FOSTERING DIVERGENCE DURING CONCEPTUAL DESIGN WITH INDUSTRIAL-BASED STUDENTS

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ABSTRACT

Teaching the same design module to two different cohorts, traditional design students and industry-based students, the outcomes of the conceptual design stage has shown differences in divergence achieved, looking at both number and quality of concepts. The activities of both cohorts across two years are explored, combining on campus studio based teaching and online teaching, through comparison of teaching approaches for both cohorts and their effect on the design outcomes. Findings show that the traditional design students create significantly larger number of concepts, discussed in more detail and engage more fully in the divergence-convergence design process. Then the recommendations are provided for approaches and techniques that could be implemented to the industry-based student teaching to encourage divergence during idea generation. These include increased levels of studio work focused design work separated from industry needs, more structure and mandatory use of all instructed design techniques by inclusion in the assessment, increased focus on intermediate tasks and contextualisation of design terms to the fields they are familiar with.

Keywords: Conceptual design, Design education, Training, Industrial design

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1 INTRODUCTION

One of the key teaching activities in structured product design instruction is the discussion and demonstration of methods and tools for idea generation. The aim is to support the students' creativity and encourage them to immerse themselves in divergent concept generation. In the early stages, the goal is to ignore limitations and produce designs that do not have to be realistic or conventional. As designs progress they are evaluated and converged to derive a single solution that fulfils the project brief and student-created Product Design Specification (PDS). This design process is an integral part of any design module and this paper will examine its delivery in two slightly different versions, with two different cohorts of second year undergraduate students - traditional product design students (full time residential undergraduate students, referred as "design students" in this paper) and apprentices taking a full time Bachelor's degree in Design and Manufacture while also working full time in various engineering companies (in this paper referred to as "industry-based students"). Typically, the product design students' module is delivered in face to face studio environment with in four-hour design weekly blocks, over six weeks. In contrast, industry-based students' module degree was primarily conducted online, via a collection of five to 15-minute videos explaining different concepts. They attend two monthly intensive face-to-face on-campus sessions where three to four hours were dedicated to design classes. These on-campus sessions all happen within one semester. The mode of delivery is the key difference between the two modules, and over the years it has been noticed that the apprentices consistently tend to produce lower number of diverse concepts, and instead fixate on a preferred solution prematurely and move into detailed design and embodiment early on. This typically leads to less creative solutions. Thus, the mode of delivery was suspected to be a factor influencing the reduced divergence in concept design for the industry-based students. When Covid19 pandemic forced fully online delivery across all of the programmes perfect conditions were created to test this theory and compare both versions of the module being delivered to different cohorts in the same manner, to the way it is typically delivered. This paper reports the findings and suggests potential improvements that could be included in the mixed delivery modules to increase the divergence during the concept generation stage.

2 CONCEPT GENERATION AND DIVERGENCE

The conceptual design stage in a product design process typically includes a series of divergent idea generation spurs, followed by rounds of convergent evaluation of those ideas, until a final concept is reached (Cross, 2021). Figure 1 illustrates the shape of a typical idea generation process, where a handful of ideas are taken through most stages of a design process, explored and modified through stages of divergence and convergence. Some ideas are discarded in the process, some features are absorbed into ideas taken forward and eventually derived into a final concept.
The more creative, unlimited and extravagant the initial ideas are, the larger the range of potential design options. Evaluation and focus on product requirements eventually pull them back in and filter the possible solutions from impossible blue-sky ideas. But initially the goal is to be unbounded by reality and explore all ideas, regardless of how practical they might be, as they may lead to an innovative and creative solution to a design problem

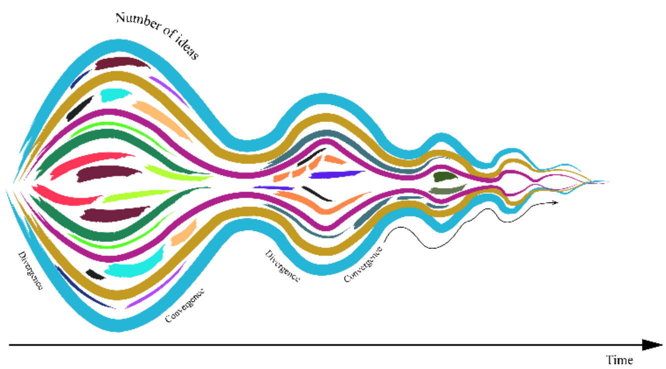

Figure 1. Conceptual design process including stages of divergence and convergence

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2.1 Why is divergence important?

