of the book contained two chapters and focused on methodology and design technology. *Stefan Fletcher's* chapter entitled: **3D printing in design engineering education** provided a comprehensive introduction to 3D printing, covering its types, applications, and significance in education. He explained why Fused Deposition Modeling (FDM) has become the preferred method for schools, citing its affordability, ease of use, safety, small space requirement, and lack of ventilation needs. These qualities make FDM printers ideal for design-focused courses in schools.

The chapter emphasized the design process as a cornerstone of engineering and problem-solving education, noting its consistent basic steps despite varying terminologies. *Fletcher* described design as a creative process based on knowledge and experience, aimed at optimal solutions. He highlighted how 3D printing bridges the gap between theoretical ideas and practical application, enabling students - especially those with physical limitations - to create and test prototypes. *Fletcher* cautioned against the uncritical adoption of 3D printing in classrooms, stressing the importance of thoughtful implementation. Teachers must stay informed about technological advancements to equip students with relevant skills and ensure that new tools are intentionally integrated without detracting from other educational priorities. Additionally, *Fletcher* underscored the motivational potential of 3D printing, as it transforms theoretical designs into tangible objects. This hands-on approach enhances learning for students who struggle with abstract concepts and fosters engagement by broadening manufacturing possibilities. Concluding with practical guidance on integrating 3D printing into the design process, *Fletcher's* chapter serves as an invaluable resource for educators considering its use, offering insights into its benefits, challenges, and educational potential.

Phoebe Perlwitz and *Jennifer Stemmann's* chapter entitled **Serious games in technical education** explored the role of play and 'serious' games in technology education. They began by emphasizing the importance of curiosity-driven discovery and play in learning, citing extensive academic support. While play is often viewed as having no purpose beyond itself, the authors argued that its inherent engagement aligns with educational goals, particularly in technical education. Examples like robotics competitions demonstrate how planning, teamwork, and hands-on challenges can make learning more engaging.

Serious games, defined as games prioritizing education over entertainment, strike a balance by remaining enjoyable while ensuring students receive clear educational value. These games foster self-efficacy, or a student's belief in their ability to succeed, which the authors linked to greater achievement in technology education. They highlighted the gender gap in the field, attributing it to societal biases and limited early exposure for girls. Serious games, by building self-efficacy, can help mitigate these disparities and encourage wider participation. The chapter also argued for the value of serious games in teaching complex, intangible concepts that are increasingly prevalent in a digitized world. *Perlwitz and Stemmann* provided examples of games suitable for various grade levels, complete with QR codes for easy access to their readers. Concluding with a case study, the authors addressed challenges in gamification, such as teacher skepticism and the difficulty of conducting further research. They presented robust arguments supported by research, making their chapter a persuasive resource for educators interested in integrating serious games into their curriculum.

Moving forward, the next section of the book focused on gender issues and contained one chapter by *Veronika Becker, Gabriele Graube and Ingelore Mammes* entitled: **On the connection between socialisation, stereotypes and gender**. In their chapter on socialization, gender, and stereotypes, *Becker, Graube,* and *Mammes* examined why women and girls remain underrepresented in STEM fields despite decades of efforts to close the gap. They argued that these efforts may have overlooked key influencing factors in school and career choices. Their analysis highlighted that while females often possess equal or superior technical skills compared to males, as shown in studies like the International Computer and Information Literacy Study (ICIL), socialization and internalized stereotypes often prevent them from recognizing or acting on this competence.

The authors adopted a socialization-theoretical lens, exploring how school and occupational gender stereotypes shape individuals' self-image, influenced by parents, teachers, and peers from early childhood. They argued that guiding children based on individual aptitudes rather than gender is crucial to breaking these stereotypes, though they acknowledged the difficulty of overcoming deeply ingrained societal norms. While the chapter presented a compelling case for focusing on socialization, it has limitations. The authors overlooked the potential role of biological influences in gendered behavior, a topic gaining renewed interest. Acknowledging such factors could have added nuance to their argument without endorsing biological determinism. Additionally, untranslated German figures limit the accessibility of their data to a broader audience. Despite these issues, the chapter provided valuable insights into how stereotypes influence STEM participation and calls for a more individualized approach to education and career guidance, offering practical strategies for educators and parents to combat gender bias effectively.

The next section investigated the role of diversity in STEM teachers' perceptions with *Hao He, Johannes Strobel and Alexander F. Koch's* chapter entitled: **"Troublemakers"**. In their chapter, *He, Strobel,* and *Koch* redefined "troublemakers" as students who embrace free thinking and seek unique self-development, emphasizing their importance in technology education for driving innovation and problem-solving. The chapter aimed to explore teachers' perceptions of troublemakers as a basis for future research while addressing stereotypes linked to ethnicity and gender.

