MENTAL IMAGERY VIVIDNESS AND ITS IMPACT ON LEARNING ATTAINMENT IN DESIGN EDUCATION

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ABSTRACT
Recent research has determined that a diverse experience of mental imagery exists between individuals, even amongst those working in design. Designers, including those within engineering and product design, can experience mental imagery in varying levels of vividness across all sense modalities, from visual to emotional, and little is known about how this cognitive diversity impacts on their design process, or on their educational success. This paper poses the question: Does higher mental imagery vividness lead to better performance in a design module? By recruiting students from two engineering design classes to complete a psychometric questionnaire measuring multisensory imagery vividness and comparing these responses to final class grades, correlations have been determined between success in a design class and multisensory mental imagery vividness. The findings of this study confirm that the hypothesis posed is incorrect, with any correlations found showing that the higher a student scores their imagery vividness, the worse their final class grade is. These results pose further questions about the need for consideration of cognitive diversity in design education and how we can create more inclusive learning environments in engineering design.

Keywords: Mental imagery, design cognition, engineering design, education, inclusivity

1 INTRODUCTION
The experience of mental imagery, the perception of an image within one's mind, is often considered integral to a designer's cognition [1] and beneficial for designers across fields [2]. The experience of mental imagery allows those working in creative fields access to internal thoughts, emotions and senses [3]. Imagery is commonly believed to occur more vividly in creative individuals [4] and there is evidence that utilising the experience during the design process can improve outcomes [5]. One example of this is evidence indicating that utilising mental imagery to visualise a user while generating solutions can increase empathy and support user-centred design [5]. However, mental imagery is reported as being underutilised by experienced designers [6], with many claiming indifferences to the phenomenon in their design work, potentially due to the casual nature of the experience [7,8]. Additionally, prior research shows the assumption that designers inherently experience vivid mental imagery is not accurate, and for those it does hold true for, it is an experience unique to the individual, with diverse elements, processes and dimensions [9,10,11]. Understanding the scope of this cognitive diversity could improve student engagement, as well as engagement in settings such as codesign for healthcare due to an improved understanding of the requirement for personalised learning and design environments [12].
Commonly, mental imagery is discussed solely in terms of visual imagery, the experience of visualising an image within the mind. Visual mental imagery is considered useful in design working, with it actively assisting creative output in designers that experience the phenomenon [13]. However, mental imagery is experienced across varying modalities that cover different senses: olfactory, auditory, gustatory, tactile, and kinaesthetic [14,15]. Emotion mental imagery manifests in a similar manner with emotion imagery sharing traits akin to physical emotion perception, as is the case with other sense modalities [10;16]. Further to the diverse modality experiences, there are various dimensions of mental imagery that impact on a designer's cognition, such as rotational ability [17], or visuospatial imagery ability [18]. Often, mental imagery is discussed in terms of the "strength" of the image, referred to as the vividness of mental imagery [19]. The vividness of mental imagery ranges from aphantasia, the complete lack of imagery, to hyperphantasia, imagery described as being as vivid as real life [11]. Aphantasia is thought to impact around 1-3% of the population and hyperphantasia around 3-7%, with the remaining population experiencing mental imagery in-between, on a scale of sorts [11]. Further, individuals have

been found to experience different mental imagery modalities in varying levels of vividness, with it being possible to experience mental imagery in one sense but not another or to experience every sense at different levels of vividness [15].

Complicating mental imagery research into the diverse experience is the subjectiveness of the phenomenon [20,21], with it being difficult to measure due to it occurring entirely within an individual's mind and there being a limitation on objective measurement options. Currently, mental imagery is regularly measured through psychometric self-response questionnaires that attempt to measure the vividness of mental imagery through self-responding to scenario-style questions [22]. The Plymouth Sensory Imagery Questionnaire (PSIQ) [23] is a self-response questionnaire that measures mental imagery vividness across seven modalities: appearance, sound, smell, taste, touching, bodily sensation, and feeling. It presents individuals with five scenarios for each of the seven categories and asks them to rate their mental image on a zero to ten measurement scale, with zero representing no mental imagery, and ten an image as vivid as real life perception.

It has been found that there is a gap in existing research to investigate the diversity of mental imagery experiences within the field of engineering design [10], and in particular engineering design education. Compared with experienced designers, novice engineering designers have fewer external cognitive influences due to their limited design experience and knowledge. Studying engineers at the outset of their careers is therefore justified, as the impact of prior knowledge is comparatively low. It is hypothesised, based on existing research that the mental imagery experience is inherently useful in designers [11] that higher reported levels of mental imagery vividness across modalities, as measured by a pre-existing psychometric questionnaire, will lead to higher attainment levels in an engineering design module. The paper aims to confirm this hypothesis by comparing mental imagery vividness reports to grade attainment of engineering design students in specified design modules to find any potential correlations.