Successful product generation is commonly aided by a design process that diverges and converges multiple times while the number of concepts overall is gradually decreasing until one or a handful of final concepts are taken forward to detailed development (Pugh, 1991, Cross, 2021). While both divergence and convergence are taking place concurrently, and are both necessary to support the design process, it was found that divergence usually accounts for a larger amount of activity (Goldschmidt, 2016). Good designers possess vast domain knowledge and also have ability to structure ill-defined problems, generate fluent and flexible design solutions and visualise solutions in their imagination (Shah et al., 2012). Divergence, or generation of a wide range of concepts, supports the principal aim of design i.e. generation of promising concepts increasing the possibility of better product creation (Liu et al., 2003). Divergent thinking is defined as an ability to explore the design space or create many alternative solutions (Shah et al., 2012). Some researchers argue that including sets of generation and evaluation, increases the effectiveness of exportability of concepts, as evaluation and selection can happen at points where designers can apply them meaningfully, while the range of concepts is not too wide (Liu et al., 2003). However, the consensus is that early on divergence is a positive development in concept generation.

Domain specific divergence, iteration within a landscape of possible solutions, is also generally seen as a good indicator of creativity in both creativity research and educational practice i.e. creation of original and appropriate ideas to solve a given problem (Baer, 2014). Most techniques supporting divergence include connecting an idea or concept from memory or environment with another idea in a way that they have not been connected in the past, meaning both environment and domain specific knowledge affect the process (Kilgour, 2006). More recently it has been suggested that it is possible that creative output arises from a mix of flexibility and persistence, inspiration from highly related and unrelated ideas (Peterson and Pattie, 2022). While creativity is difficult to measure, the general consensus is that divergence in idea generation aids it. Vague and not fully defined ideas can spark new concepts and their reinterpretation can lead to interesting solutions. Hence, when teaching concept generation tools, the focus is often on techniques that aid divergent thinking and generation of wide solution space. It was seen that not all students engage in divergence equally well, for example engineering students have been found to struggle to diverge doing design work (Daly and Yilmaz, 2015).

2.2 Encouraging divergence while teaching conceptual design techniques

Shah et al. (2012) propose a number of measures of divergent thinking: (1) the number of ideas generated (fluency) - also often a measure of creativity, (2) variety - how broadly the design space has been explored, (3) originality - the ability to expand the design space (thinking outside the box), and (4) quality - are the ideas technically feasible? They also explore indirect measures: (1) abstractability - the ability to abstract, (2) afixability - ability to not favour a design from previous experience, and (3) decomposability - ability to identify key issues and conflicts. After performing a study testing if it is possible to measure divergent thinking, it was suggested that three key elements would improve design learning: "explication of design skills, association of skills subsets for each design exercise and record keeping and aggregation of scores organized by skills" (Shah et al., 2012). They also conclude that aggregating a score of divergent thinking is not as helpful as encouraging divergent thinking by rewarding "out-of-the-box thinking, risk taking, unconventional and unusual ideas".

It has been found that divergent thinking likely has physical indicators, for example eye deviation from orbital centre (termed "look around") while divergent thinking is happening, or designers touching their lips, neck, or cheek imminently before transitioning into divergent thinking (Hu et al., 2019). Those indicators could potentially be used to create pro-active creativity support tools. Certain types of feedback have been known to prompt divergent thinking, e.g. suggestions to broadly explore the ways an idea can be accomplished or suggestions to more specifically consider multiple options (Daly and Yilmaz, 2015).

