Design and Technology Education: An International Journal

29.3

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:

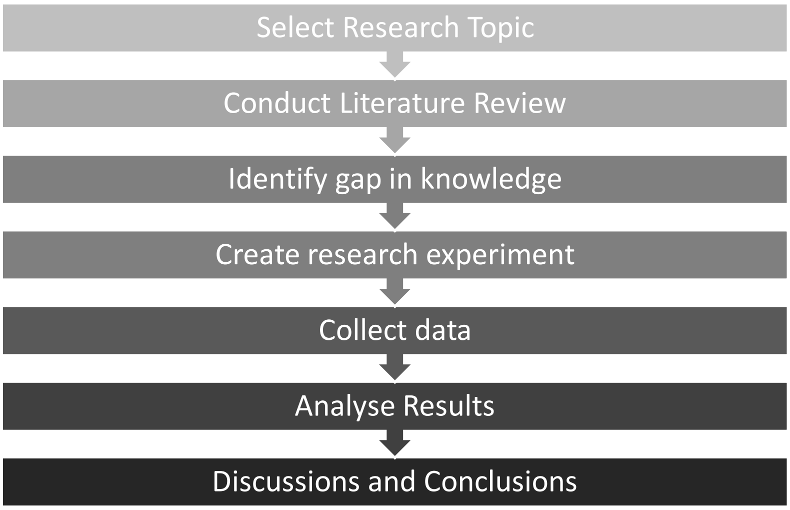

Figure 1. Research procedure

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.

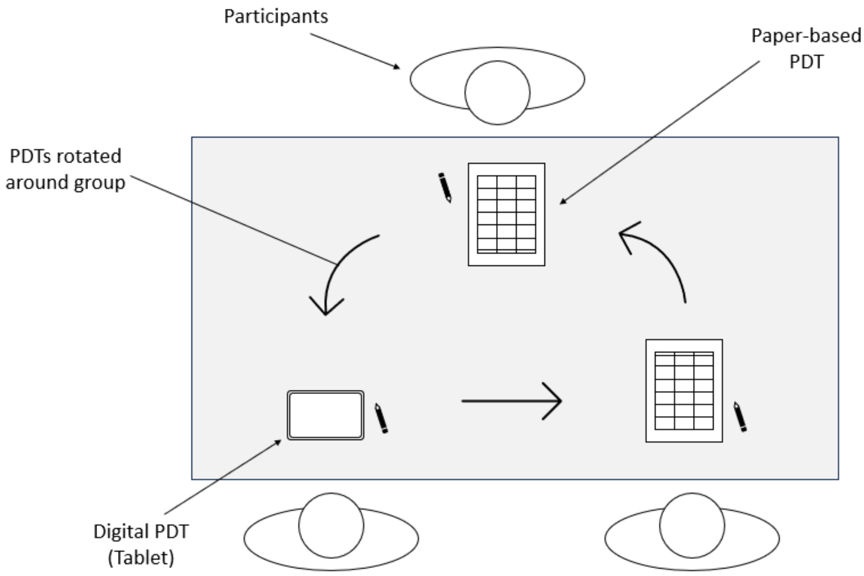

Figure 2. Experiment procedure

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.

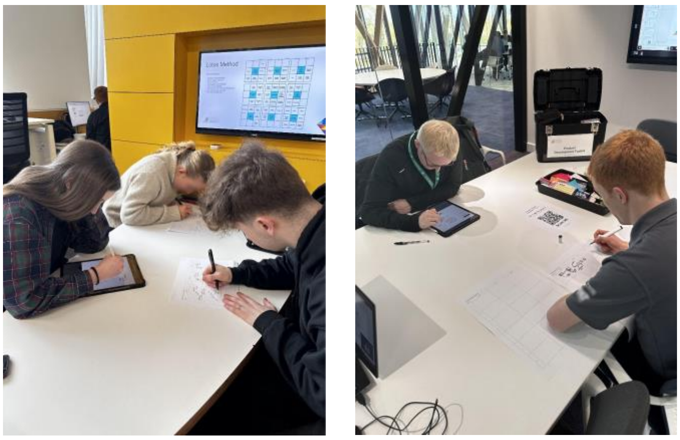

Figure 3. DMEM students (LEFT) and NMIS design engineers (RIGHT) participating in experiment

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%.

