IDEATION TECHNIQUES FOR ENGINEERING STUDENTS: STATE OF THE ART AND RECENT CASE STUDIES

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ABSTRACT

Engineering students must be able to generate diverse, creative solutions to problems as a key skill for their future careers, as industry and the environment requires innovative solutions to complex problems. This paper reviews some current best practice in ideation and problem framing that are taught in engineering programmes and surrounding education. Frameworks include morphology analysis, design heuristics, SIT tools and generative-AI. Each framework aims to present problems in different perspectives and encourage students to solve them creatively, with each demonstrating an improvement in student creativity and diversity of thought when they are taught in project-based activities. Following this review, two case studies from The Engineering & Design Institute London (TEDI-London) are

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presented, illustrating how students utilised various ideation tools during an engineering product design module. The paper concludes with key lessons for educators interested in incorporating such tools into their teaching. Overall, the paper highlights innovative methods to foster creative problem-solving skills among engineering students.

1 INTRODUCTION

Engineering education needs to consistently innovate so that engineers entering the workforce are better equipped to tackle industrial, societal and environmental problems (Nordin and Norman 2018). Courses on user-centred design, and teaching where students tackle open-ended projects are seen as an emerging part of innovative engineering education (Graham 2018), and ideation (forming ideas or concepts) is a key stage in problem solving (McGlashan 2018).

Ideation and problem framing are key to better develop problem solvers, with project-based learning (PBL) offering a practical, hands-on approach to training engineers in ideating and in improving creativity (Chang et al. 2022). PBL courses have become increasingly popular in engineering education. For example, University College London have adopted PBL modules within the integrated engineering programme (Hailes et al. 2021) and newer providers such as the New Model Institute for Technology and Engineering (NMITE) or The Engineering & Design Institute London (TEDI-London) have emerged, and primarily teach using PBL.

There are several widely used frameworks and concepts for ideation, including group brainstorming and the ‘theory of inventive problem solving’ (TRIZ). Group brainstorming, has been shown to significantly reduce the productivity of ideation (Mullen, Johnson, and Salas 1991). TRIZ (originally derived from the study of inventive patterns in patents), meanwhile has been shown to improve the novelty and variety of ideas, compared with ad-hoc ideation (Hernandez, Schmidt, and Okudan 2013). TRIZ can be challenging for newcomers with 40 different inventive principles (Ilevbare, Probert, and Phaal 2013), however, through simplifications, and derived techniques such as ‘systematic inventive thinking’, these can be potentially fruitful alternative ideation techniques for engineering students.

Accordingly, in this paper, we (i) present an overview of emerging methods for ideation and (ii) present two short case studies from our institution where example tools have been used in diversifying potential solutions. Finally we highlight key take-aways for educators looking to implement such techniques in their programmes.

2 IDEATION METHODS

2.1 Morphological analysis

The process of morphological analysis is defined by breaking a problem down into its constituent parts, subcomponents and functions, and ideating for each individually, resulting in a morphology chart. In this different combinations of solutions are selected together to design products. There is little academic literature to define how to select different solutions, as the number of total solutions may be unreasonable to consider, e.g. a chart with 6 functions and 7 different solutions per function yields over 117,000 solutions. Approaches may include systematic combinations of all functions, intelligent combinations or random combinations. In any case, this is often seen a vague to students and can be challenging to apply if a student is not comfortable the procedure.

There are few recent academic studies on the use of morphology charts in design thinking. One study (Daly et al. 2016) compared creation ideation techniques with beginning designers investigating the use of morphological analysis, design heuristics and individual brainstorming. This found individual brainstorming to be the simplest method of idea generation, producing the most concepts. Alternatively, with appropriate teaching, morphological analysis resulted in more elaborate concepts than individual brainstorming. An additional study of 54 mechanical engineering students (Smith et al. 2012) lead to the development of guidelines for the use of morphology charts in design thinking. This stated that designers should explore and expand the design space through the use of additional solutions, rather than functions, and that primary and critical functions should be focused on.