Most conceptual design techniques aid divergence. Brainstorming is one of the most common idea generations techniques taught to product design students (Osborn, 1957). While easy to learn and often effective, it does come with drawbacks, as demonstrated by the experiments of Charlan Nemeth (Nemeth et al., 2004). Dominant team members can end up leading it and groups that are not used to it often fixate on solutions too early. 6-3-5 method was developed as an alternative to brainstorming (Rohrbach, 1969). It guides six designers (although this number is adaptable to the size of the team) in developing three concepts over a number of five-minute sketching activities, in the process creating a number of iterations

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of the original concepts. The iterations happen as designers pass their three sketches after each five-minute round of activity, and continue developing the ideas they have received from the designer next to them in the next round of the activity. It completes the same goal of divergent idea generation the brainstorming does, but it removes the direct interaction and discussion between the participants. The function tree (Andreasen 1980) is a method of modelling a product starting by systematically decomposing its intended functions. Morphological analysis is a process of development of an object by progressive introduction of form features (Brun, 1994). Function tree can be combined with morphological analysis by basing the form development on the functions the product needs to support. It is a good tool to use when focus on function of a product is needed, and provides an inbuilt opportunity for divergence by guiding the designers to focus on individual functional challenges, aiding divergence, which can then be integrated while being further developed into an overall solution. SCAMPER (Eberle, 1996) is also an extension of brainstorming, presenting the designers with possible actions
Substitute-Combine-Adapt-Modify/Magnify/Minimize-Put to other uses-Eliminate-Reverse/Rearrange that may be used to develop solutions to a design problem. Force fitting is an idea generation technique that is "forcing together of two or more objects, products, or ideas to produce new objects, products, or ideas" (Hender et al, 2001). As forced blending of two ideas is likely to be the first time the designers are considering specific issues they present, there may be a greater chance of generating new ideas via this technique.

Brainstorming and morphological analysis were found to lead to similar solution diversity, although brainstorming was found to produce quantitatively more concepts (Daly et al., 2016). When prompts were used to stimulate idea generation (SCAMPER and force fitting use this approach to an extent) it was found that more mature entities lead to more fixation than ambiguous, abstract entities did (Benami and Jin, 2002). Sketching is an important element of design thinking (Buxton, 2010, Isaksen et al., 2010), and including it in design space exploration has been found beneficial for the idea generation process, even when used by participants who are not highly skilled in sketching (Gallagher, 2017). Finally, it has been found that both using multiple concept generation techniques (Sangelkar et al., 2015) and combining them into a single technique has resulted in generation of diverse ideas (Leahy et al., 2018).

3 OUTCOMES OF CONCEPT GENERATION FOR DIFFERENT VERSIONS OF THE MODULE AND COHORTS

Two versions of the same module were delivered to product design student cohort and industry-based student cohort. Both modules follow the process described in Figure 2.