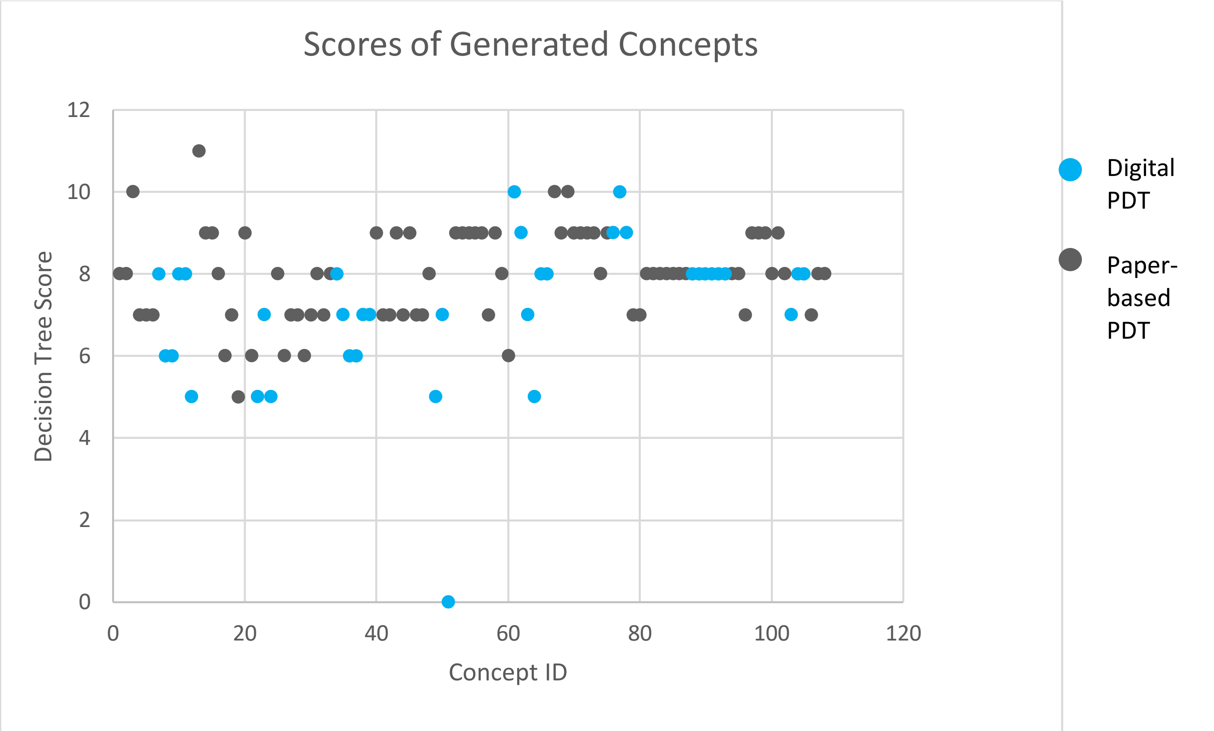

Figure 4. Score evaluated using decision trees against concept ID

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%.

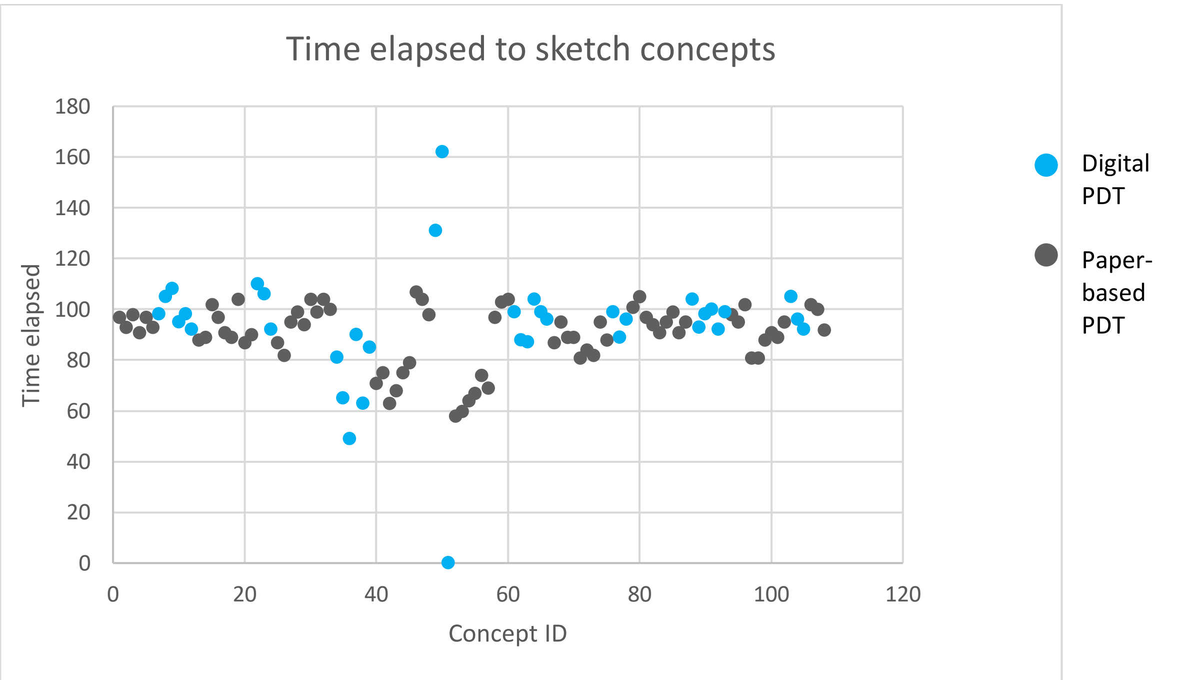

Figure 5. Time elapsed against concept ID

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.