The authors reviewed literature on student misbehavior, attributing its causes to various factors while questioning the validity of many claims. They highlighted the pivotal role of teachers' perceptions and responses, noting that supportive teachers foster student motivation, while reliance on extrinsic incentives can stifle engagement. They also observed that repeated exposure to problematic behavior can erode optimism among teachers, potentially driving them out of the profession. Their study, though limited by a small, homogenous sample, revealed intriguing findings. For instance, seasoned teachers tend to perceive more behaviors as problematic over time, possibly due to shifting societal norms or accumulated negative experiences. This shift may create feedback loops where students feel more stress, exacerbating troublemaking behavior and reinforcing teachers' negative perceptions.

The chapter critiqued the assumption that good students are inherently self-motivated, a belief that absolves teachers of responsibility for guiding less-driven students. Instead, the authors advocated adopting educational frameworks to better engage and guide all students, emphasizing professional development as essential for effective teaching. While acknowledging their study's limitations, the authors successfully argued for further research into the role of troublemakers, offering valuable insights into how perceptions and approaches to behavior can shape classroom dynamics and student outcomes

The next section dealt with language as *Julia Pötzl, Verena Rasp* and *Alfred Riedl's* chapter entitled: **Learning opportunities to promote language skills for industrial-technical occupations** examined the critical role of language acquisition in vocational education, particularly for students transitioning into the workforce in Germany. They argued that success in industrial technical classes and subsequent career readiness depends on mastering multiple layers of language: everyday communication, academic discourse, technical jargon, and professional language. The authors stressed that these linguistic competencies are especially challenging for language learners, as technical and professional terms often differ greatly from their everyday counterparts. The chapter highlighted specific hurdles faced by language learners, such as words with multiple definitions (e.g., "field" being a place to play soccer or an area of magnetic influence). This chapter again incorporated untranslated figures further restricting the effect of their arguments to a German context. The authors focused on German-language issues, but their insights underscored the universal need for tailored language support in vocational education.

One key critique is the reliance of Germany's dual training system ("Duales Ausbildungssystem") on schools for language development, with less emphasis on workplace training programs. The authors suggested that integrating language instruction into workplace training would not only support non-native speakers but also help all students master technical jargon essential for their careers. They offered strategies for workplace partners to better support apprentices with language needs. The authors argued for prioritizing language proficiency to equip all students for the evolving workforce as automation continues to reduce low-skill jobs. They concluded by emphasizing the importance of collaborative efforts between schools and workplaces to ensure equitable opportunities and effective preparation for career success. This chapter provided valuable insights for improving vocational education systems, particularly in linguistically diverse settings.

The next section on curriculum development was the largest of the book, with four chapters dedicated to the topic. *Ibrahim Delen, Kadir Demir, Dury Bayram, Elise Quant* and *Ruurd*

Taconis's chapter entitled: **Using technology to support design-based pedagogy in teacher education** examined how technology can support design-based pedagogy in teacher education, addressing the ongoing tension between information and communication technologies (ICT) or educational technologies and technology/design education. The authors explored this issue by reviewing literature on ICT in education and design-based pedagogy, with a focus on pre-service teacher education. They highlighted the misinterpretation of the role of technology in education, particularly the conflation of educational technology and design-based pedagogy. The main interest driving their inquiry was how technology can support design-based processes in teacher education.

The authors used case studies from Eindhoven and Dokuz Eylul Universities to illustrate how ICT is applied in teacher preparation programs that incorporate design-based pedagogies. While the case studies were informative, the literature review that preceded them lacked methodological rigor and failed to clearly distinguish between ICT and design education. The Eindhoven case study, focusing on a curriculum design course, did not align with typical design-based pedagogy. However, the second Eindhoven case, involving AI-based video game design, more closely reflected design-based curriculum. The case studies from Dokuz Eylul University focused on courses in computer networks and computer-aided modeling and were not explicitly focused on design-based pedagogy.

Despite methodological issues with the literature review, the chapter concluded that further research is needed to understand how ICTs can enhance design-based pedagogy. However, the conflating of ICT/educational technologies with design-based technology education throughout the chapter makes the call for clearer distinctions between educational technologies and design education ironic. What this chapter did, by way of being a recursive example, highlighted the importance of nuanced discussions to improve the integration of technology in technology education teacher training.

Esther Booth, Ingelore Mammes and *Dieter Münk* chapter entitled: **Career choices of women and men in STEM** analyzed gender preferences in STEM subjects and careers, comparing data from 1998 and 2018 to evaluate progress in gender equality. Unfortunately, this chapter covered much of the same ground as *Becker, Graube,* and *Mammes'* previous chapter on stereotypes and gender. This points to the ambiguous nature of the book's organizational structure as mentioned in this review's introduction. Regardless, they continued to focus on the underrepresentation of women in STEM fields, stating that females occupy about one-third of all positions in school and work globally, including in Germany. Their main research question asked whether emancipatory and political efforts have increased female participation in STEM, to which they concluded that the answer is largely "no." While some areas, such as chemistry and math, saw gains in female participation (e.g., rising to 49%), these were outliers.