2 METHODOLOGIES

Participants were invited from University of Strathclyde's Department of Design, Manufacturing and Engineering Management (DMEM) undertaking The Design Emotion and Experience module (Module 1) or The Design Form and Aesthetics module (Module 2). During both modules students undertake an individual design project considering the full design process. Mental imagery vividness was measured in the study with a variation of the PSIQ [23]. Alterations were made to the PSIQ to remove smell and taste after a pilot study revealed negligible results from the inclusion of these questions. The PSIQ is measured on a scale of zero to ten. For this study, this measurement scale was interpreted as possible aphantasia (scores less than one), very low imagery vividness (scores one to two), low imagery vividness (scores two to four), moderate imagery vividness (scores four to six), high imagery vividness (six to eight), very high imagery vividness (scores eight to nine), and possible hyperphantasia (scores above nine). The PSIQ was provided to students as an online questionnaire, with an average response time of seven minutes and six seconds. The PSIQ results were compared with module grades, out of 100, allowing for equal comparisons. The results have been analysed by statistical analysis, and the calculation of Pearson Correlation Coefficients (PCC) between PSIQ results and module grades.

3 RESULTS

3.1 Overall PSIQ

There were 1,050 responses in total from the 42 participants, with 775 from the Module 1 cohort, and 275 from Module 2. Overall, 0.76% of the responses were measured as aphantasia, while 14.38% were measured as hyperphantasia. Of the Module 1 cohort, 35.48% of responses were very high imagery vividness, 29.03% were high, and 35.48% were moderate, while of the Module 2 students, 54.55% of responses were very high, 18.18% were high, and 27.27% were moderate (Figure 1). Overall, 40.48% of responses were very high, 26.19% were high, and 33.33% were moderate level imagery vividness (Figure 1).

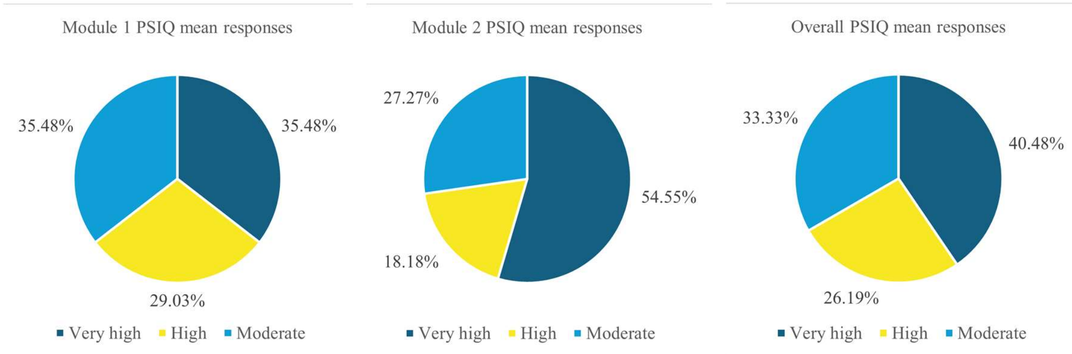

Figure 1. PSIQ mean responses by cohort and overall

Statistical analysis was performed on the PSIQ responses by calculating and comparing means, modes, medians, ranges and standard deviations of both modules and overall (Table 1). Means were similar between both modules and the overall, with 6.92 for Module 1, 6.99 for Module 2, and 6.94 overall. Both modules returned high overall means, with the exception of the feeling modality for both Module 1 and overall, both of which resulted in means of moderate level imagery vividness. The modes were calculated as very high vividness with a small number of exceptions: appearance for Module 1 and appearance overall were both possible hyperphantasia level vividness and touching for Module 1 and feeling for Module 1 were both moderate level vividness. The medians calculated were also mostly high vividness, with overall median for Module 1 7.00, for Module 2 8.00, and all 42 participants total 7.00. The only exception was for the feeling modality for Module 1 which resulted in a median of 6.00, or moderate level vividness. For the ranges, all results were large ranges 6.00 to 10.00 for Module 1, 8.00 to 10.00 for Module 2, and 8.00 to 10.00 for the overall results.