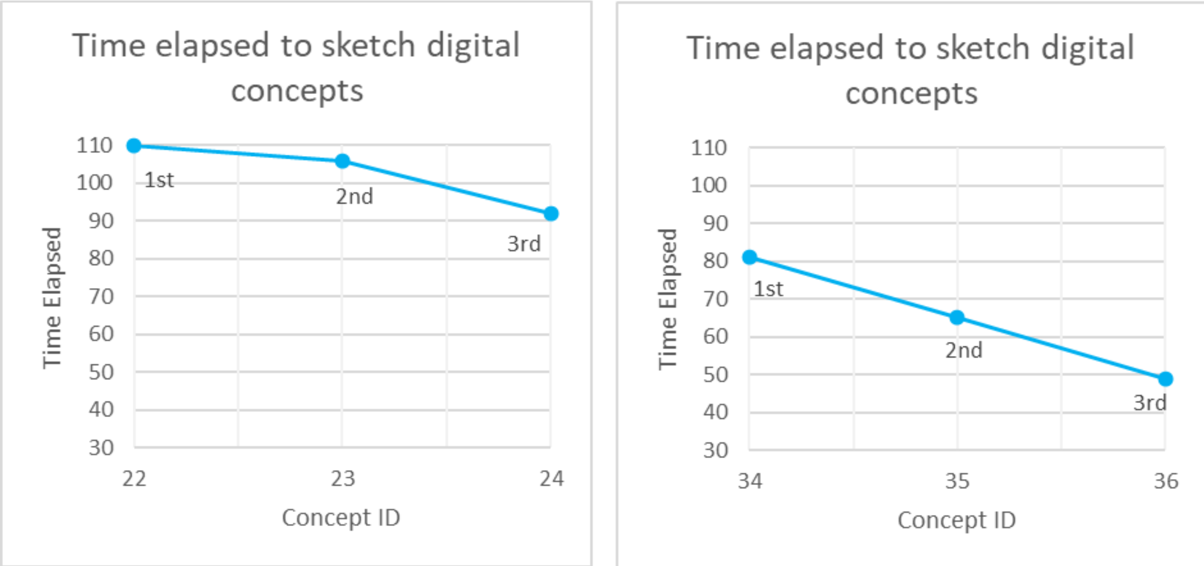

Figure 6. Time elapsed to digitally sketch concepts 22, 23 and 24 (LEFT), and 34, 35 and 36 (RIGHT)

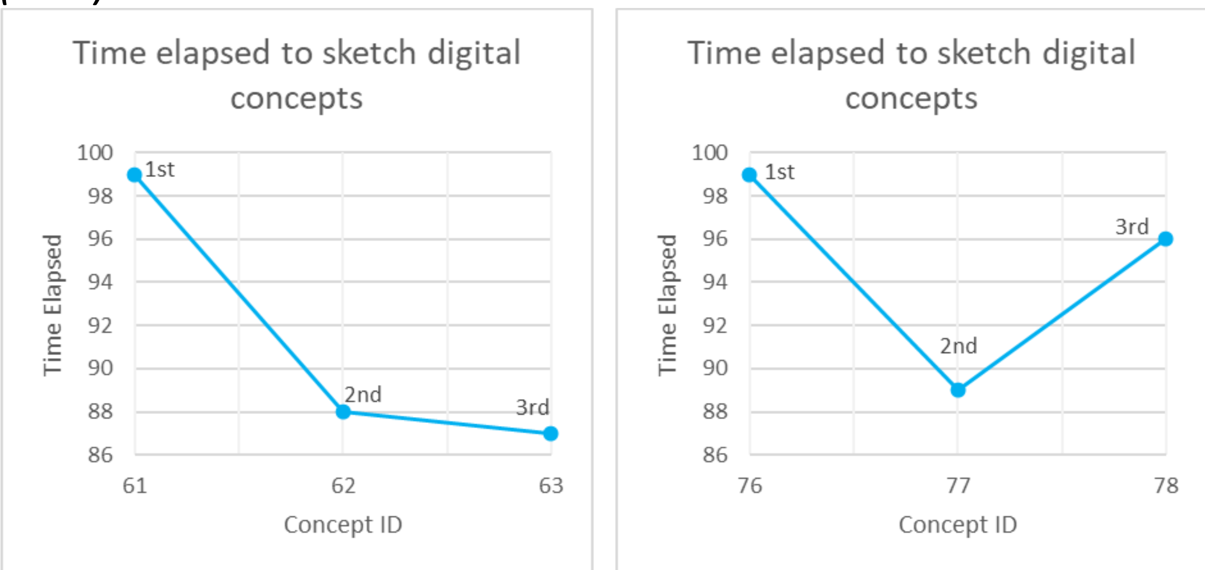

Figure 7. Time elapsed to digitally sketch concepts 61, 62 and 63 (LEFT), and 76, 77 and 78 (RIGHT)

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).