2.2 Design heuristics

Design heuristics are design strategies that can be employed in ideation, and may be considered ‘rules of thumb’ (Yilmaz et al. 2016) to apply in the design process, to aid in generating a wide range of concepts and, to help designers avoid becoming ‘fixated’ on early ideas. There are many design heuristics, often tailored to different fields. For example, Yilmaz (Yilmaz et al. 2016) analysed key features and functional elements of 400 award-winning products, from different designers, and from this extracted 40 design heuristics. They extracted well-specified heuristics that other designers could clearly identify with and apply to their own designs. The heuristics included principles such as “implement characteristics from nature within the product”, “allow user to reorient” and “use the inner surface space of the product for different functions”. They went on to study how the heuristics aided undergraduate industrial designers during ideation, and found that, on average, concepts that showed evidence of using the heuristics were more creative, and also more diverse.

In recent progress, authors from ETH Zurich (Blösch-Paidosh and Shea 2021, 2022) summarised a set of design heuristics for design for additive manufacturing. This set of 25 design principles included “consolidate parts to reduce assembly time” and “create multi-functional artifact with reconfigurable structures”.

Heuristics are helpful “quick and dirty” tools that can help spark ideas for a wide range of design scenarios. As there are plentiful resources of design heuristics for many highly specific areas, teaching these to undergraduate students can pay dividends in (i) increasing creativity (ii) increasing diversity of concepts and (iii) increasing productivity of designers by ensuring they build on others’ findings.

2.3 AI-Assisted techniques

With recent advances in AI technology, in-particular Generative AI (Gen-AI) and Large Language Models (LLMs), studies have attempted to decipher the usefulness and drawbacks of this technology in design thinking, innovation and creativity. Gen-AI has made rapid advances typified by Open AI’s ChatGPT chatbot which is able to match or improve on human performance in examinations and, Microsoft Co-Pilot able to aid in writing and debugging code. Furthermore, Midjourney and Microsoft Designer, based on DALL-E 3, are able to produce images from text. Various sectors have begun utilising the use of Gen-AI including in healthcare, business and design (Chong et al. 2022) with the benefits of Gen-AI being extensively researched for their use in design, ideation and in co-design (Kim, Maher, and Siddiqui 2021; Chiou et al. 2023).

Prior to the release of this software, a studied showed innovation managers regarded idea generation and idea evaluation as the least important areas for AI application within the design process (Füller et al. 2022). Since then studies have shown a remarkable increase in the use of Gen-AI in design thinking. Students from engineering and design courses used a range of tools including ChatGPT and Midjourney during both the research and empathy phases and the ideation and prototyping phases of a makeathon (David, Krebs, and Rosenbaum 2023). Within the study, 82% of engineering, and 76% of design students used Gen-AI tools to aid in the creation of their solutions. During the research and empath stages 67% of students used textual only tools (ChatGPT) and 19% used visual only Gen-AI tools (Midjourney). This significantly increased to 30% using visual only in the ideation and prototyping phases with students using visual Gen-AI tools to visually validate and develop their solutions. This approach is supported by a number of other studies, suggesting that Gen-AI can work with human designers rather than replace them (Esling and Devis 2020; Bilgram and Laarmann 2023).

Bilgram (Bilgram and Laarmann 2023) showcased the use of Gen-AI in accelerating the digital prototyping and innovation phases of design, through the production of an app. In this, discussions with ChatGPT were used to create HTML/CSS prototype at an accelerated rate through aiding the user in debugging the software, providing instructions and code snippets, however limitations were reached due to extensive conversations leading to content being ‘too for back’ for the AI to remember features and requirements.

It is seen that Gen-AI may be a game changer in early prototyping as the delegation of tasks can lead to faster iterations and reduced costs. Numerous studies have shown the positive impact on the early stages of design (Tholander and Jonsson 2023; Chiou et al. 2023; Girotra et al. 2023). However, this is often reliant on two factors. (i) the quality of the prompt used for generation and (ii) the input of the designer to co-create with Gen-AI rather than replacing the designer. Although studies have shown that Gen-AI is capable of matching or surpassing professional designers in idea generation judged on novelty, customer benefit and feasibility in some scenarios (Joosten et al. 2024), often designers find the tools to be useful for ‘going wide’ on a topic rather than ‘digging deep’.