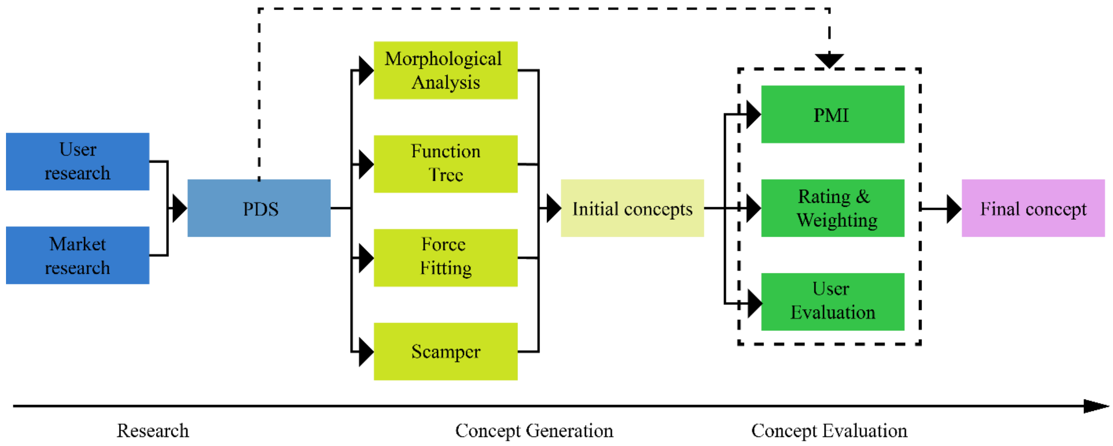

Figure 2. The techniques taught in the design module and their outputs

Firstly, techniques are taught covering market and user research, helping the students identify the key elements to include within a PDS. Then techniques are delivered that guide initial idea generation leading to development of diverse, unlimited and innovative concepts, that do not have to be realistic but provide a seed for further development. Both cohorts of students are taught morphological analysis and function tree, force fitting and SCAMPER. Then the content moves on to evaluation where the work is converging and focusing on the PDS and complying with the requirements for the product.

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Techniques covered are PMI, rating and weighting and user evaluation. Students are then instructed on techniques for detail and embodiment design, along with prototyping and other processes. These fall outside of the scope of this study. Both cohorts of students are taught brainstorming and controlled convergent matrix evaluation in the first year, so they are well versed in those by year two. There are two slight differences in the target product students are asked to design. The traditional design student cohort is asked to design a means for transporting children under the age of 2. Apprentices are asked to design a means for transportation of "something" (e.g. materials, parts, tools, final products) in their workplace. These projects are chosen as they are considered to have the similar level of technical difficulty and likely contain the comparable amount of standard parts and mechanisms. However, the difference is there to ensure that the students in both cohorts have the opportunity to perform observation of users interacting with existing products. Design students can easily observe parents in the parks nearby the university, but transportation of children is something they are unlikely to have direct experience of and pushes them out of their comfort zone. Industry-based students can observe other employees in their workplaces moving objects that need to be moved, however designing a product to aid that movement is typically not something they would be tasked to do. The second difference is what the students are asked to do with the techniques, and is illustrated in Figure 3.