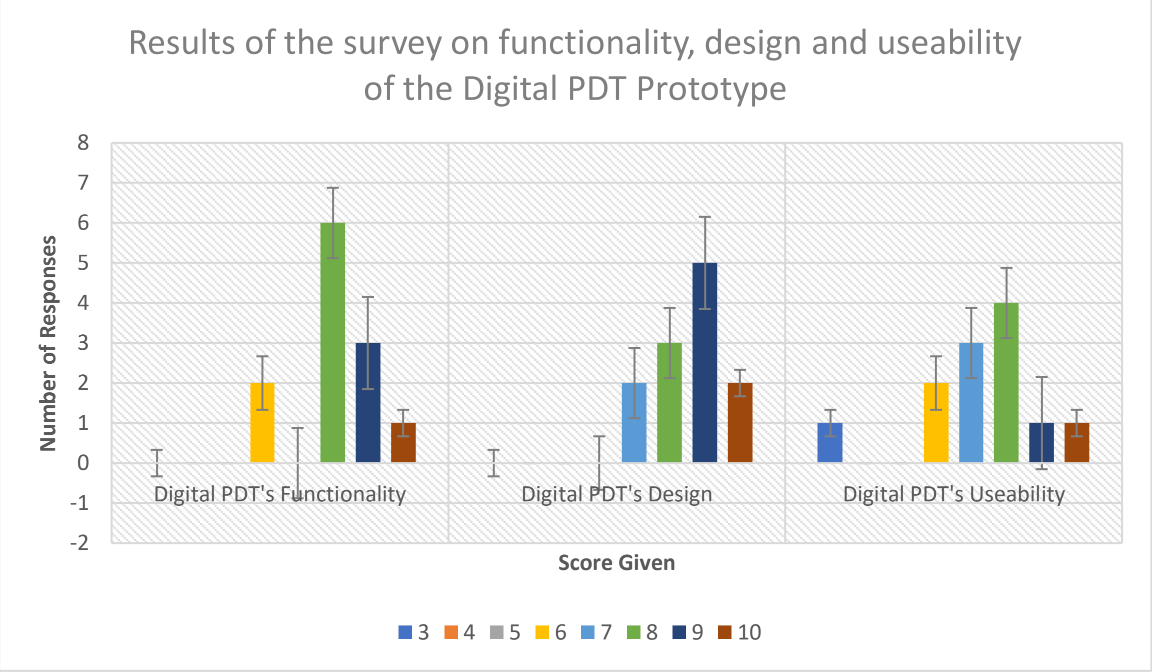

Figure 8. Results of survey on functionality, design and usability of the digital PDT prototype

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.

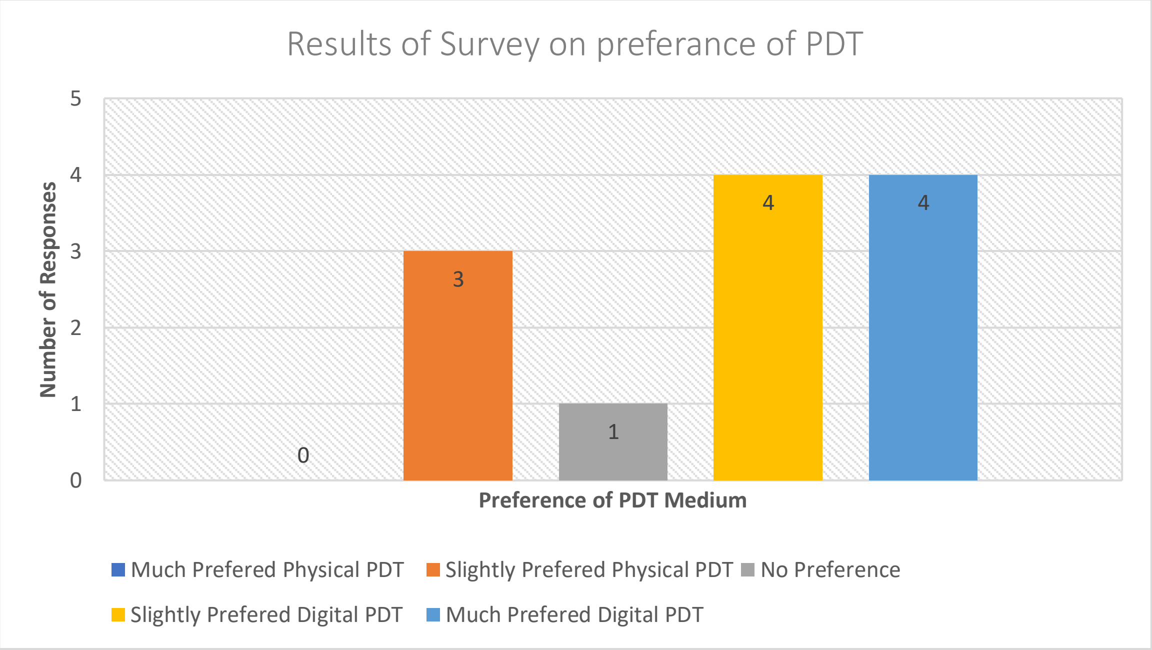

Figure 9. Results of survey on participant's preference between the digital and physical PDT

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.