This is a rapidly changing landscape with new tools and capabilities of LLMs and Gen-AI being developed at unprecedented rates creating new scope for idea generation and development.

2.4 Systematic inventive thinking

Systematic inventive thinking (SIT) is a derivative of TRIZ (Boyd and Goldenberg 2013), and as well as being a thinking method, is also the name of an innovation consulting company (SIT 2024). In SIT, designers implement five different “thinking tools” to generate new ideas. Initially, designers create an inventory of the components in the product, then apply one or more of the thinking tools, which are:

1. **Task unification**. Each component is converted to a resource to be used in another way. The tool then assigns a new task to the existing component.
2. **Multiplication**. One component of the inventory is multiplied, whilst giving it a qualitative change that makes it different from the original in some way.
3. **Division**. The components are divided up, physically or as a function of time.
4. **Subtraction**. Components are divided up, then one or more are removed.

5. **Attribute dependency**. Internal variables are corresponded to external variables to check if there is an attribute dependency on the internal variable to the external variable, then imagines that there is one, or vice versa.

The new ideas are then generally reflected on to evaluate whether the new ideas align with design principles. Designers ask the questions “what are the potential benefits”, “who may find this change valuable?” and “how may this help to address a problem” in response to the change made to the product.

(Barak and Bedianashvili 2021) showed several examples SIT for ideating and problem solving, for example the innovation of a spirit level to measure the specific slope of a surface. The authors described how, when a set of 110 engineering experts were given a 30-hour workshop on problem solving, including the SIT method, the engineers were able to show a marked increase in the number of inventive solutions (from 0.65 up to 4.84 solutions) in an exam, after the workshop.

3 CONTEXT: THE ENGINEERING & DESIGN INSTITUTE LONDON

3.1 Education Setting

In this paper, two case studies were examined using different ideation techniques by 2nd year Global Design Engineering students at TEDI-London . The degree programme primarily focuses on educating students through project-based learning. The case studies presented are indicative of the concepts and frameworks taught a module titled “User Centred Product Design” (UCPD). In this module students are required to define their own problem statement, ideate potential solutions and present their developed idea in a final assessment. The project theme was “design and prototype wearable technologies”. The final assessment is a design history file with physical prototype. Some of the learning outcomes of the module include (i) the ability to research and evaluate user needs as applied to the design of a product (ii) establish and apply aesthetic and ergonomic design and (iii) generate concepts and evaluate, iterate, and develop them.

Students are introduced to frameworks and tools through a blended approach. Background theory and formative tasks are delivered through online learning, allowing students to work at their own pace and become familiar with the tools by completing tasks adjacent to their main project. Some of the design tools include the use of journey maps, ethnographic tools and ideation techniques, including theory on how these help to overcome cognitive fixedness.

During in-person classes, theories and frameworks are presented and discussed in greater detail, often with workshops to practice using them. Students learn how to apply the tools to the situations they are solving, providing them with the opportunity to explore the possibilities. Students are given a range of frameworks to choose from, enabling them to select the tools and methods that best suit their situation and timeframe within the product development cycle.

3.2 Case Study 1: Systematic inventive thinking

During UCPD, 35 students took part in the module. Over ten weeks, students engaged in user research, and were required to produce material highlighting user pain points (both explicit and, latent pain points) and, from this, elicit design principles, that is, the characteristics (or “attributes”) that ideas must have in order to successfully overcome the identified pain points. Students initially worked in groups of three to four and gave an assessed interim presentation of their research and initial ideas. After the presentation, students worked independently on one selected idea. Whilst students were free to research any area, they were required to find problem areas that may be conceivably aided using wearable technologies.

Beyond the more obvious example (around ergonomics and battery life etc.) the type of design principles that students uncovered were varied, but some representative examples included: “Doesn’t add stress to the user’s life.” and “encourage conversation also … encompass immersivity”. The 5 SIT tools were applied to existing wearable technologies, to see if ideas could be sparked to create helpful innovations. The results were, very varied, but in some cases, laid the foundation for some innovative concepts. Some examples included:

- Division of a smartwatch into small modules, so a user could physically ‘leave’ a certain function at home, to reduce distraction or anxiety, initial sketches shown in Figure 1.
- Using the task attribution tool to assign the task of monitoring and calculating UV exposure and dosage, to a hair clip.