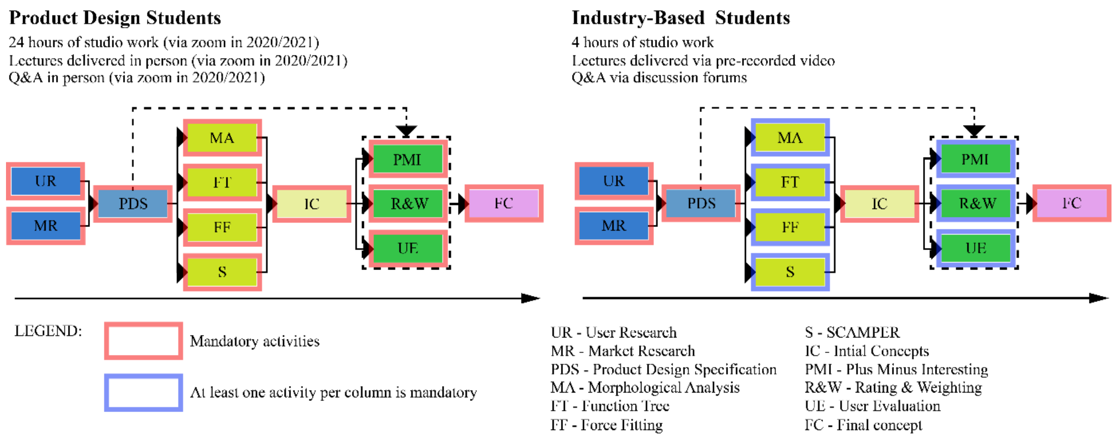

Figure 3. Activities performed for each cohort in 2020/2021 and 2021/2022

The design cohort is asked to use all of the techniques, even if they do not believe they will be useful. The industry-based cohort is allowed to choose concept generation and evaluation techniques they use, but is advised that they should ideally be using more than one. Final difference is the amount of both studio time and synchronous time for Q&A with teaching staff for the two cohorts. Design students spend 24 hours per semester in the studio, whereas industry-based students spend only 4-6 hours per semester in the studio. For design students Q&A is face to face, during the studio sessions. For the industry-based students it is encouraged during the studio hours, but as the time is quite limited more Q&A happens asynchronously via discussion forums, after the studio sessions have already taken place. During 2020-2021 academic year, while remote teaching was mandated by COVID19 restrictions, effort was made to recreate the studio environment in the same duration as it would take place in the studio but via Zoom.

In 2021-2022, with post COVID19 return to on-campus teaching, an hour-long session teaching the 6-3-5 technique to the industry-based cohort was included, in order to encourage concept generation. This was in reaction to the observation that previous industry-based cohorts were consistently producing less concepts. The students were guided through the process which included a discussion on why 6-3-5 is used and how ideas generated can be further explored as they continue their group work.

Both cohorts work in groups of 3-5 students, and have produced a range of concepts that they have, after a different number of divergence and convergence cycles, developed into a final concept that they then took to detailed design and embodiment. Design cohort groups typically chose to have two rounds of evaluation. Industry-based cohort group typically only included one round of evaluation.

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Table 1. Number of concepts generated

Year	Cohort	No. groups per year	Average no. group members	Average no. concepts after first concept generation	Average no. concepts following evaluation
2020-2021	Traditional design students	10	4.9	28.9	5.2
2020-2021	Industry-based students	6	4.5	8.2	4.5
2021-2022	Traditional design students	8	4.8	23.3	6.5
2021-2022	Industry-based students	9	4.3	9.7	3.6

Table 1 illustrates that traditional design students consistently produced more concepts, regardless of the delivery mode, with 4-5 concepts per member of the team on average. Industry-based students typically produced 1-2 concepts per team member on average. Following the evaluation, the product design students converged on roughly one developed concept per person, that, following their evaluation, converged into one concept overall. Industry-based students effectively developed most concepts further (towards a fully realised concept) before they converged into one final concept overall. In addition to quantitatively producing more concepts, traditional design students also included more notes on the function of the elements of their concepts and used a wider range of development methods.

Table 2. Percentage of groups that used generation/evaluation methods

Year	Cohort	Brain storming	Functional Tree	Morphological Chart	Scamper	Forced Fitting	Dot Sticking	Plus Minus Interesting	Controlled Convergence Matrix	Weighting & Rating	User Evaluation	Focus Group	6-3-5
20-21	Traditional		90	100	90	100		100	100	100	70	10	
20-21	Industry	83	33		17	17	17	17	100		17		
21-22	Traditional		100	100	100	100		100	100	100	75	25	
21-22	Industry	89	67		22	11		22	56	56			22

Table 2 illustrates the range of techniques used by different cohorts. Unsurprisingly, the traditional design students followed the directions and used all of the suggested techniques consistently. Industry-based students, given the choice, only used a few techniques consistently. In 2020 they predominantly used Brainstorming and Controlled Convergence Matrix (CCM), and only a few teams attempted function tree, scamper, force fitting, dot sticking (not explicitly taught) and user evaluation. In 2021 the range of techniques, and times they were used was higher, and majority of groups used function tree, CCM and weighting and rating more consistently too. Although all groups did 6-3-5 in one of the on-campus sessions, only two groups decided to include its results in the folio.

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3.1 Differences in generated concepts

Figures 4 and 5 illustrate a selection of design students' concepts and industry-based students' concepts.