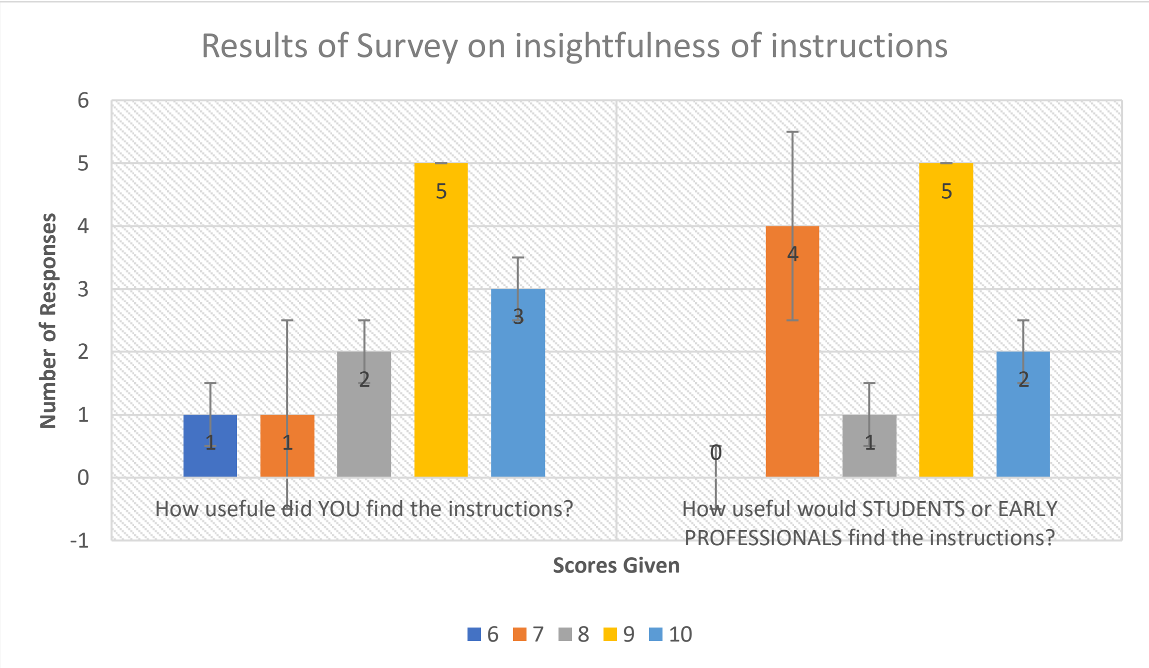

Figure 10. Results of survey on the insightfulness of instructions

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.

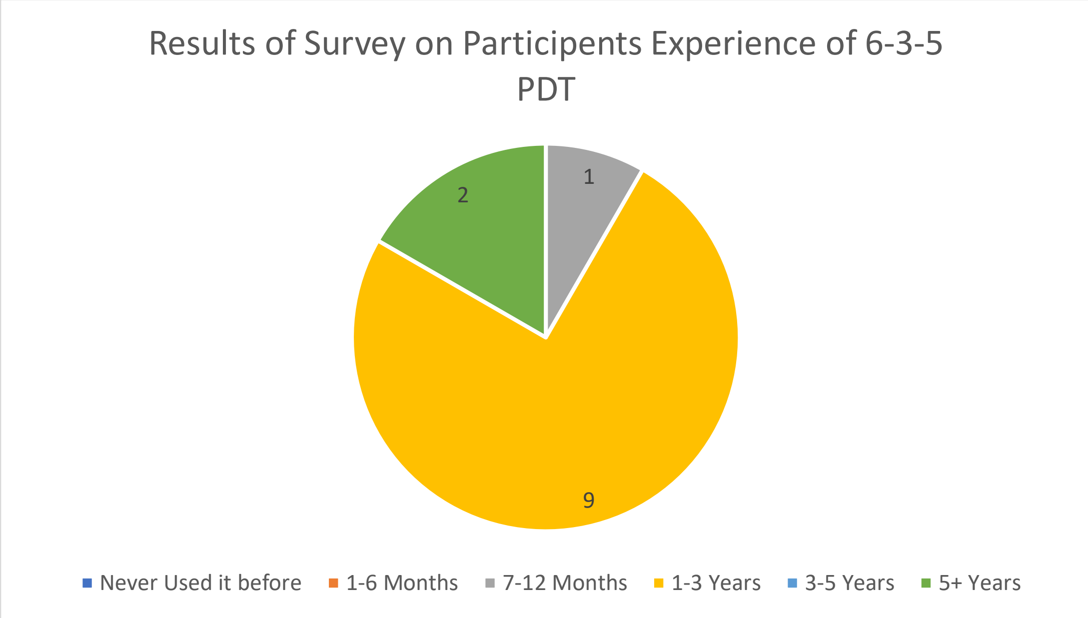

Figure 11. Results of survey on participants experience of 6-3-5 PDT

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.