The authors pointed to cultural stereotypes and societal perceptions of gender roles in occupations as key barriers to greater gender parity in STEM. They noted that in vocational training and non-university education, fields typically dominated by women have seen increased participation, suggesting that university-level initiatives may be more successful than those in vocational education. *Booth, Mammes,* and *Münk* proposed early intervention at the primary school level to break down gendered occupation stereotypes, citing research that shows children as young as four internalize gender roles. They argued that changing these historical social structures is crucial not only for improving female participation in STEM but also for creating broader gender equality in the workforce, including encouraging men to enter traditionally feminine fields.

Martin Lang and *Wulf Bödeker's* chapter entitled **Education for sustainable development as a guiding principle of modern technology teaching** emphasized the urgency of Education for Sustainable Development (ESD), connecting its principles to the United Nations' Sustainable Development Goals for 2030. They argued that achieving stable societies requires balancing ecological, economic, and social development, and ESD is key to advancing this balance. The authors stressed the integration of these goals into curricula, particularly in technology education, where they advocated for incorporating the "human-social dimension of technology." According to *Lang* and *Bödeker*, technology education should adopt Klaus Tuchel's 1967 model, which considers human needs, satisfaction, production, use, and evaluation in the context of technology, emphasizing that technology development is inherently tied to economic and social impacts.

The authors advocated for a design-oriented approach to teaching technology that incorporates ESD throughout, highlighting the importance of factual, human-social, and value-based perspectives in the design process. They concluded with recommendations for teacher training, suggesting it should mirror the principles of ESD by being an open learning environment where educators develop their own practices. Teacher training should be grounded in subject-specific knowledge while promoting cooperative learning and sustainable practices. *Lang* and *Bödeker's* chapter underscored the critical role of technology education in fostering sustainability, advocating for pedagogical approaches that emphasize long-term societal impacts and sustainable development.

The section on curriculum development ends with *Charles Max*'s chapter entitled: **Investigating learning and teaching practices in Elementary Science and Technology education.** In this chapter *Max* set the goal of developing "a conceptual framework based on a thoughtful orchestration of dynamic, interactive and context-sensitive approaches to conceive, enact and reflect on instructional practices in Elementary Science and Technology." *Max* wasted no time before diving into the positive aspects of using activity to foster growth in technology education. However, he was likewise quick to point out issues that may arise when student led activity is the main approach. Things such as interactions between groups or a single member being more knowledgeable can lead to obstacles in the learning process.

Max further developed the chapter by highlighting the importance of cultural entanglement in human reactions, both with handling and using technology, and in technology education itself. He referred to Cultural-Historical Activity Theory (CHAT), as developed by Vygotsky to help support the argument. This chapter paired well with the previous chapter on sustainable development as it reiterates the importance of social connectivity in the fundamental building blocks of technology education. Interactions with others and our environment will both give deeper meaning to aspects learned by the student.

The chapter concluded with *Max* fleshing out methods of implementing this action-based learning model in the technology education classroom. He gave the reader ample support and information for strengthening weaknesses in the approach and leveraging its strengths to ensure both teachers and students can get the most out of the model. In all, Max's chapter sets out a strong theoretical framework for how technology education could be implemented in the classroom.

The final section and chapter in the volume are entitled: **International communication in technology education – developments.** Author *Marc J. de Vries* summarized the importance of international collaboration within the technology education community to bolster support and evidence for continued inclusion and elevation of the subject in compulsory education. The author focused on three main avenues of international communication and collaboration - conferences, journals, and networks. For anyone familiar with the technology education research community this is a nice summary of the most well-known avenues such as PATT, the International Journal of Technology and Design Education, and the Centre of Excellence for Technology Education - the network responsible for the book under review. *de Vries* highlighted the influence that international connections have had on strengthening technology education as a curricular area and reiterated the importance of personal connections making concrete differences worldwide. For anyone new to the area of technology education research, the chapter is also an invaluable starting point for understanding the resources and networks that exist within this space. The capstone chapter gave a good sense that we are not alone in our endeavours, and that was a really nice way to end the book.

As we have analyzed and discussed, *Future Prospects of Technology Education* does have some valid and interesting takes on technology education, but it does fall short of its stated aim of illuminating future paths forward. Whether it was the discussion of automation and computerization or the gender gap in technical school and work or the role of sustainability within the curriculum, these issues are all long standing themes within the technology education community. While a reader could assume that the topics covered in this volume will continue, there is really no concerted effort to forecast potential areas that might open new possibilities for the discipline - such as the return to space travel and interplanetary exploration or the cybernetic links between computers and humans that are just starting to turn science fiction into reality. There are also copy editing, translation, and structural issues that should be considered for anyone that would like to use this within a pre-service teacher program or for graduate level programming. Overall, it really feels like an intellectual “scrap quilt” that was advertised as something much more. That being said, “scrap quilts” do have their charm and this volume could be useful in a very selective and purposeful manner.