Table 1. Statistical analysis results by cohort and overall

	Appearance	**Sound**	**Touching**	**Body**	**Feeling**	**Mean**	**Mode**	**Median**	**Range**	**SD**
Module 1	7.92	7.00	6.75	6.70	6.23	6.92	8.00	7.00	10.00	2.32
Module 2	7.36	6.56	7.18	6.91	6.91	6.99	8.00	8.00	10.00	2.28
Mean (total M1&2)	7.78	6.89	6.86	6.76	6.40	6.94	8.00	7.00	10.00	2.31
Mode (total M1&2)	10.00	9.00	8.00	8.00	8.00					
Median (total M1&2)	8.00	7.00	7.00	7.00	7.00					
Range (total M1&2)	8.00	10.00	10.00	10.00	10.00					
SD (total M1&2)	2.01	2.44	2.16	2.22	2.46					

The standard deviations calculated were mostly between 2.00 and 2.56, with the exception of the appearance modality for Module 1 which resulted in a standard deviation of 1.89, and the sound modality for Module 2 in which the standard deviation was calculated at 2.84. The PCCs calculated, found in Table 2, were found to be all positive when considering the 42 participants together. This included two weak correlations for appearance versus feeling and sound versus feeling, and three strong correlations for sound versus touching, sound versus bodily sensation, and touching versus bodily sensation.

Table 2. PCC calculations by cohort and overall

Module 1	*Sound*	*Touching*	*Body*	*Feeling*
Appearance	0.4243	0.4120	0.2011	0.1985
Sound		0.5502	0.5497	0.0836
Touching			0.7208	0.2037
Body				0.3167

Module 2	*Sound*	*Touching*	*Body*	*Feeling*
Appearance	0.5007	0.2164	0.4896	-0.1907
Sound		0.8493	0.8370	0.2561
Touching			0.8463	0.2741
Body				0.1603

Overall	*Sound*	*Touching*	*Body*	*Feeling*
Appearance	0.4551	0.3349	0.2559	0.0814
Sound		0.6194	0.6084	0.1076
Touching			0.7487	0.2314
Body				0.2925

3.2 Module versus PSIQ comparisons

Further PCCs were calculated to find correlations between the PSIQ responses and the grades for each module, and the overall cohort of participants. These were calculated for each modality mean versus the overall grades, as well as the overall PSIQ means versus the overall grades. All Module 1 correlations, as per Table 3, were found to be negative with the strongest negative the feeling modality versus overall grades at -0.4035 and the weakest the sound modality at -0.1419 (although it should be noted this is not a negligible correlation). With the Module 2 correlations, all correlations were negative but were slightly weaker than Module 1 with feeling the strongest at -0.3811 and appearance the weakest at -0.0003 (Table 3). Overall, all correlations found between the PSIQ responses and the overall module grades for all 42 participants were negative, with strength ranging from -0.4088 for the feeling modality to -0.1156 for the sound modality (Table 3). The largest difference was in appearance with -0.3655 for Module 1 to -0.0003 for Module 2, with an overall PCC of -0.2696, while the feeling modality returned the strongest negative correlation across both modalities and overall.

Table 3. Statistical analysis results by cohort and overall

Pearson	**Module 1**	**Module 2**	**Total**
Appearance	-0.3655	-0.0003	-0.2696
Sound	-0.1419	-0.1287	-0.1156
Touching	-0.2280	-0.2231	-0.2318
Body	-0.1715	-0.1924	-0.1776
Feeling	-0.4035	-0.3811	-0.4088
Overall	-0.3796	-0.2390	-0.3440

4 MENTAL IMAGERY IN DESIGN EDUCATION

4.1 PSIQ

The level of vividness across the entire participant pool was high on average, with an overall mean of 6.94. It is commonly understood that designers and creative individuals often experience high vividness of mental imagery [1], and that appears to extend to the novice engineering designers in this study. An interesting area of future work would be investigating the reasons for this occurrence. The mean results are similar across all modules and overall, with one suggested explanation that participants' work in design may allow them a better understanding of their own mental imagery experience, although it is hard to conclusively give a reason without further exploration. For participant mean results, there are no extremes of 0.00 or 10.00, and only one participant's responses resulted in a mean of under 5.00 (still within the moderate level). Considering the mean results (Table 1 and Figure 2), participant results appear clustered into the moderate to very high-level vividness space, an unsurprising result for a group of engineering designers given prior research on the topic [1,10]. A result of note is the lower mean scores for the feeling modality for the Module 1 cohort and the total cohort, which is surprising given the high focus on emotion within the course teachings. It has been highlighted when considering the individual responses to questions, that the questions themselves may have an impact on responses. For example, one question in the feeling modality is "in love," which is a highly subjective emotion that will be impacted by an individual's own experiences.