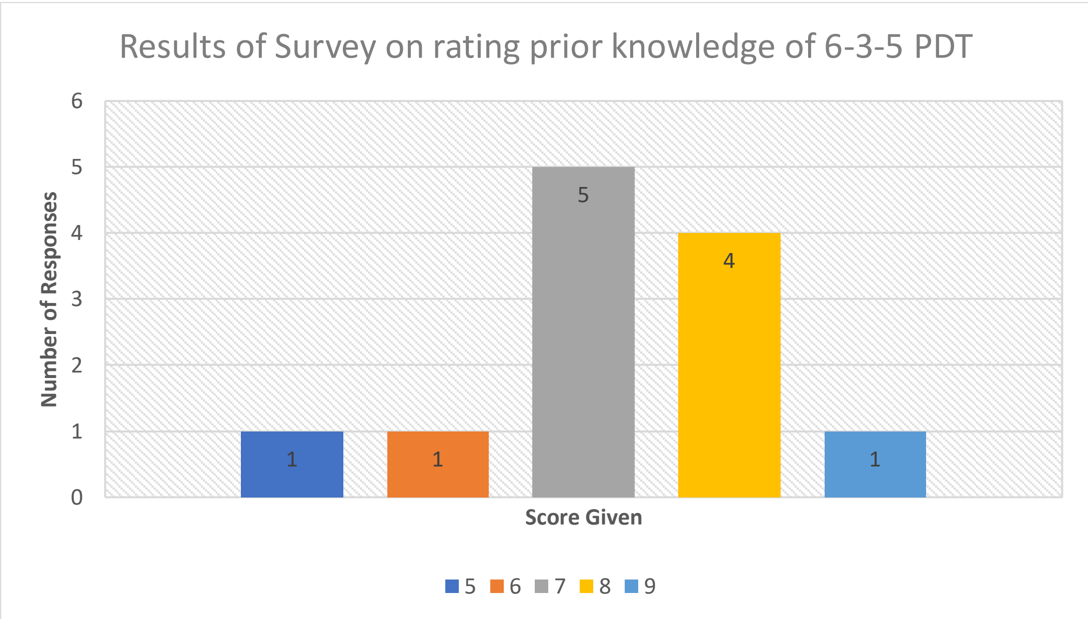

Figure 12. Results of survey on rating prior knowledge of 6-3-5 PDT

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).

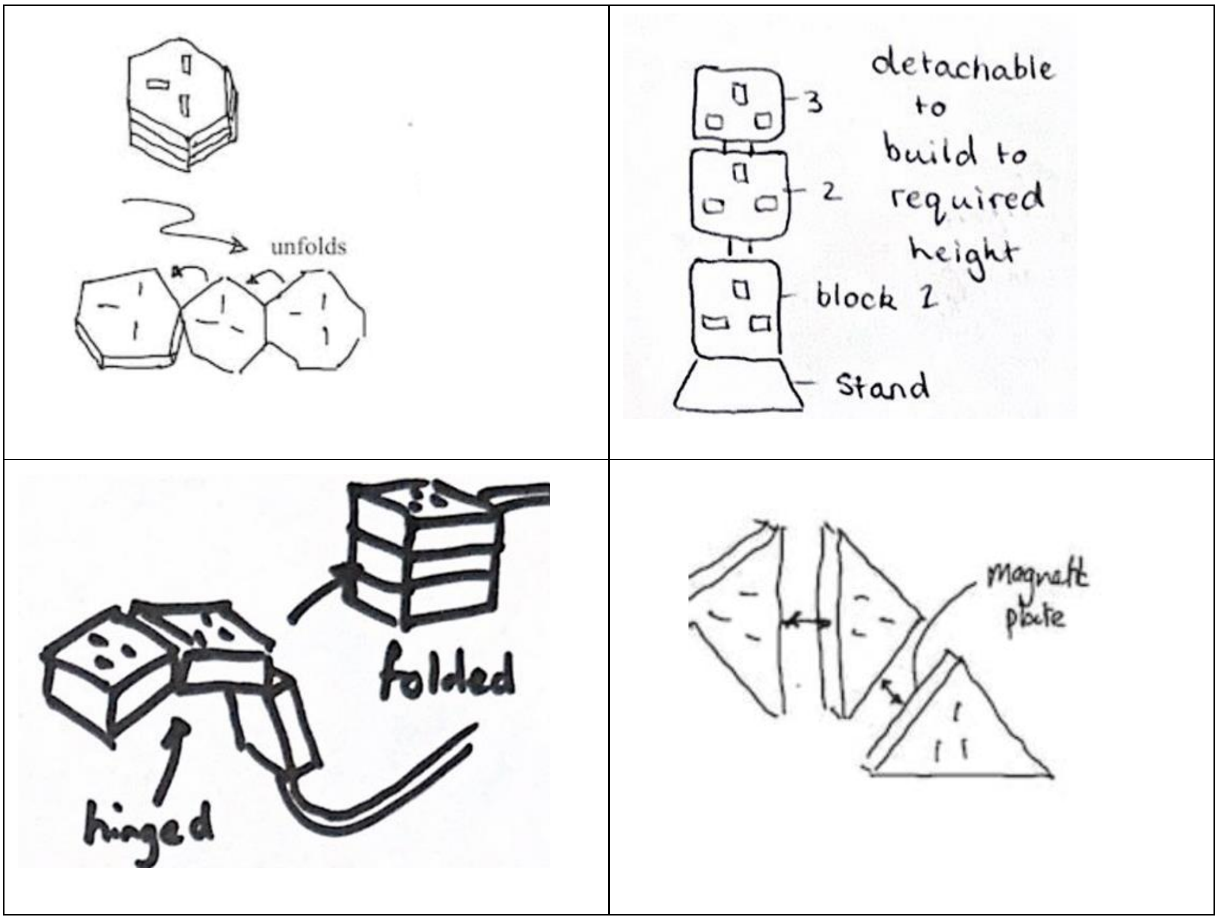

Figure 13 – Example outputs of the digital PDT (left) and paper sketching (right)

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.

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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.