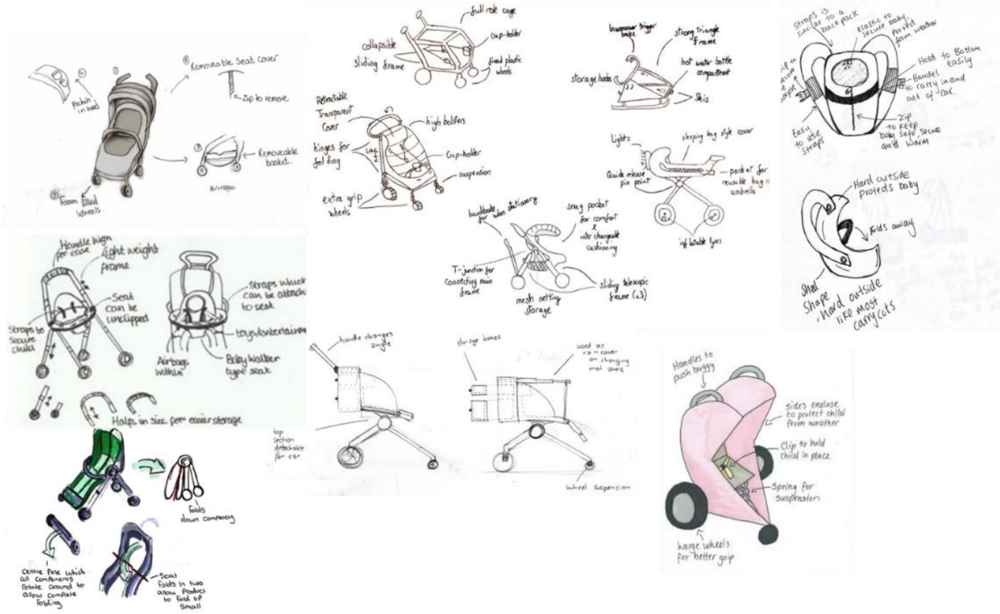

Figure 4. Representative selection of design students' concepts

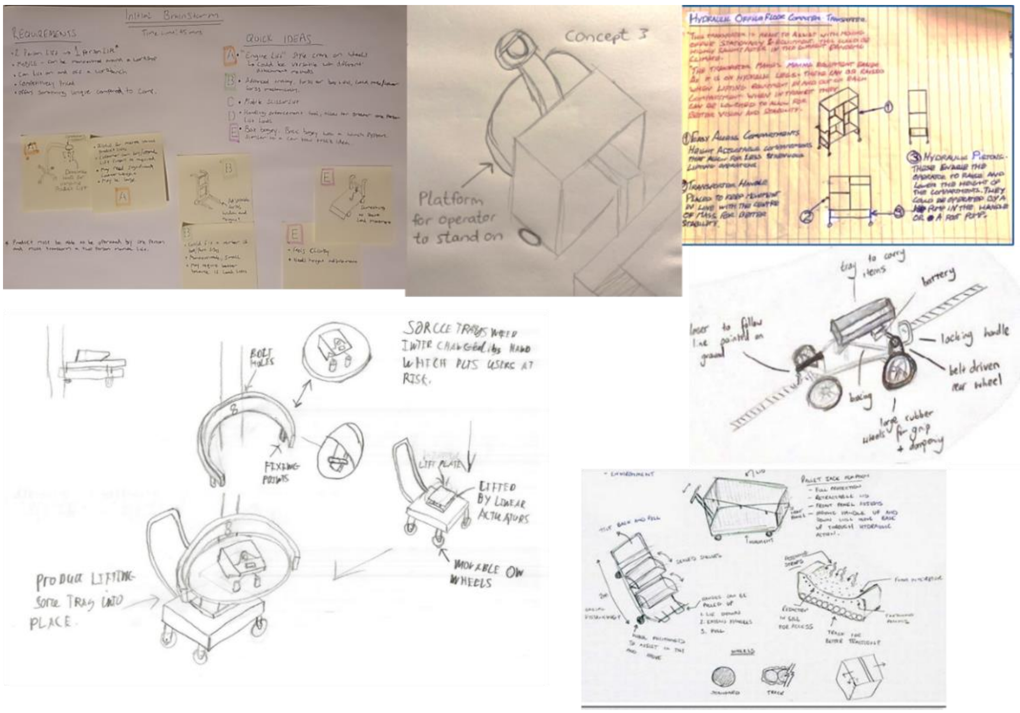

Figure 5. Representative selection of industry-based students' concepts

It is noticeable that traditional design students' concepts more consistently contain higher amount of annotations, and clearer illustrations of concepts. Industry-based students, in many cases tend to include sentences or paragraphs of text that describe concepts that are not always clearly visible in the sketches they are linked to, whereas design students include succinct callouts to key features and convey more information using less text. It is possible that this is a consequence of lower level of sketching skills. While sketching is encouraged throughout the course, industry-based students backgrounds are very varied and often would not include sketching or visual representation of concepts in any form outside of university work. Consequently, by reviewing their engagement on the online learning platform used for the course, we have noticed that they dedicate more attention to easily measurable activities such as formative quizzes or exercises for exams, rather than performing the activities aimed at developing the skills they cannot see a tangible link to the assessment in.

3.2 Effect of mode of delivery

Initial expectation was that studio-based work would produce more concepts. The traditional design students actually created marginally more concepts while working online, while industry-based students created marginally less, however mode of delivery did not appear to have a great amount influence on their outputs quantitatively. It should be noted that feedback was received from students stating that they felt isolated working from home and not being able to meet their team members, particularly where they did not know them prior to working together as a team. Inclusion of on-campus sessions for industry-based students in 2021 possibly did make a difference, as ability to guide their activities in those sessions could have contributed to slightly higher initial concept idea numbers, use of more varied techniques and led them closer to the divergence-convergence product development process.

3.3 Differences due to cohort backgrounds

Cohort background seemed to impact the outcomes more. Industry-based students fixated on a solution early, and most development was focused on mechanical elements and detailed design, rather than concept generation and development, which was the focus for the traditional design students. Industry-based students were good at drawing from the experience, but not necessarily connecting to the problem at hand in a novel way due to a lack of creative exploration being engaged in. Additionally, industry-based students were initially confused about the purpose of the 6-3 5 exercise, as it was not explained why they were undertaking it. They were just given the guidelines on what to do. It did seem to lead to slightly higher number of outputs that were converged more effectively. Following the exercise, a discussion on what was done, why and what is hoped to be gained from it was conducted, and the feedback from the industry-based students stated that this was found to be useful, leading them towards ideas they did not think of earlier.