For the Module 2 cohort, 54.55% of results were measured very high-level vividness, while 35.47% of the Module 1 cohort responded very high. This discrepancy could be explained by the Module 2 participants being further along in their education as it has been found that experienced designers are able to visualise faster [19]. Over 50% of Module 1 participants results of imagery vividness was within the high and very high categorisations, alongside over 70% of Module 2, corroborating the strong mental imagery vividness on average result. Of the total 1,050 responses, only 0.76% were aphantasia-level results, while 14.38% were hyperphantasia-level. Considering it is believed that aphantasia affects approximately 1-3% of the population, while hyperphantasia affects around 5-7% [11], it is expected that the levels of hyperphantasia will be reported higher in a study, although the jump to 14.38% here is above average. While this is a high number, the overall mean scores show that the level of possible hyperphantasia is closer to the expected average, with these results confirming that individual experience of mental imagery is complex and unique within a person's cognition.

Of the statistical analysis, there is consistency amongst the mode, median and range results, although there is a clear presentation of diversity in the mental imagery experience. This is clear with the high ranges, with participants responding at all levels of the imagery vividness scale, both within themselves and between participants. The standard deviations are all above 2.00 which is high and shows a large variation from the mean, despite also being consistent across modality and cohorts. For the PSIQ PCCs, while there are numerous weak correlations that have been disregarded due to a lack of conclusive correlations, the remainder are largely positive across all results. The feeling modality is an anomaly with more variation observed in the correlations. In particular, the appearance versus feeling modality correlations revealed a great deal of variation, with the Module 1 cohort's PCC calculated as 0.1985, and the Module 2 cohort as -0.1907, resulting in the overall PCC calculated as 0.0814. Further investigation into these results would be interesting as there are clear distinctions between cohorts.

4.2 Comparative results

PCCs were calculated for each of the modality means and overall means, both by separate cohort and overall. The weak correlations indicate more clustered data rather than true correlations so have been deemed negligible and removed from analysis. These results do not give a definitive answer to the hypothesis so are irrelevant within the scope of this research. Of the remaining results, all correlations found between PSIQ results and class grades were negative, with no positive correlations uncovered. This indicates that the hypothesis was incorrect and that higher levels of imagery vividness in novice engineering designers often leads to lower performances in a design-based module. Considering the common assumption that creative individuals often have more "useful" imagery [1], this is an unexpected result and further exploration of why would be advantageous.

Of the two separate modules, overall, the results from the Module 2 cohort were weaker than the Module 1 cohort, and the total. This is with the exception of the bodily sensation modality, although the differences are almost negligible. Potential impacts on these results are: the year group and length of study so far; the module project the participants have been assigned; their individual academic performance; their university course, faculty or institution itself; or their mental imagery experience itself. Further investigation into multisensory mental imagery would also be useful, for example, to consider why the correlations for the sound modality in particular are weaker than other modalities. One reason could be that sound imagery is not as regularly utilised during a design project, while appearance, touching and bodily sensation are often essential when creating products that have a user-interaction element. Additionally, prior research has found that there is direct impact from the questions, with individuals having unique experiences of the scenarios presented. For example, the sound of a cat mewing might be more familiar and therefore an "easier" imagery experience to consider for someone who lives with a cat, than for someone who has not regularly been around a cat. This is especially true for feeling mental imagery, with emotion being subjective to an individual's own emotional cognition.

5 CONCLUSIONS

This paper presented a correlation study with hypothesis that higher levels of mental imagery vividness would lead to better performance in a design module. It considered the question in the context of engineering design education by presenting student engineering designers with a mental imagery vividness questionnaire (the PSIQ) and comparing their responses to their class grades in a design-based module. The hypothesis was proven incorrect through statistical analysis undertaken on the results, which presented conclusively negative correlations between the PSIQ results and class grades investigated. The result here confirms that, on average, higher levels of mental imagery vividness in engineering design students results in lower grades in certain design-based module. The purpose of this paper is to share the correlations found between mental imagery vividness reports and grade attainment, with the results providing initial evidence of the importance of consideration of mental imagery experience diversity in education, and beyond. While simply asking pre-set questions that measure mental imagery vividness is not enough to fully understand the extent of the diverse experience and further development of more appropriate methods for measuring the mental imagery experience would be beneficial, the work begins the conversation about how and why this should be considered in learning environments. This work is a first step towards a goal of defining the mental imagery experience in engineering design students and understanding the diverse experiences and their impact on engineering design education. In addition, it encourages conversation on whether the correlations uncovered could extend to learning environments within codesign settings, such as in healthcare design projects that require educational considerations for patients, carers, and healthcare professionals new to design environments, and how this cognitive diversity could be accounted for within these more complex settings.