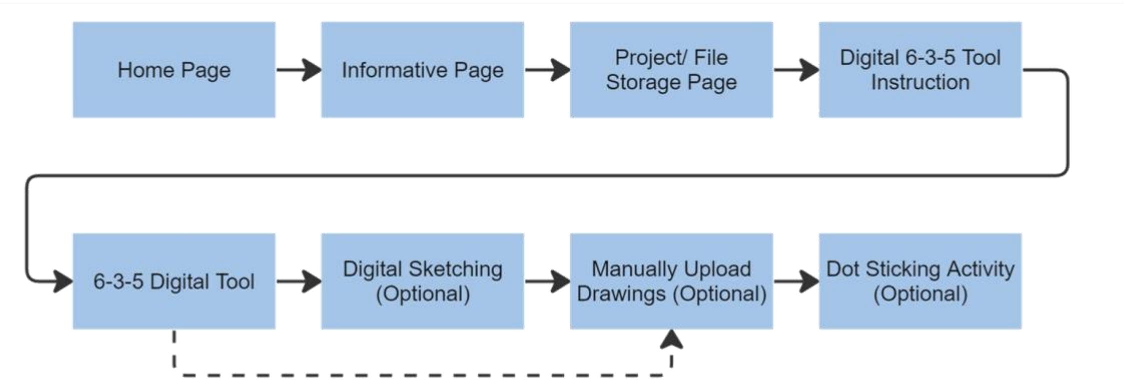

Figure 14. User Journey of the NMIS online PD toolkit app

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.

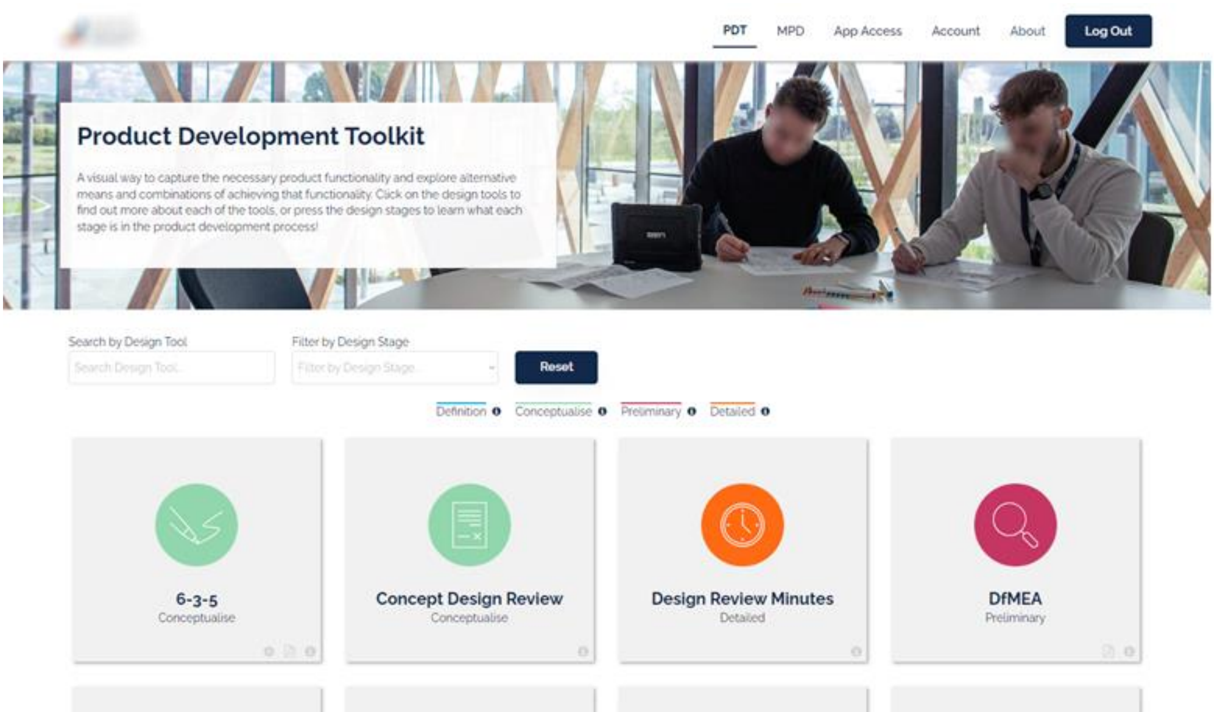

Figure 15. NMIS online PD toolkit: Home page

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.