4 SUGGESTIONS FOR INCLUSION IN TEACHING PLANNING

Industry-based students typically work in environments that require quick solutions and excessive work spent on generating solutions that will not be tangibly productive, does not come naturally to them. They may feel like they are "wasting their time" sketching designs they will then discard. They are very goal focused and will complete an activity if they see a clear link to the assessment. However, as a specific number of concepts to be created, or techniques to be used is not specified within any marking scheme, these students tend to not spend a lot of time developing those skills. To counter this, providing a studio-based environment for the industry-based students, where they complete tasks that are initially not explicitly linked to the project they are completing, and then facilitating discussion to identify what elements of their final solution are actually produced from activities such as 6-3-5 seems to have a greater effect than allowing them to choose the techniques to engage in. Specific, non-negotiable tasks provide an opportunity to complete the activities and then reflect on them. The feedback received does confirm that majority of students are in the end able to see the value of the activity.

A studio environment would see these industry-based students removed from their workplace, and therefore their comfort zone, freeing them from its influence and enabling students to be less fixated on specific solutions linked with their work-based activities.

Additionally, the focus on assessment and the elements that will be assessed seems to be much higher for the industry-based students. This could partially be due to the fact that, for many of them, the course is a contractual obligation and they have stricter time limitations in comparison to traditional design students. While this poses a challenge when the students only focus on elements of work they believe is tangible to the mark, typically resulting in reduced numbers of concept created, this can also be transformed into a benefit. By reorganising the teaching and assessment criteria, so that the creative methods to be performed are mandatory to include and where inclusion and reflection on the usefulness of the method at the end of the project is assessed, students engage with more creative processes, resulting a greater volume of divergent concepts. Mandatory, but fairly informal, reflection sessions after the use of these processes, to explain the concepts they just took part in and provide insight into the benefits of their use have also been found to have a positive influence.