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REFERENCES

[1] Pearson D. G. Mental Imagery and Creative Thought. *Imaginative Minds*, 2007 (Proceedings of the British Academy).

[2] Hart E. and Hay L. Do You See What I See? Exploring Vividness of Visual Mental Imagery in Product Design Ideation. *Proceedings of the Design Society*, 2022, 2, 881-890.

[3] Palmiero M. et al. The Relationship between Visual Creativity and Visual Mental Imagery in Ageing. *Psychology of Creativity*, 2016, 6, 1870.

[4] Martindale C. Creative Imagination and Neural Activity. *The Psychophysiology of mental imagery: theory, research, and application. Amityville, NY, Baywood Pub. Co*., 1990.

[5] Dahl D. W., Chattopadhyay A. and Gorn G. J. The use of visual mental imagery in new product design. *Journal of marketing research*, 1999, 36(1), 18-28.

[6] Athavankar U. A. Mental imagery as a design tool. *Cybernetics and systems*, 1997, 28(1), 25-42.

[7] Pearson D. G. Mental Imagery and Creative Thought. *Imaginative Minds, I Roth, British Academy Scholarship*, 2007.

[8] Casakin H. and Kreitler S. The cognitive profile of creativity in design. *Thinking Skills and Creativity*, 2011, 6, 159-168.

[9] Gallagher J. Aphantasia: Ex-Pixar chief Ed Catmull says ‘my mind’s eye is blind’. *BBC News*, 2019, https://www.bbc.co.uk/news/health-47830256.

[10] Macfie R. L., Hay L. A. and Rodgers P. A framework for understanding mental imagery in design cognition research. *Proceedings of the Design Society*, 2023, 171-180.

[11] Zeman A. Blind Mind’s Eye: People with aphantasia cannot visualise imagery, a trait that highlights the complexities of imagination and mental representation. *American Scientist*, 2021, 109(2), 110.

[12] Hodson E., Svanda A. and Dadashi N. Whom do we include and when? Participatory design with vulnerable groups. *CoDesign*, 2023, pp.1-18.

[13] Taruffi L. and Küsser M. B. A Review of Music-Evoked Visual Mental Imagery: Conceptual Issues, Relation to Emotion, and Functional Outcome. *Psychomusicology*, 29(2-3), 62-74.

[14] Goldschmidt G. On visual design thinking: the vis kids of architecture. *Design studies*, 1994, 15(2), 158-174.

[15] Maciel I. M. et al. Mental Imagery for Multisensory Designers: Insights for Non-Visual Design Cognition. *Design for Tomorrow*, 2021, 1(221), 109-118.

[16] Herd K. B. and Mehta R. Head versus Heart: The Effect of Objective versus Feelings-Based Mental Imagery on New Product Creativity. *The Journal of Consumer Research*, 2019, 46(1)

[17] Pearson J., Rademaker R. L. and Tong F. Evaluating the Mind’s Eye: The Metacognition of Visual Imagery. *Psychological Science*, 2011, 22(12), 1535-1542.

[18] Allen A. D. Complex Spatial Skills: The Link Between Visualisation and Creativity. *Creativity Research Journal*, 2010, 22(3), 241-249.

[19] Kavakli M. and Gero J. S. Sketching as mental imagery processing. *Design Studies*, 2001, 22(4), 347-364.

[20] Milton,F. et al. Behavioural and Neural Signatures of Visual Imagery Vividness Extremes: Aphantasia versus Hyperphantasia. *Cerebral Cortex Communications*, 2021, 2(2).

[21] Palmiero M. et al. Domain-Specificity of Creativity: A Study on the Relationship Between Visual Creativity and Visual Mental Imagery. *Frontiers in psychology*, 2015, 6.

[22] Marks D. F. Visual imagery differences in the recall of pictures. *British Journal of Psychology*, 1973, 64, 17-24.

[23] Andrade J. et al. Assessing vividness of mental imagery: The Plymouth Sensory Imagery Questionnaire. *The British Journal of Psychology*, 2014, 105(4), 547-563.