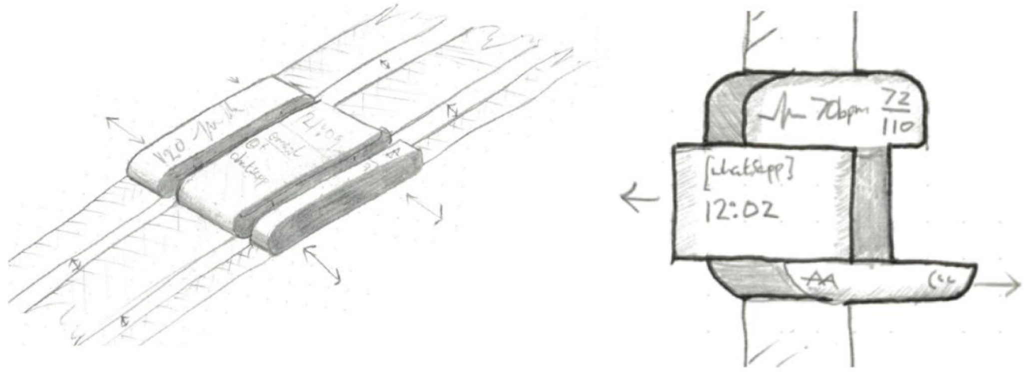

Figure 1: Examples of using the SIT ‘division’ tool for a modular smart watch design.

Out of a class of 35 students, anecdotally, nearly all engaged with, and were able to use the SIT tools. Students were generally able to generate a wide range of ideas using the framework. Of the 16 students that recorded ideas using a ‘creative matrix’ (a matrix with design principles as columns and ideation techniques as rows, with ideas in the cells), the average number of ideas in the creative matrix as generated from SIT was 15.4 ideas (minimum 4, maximum 51).

Students appeared to find the ‘attribute dependency’ tool relatively difficult to implement, whilst others were generally seen as simple and helpful. However, after the completion of the UCPD module only a handful (3 or 4 students) had continued to develop ideas that had originally been generated by SIT.

3.3 Case Study 2: Alternative worlds and visual Gen-AI

This second case study includes findings from the same cohort and module. Beyond SIT, two further frameworks were employed during UCDP to build inspiration and creativity in the product designs: ‘alternative worlds’ and visual Gen-AI. Students were encouraged to use Gen-AI throughout the design process with the majority using visual tools during the second phase: product development.

Using the ‘alternative worlds’ framework, students were asked to imagine how different brands may design their wearable products. For example, what if ‘Starbucks’ made smart glasses or ‘Beats headphones’ made VR glasses. Students selected an existing brand and identified the brand guidelines and design language used in their products to influence their own product development. Using these brand guidelines, concept images were generated using Microsoft Image Generation tools, powered by DALL-E. The results of this process can be seen in Figure 2 with examples of smart watches and ski goggles.

Figure 2: Examples of AI-Generated designs following brand guidelines established by students (a) a smart pill watch using Lemsip branding and (b) smart ski goggles using Garmin branding and design language.

Following the generation of images, students were asked to complete group design critiques of the images and designs. In this, they were required to highlight elements of the design they liked, or thought suitably matched the design language, and what elements they would change in future iterations. Students identified details of designs they wanted to progress through to final design, and further inspirations for their designs. Colorations between images critiqued and the final designs of students can be seen, with Figure 3 showing initial images generated and final renders of their products. Clear links and inspiration can be seen through the strap connectors, side buttons, shape and screen with refinements made to the designs generated by the student. These frameworks exposed students to a wider range of ideas and concepts during the development phase which enhances their creativity and diversity in idea development and ideation.