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It may be valuable to contextualise the concepts taught in terms that each student cohort are familiar with, and is distinct to the highly solution-focused attitudes they typically work in. Such highly technical environments have a focus on detailed design, where efficiency and accuracy are paramount. Conceptual design values divergent, unfinished ideas that can serve as inspiration for more further developed ideas, until suitable solution is reached; what would be seen as inefficient in some environments, is a sign of efficient concept generation.
These findings are summarised in Figure 6, with factors improving divergence when teaching industry-based students roughly grouped into high, medium and low impact groups.

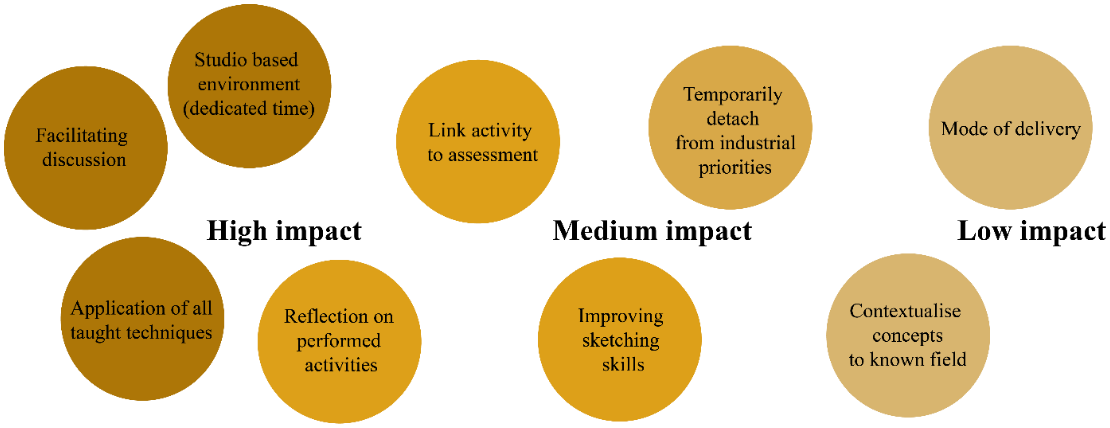

Figure 6. Factors improving divergence when teaching industry-based students

5 CONCLUSION

Outputs of two versions of a product design class taught to product design students and industry-based students show that studio work and insistence on working through different design techniques taught throughout the module have led to more productive conceptual design sessions, producing ideas with higher divergence. While initially it has been posited that the mode of delivery, mostly in-person and mostly online, may have an influence on the outcomes, it was found that the mode of delivery does not seem to have a large impact across both cohorts. Studio work and focused design work did seem to have a positive impact for industry-based students who produced slightly more solutions. It has also led to the use of a wider range of design techniques.
Including more structure and requiring mandatory use of all instructed design techniques by inclusion in the assessment scheme, might thus lead to better educational outcomes for industry-based students. They have been found to be more goal oriented and generally focus more on assessed elements of teaching. By including the reflection on the implemented design methods into the assessment they would be forced to re-assess the usefulness of those design methods, learning more about the ways to use them and their outcomes in the process. They would also be able to identify tangible benefits of their implementation on the product design.
Introduction of more extensive design studio work, focusing on intermediate tasks that do not necessarily directly tackle the final solution may be beneficial for the product design process in the industry-based cohort. Solving the problems that are separated from their day to day activities at work by inspiring them to focus on intermediate steps and disconnect them from the potential solution may inspire more effective divergent thinking and reduce fixation. It may also reiterate the need for development of sketching or visualisation skills to support this process.
Finally, contextualisation of design terms to the fields they are familiar with may aid further adoption of design techniques that may be useful in other activities they engage in daily.

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