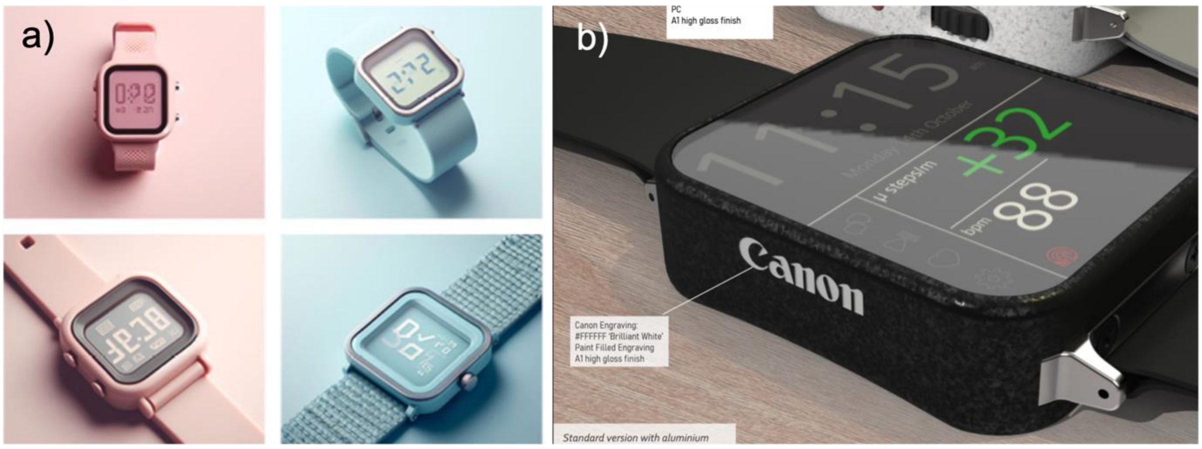

Figure 3: (a) Gen-AI images using design language from Canon products and (b) final student renders of smart watch produced by students.

4 CONCLUSIONS

Ideation and creative design are key tools for graduate engineering students starting their careers, hoping to produce innovative solutions to complex problems. This paper presented a range of tools taught across engineering design thinking programmes to increase the creativity and diversity of thought in solutions. Traditional lecture-based programmes often struggle to engage students with key frameworks due to lack of practice and integration. Project-Based Learning, and user centred design courses are alternative education styles, allowing students to engage with tools and frameworks, as well as traditional engineering practices, whilst developing their own ideas and products.

Through presenting two case studies at TEDI-London , this paper has discussed the value of two frameworks, SIT and Generative-AI in fostering creative ideas in student projects. SIT was shown to aid nearly all students (in our cohort) in the generation of a wide range of initial ideas and concepts. A smaller number of students developed these concepts to a working prototype solution. This suggests that SIT may best be taught amongst a range of other tools, rather than a sole method.

Secondly, students used Microsoft Image Generator to create concept images of a range of designs for wearable products. This process was seen aid in the generation of diverse ideas, allowing students to imagine different products being produced in distinct design language or company. Rather than students using these designs as their products, a group design critique was conducted to encourage students to evaluate the designs. Final output from the project can be seen to contain inspiration from the generated images, combining different aspects together.

4.1 Key Takeaway for Educators

The pedagogy at TEDI-London primarily utilises PBL and online learning to teach fundamental principles and the application to real-world problems. There is a growing trend in engineering education programmes towards this methodology and this paper aims to enable other institutions to learn and implement the experience gained in their own programmes. Subsequently, the key takeaway points from this experience are summarised here:

1. Frameworks such as brainstorming and morphology analysis are traditionally taught in engineering undergraduate programmes but may reduce the productivity of ideation. Students who were taught methods such as SIT, and alternative worlds tended to favour their use in the product development cycle.
2. These frameworks are suitable for undergraduate engineering courses, and do not take up too much time to introduce, but considerable time to perfect.
3. Structuring PBL courses with significant tutor lead activities for new frameworks and tools is required for student engagement with such tools.
4. Introducing students to a wide range of frameworks and tools enables them to interact with methods they find useful and creative, leading to a diverse output from the cohort. Students value the access to a wide range of these tools.
5. Students were keen to engage in new technologies such as Gen-AI during projects but educators should work with students to help develop prompts and co-create through critiquing designs produced to influence their own designs.

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