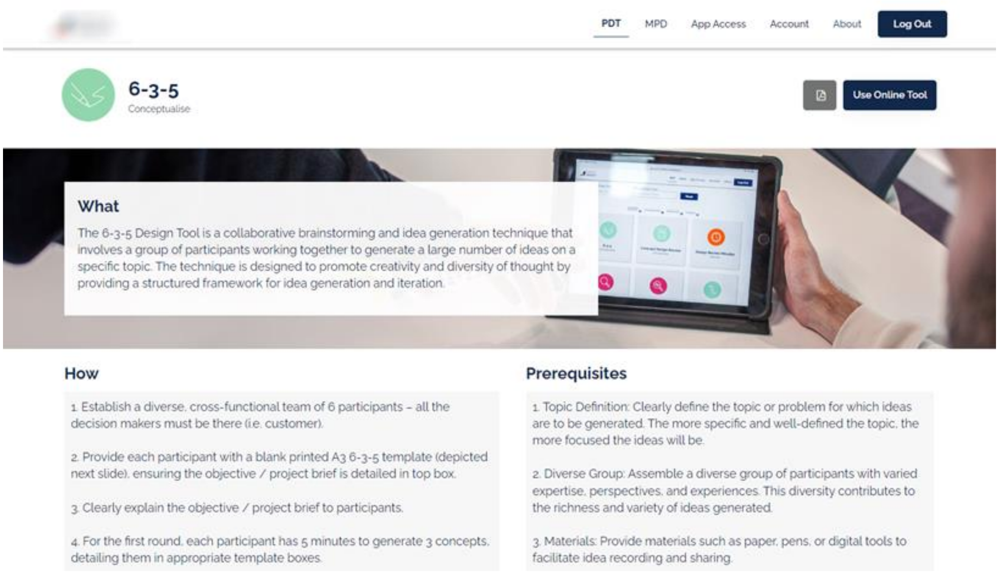

Figure 16. NMIS online PD toolkit: 6-3-5 informative page

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.

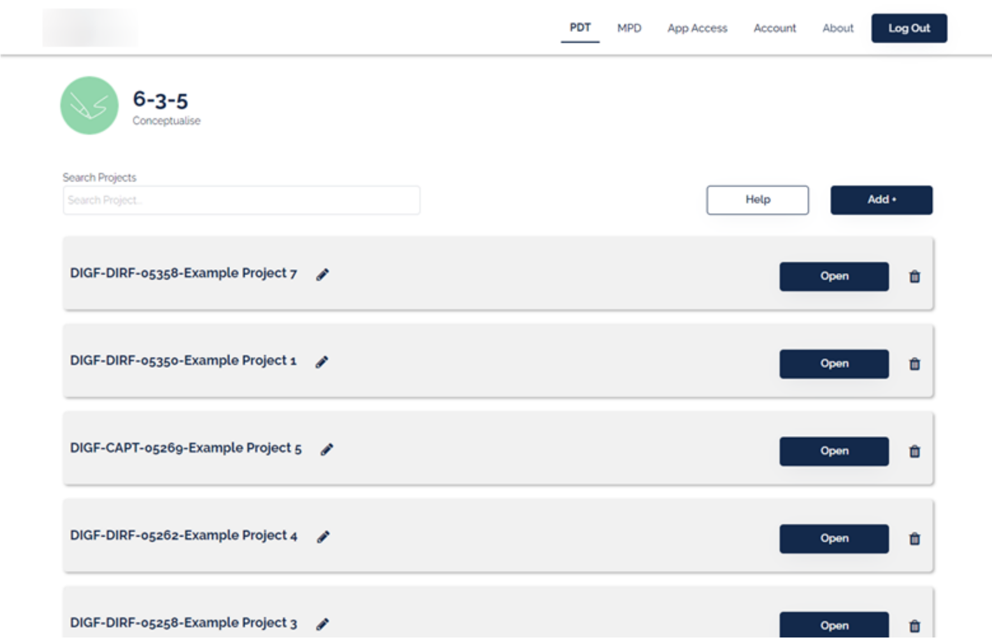

Figure 17. NMIS online PD toolkit: Project and file storage page

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.

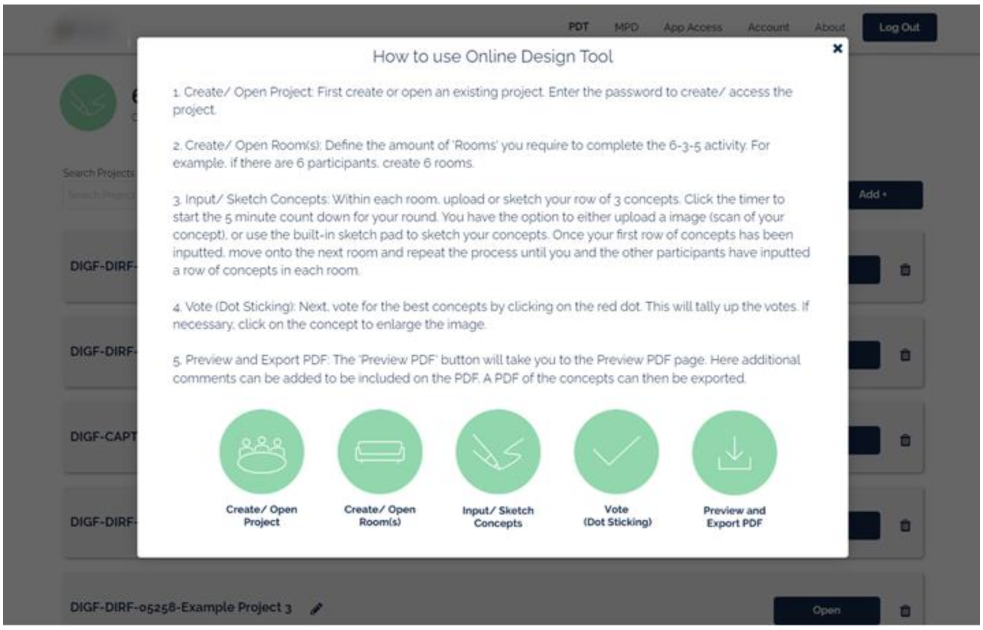

Figure 18. NMIS online PD toolkit: Digital 6-3-5 tool instructions

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.

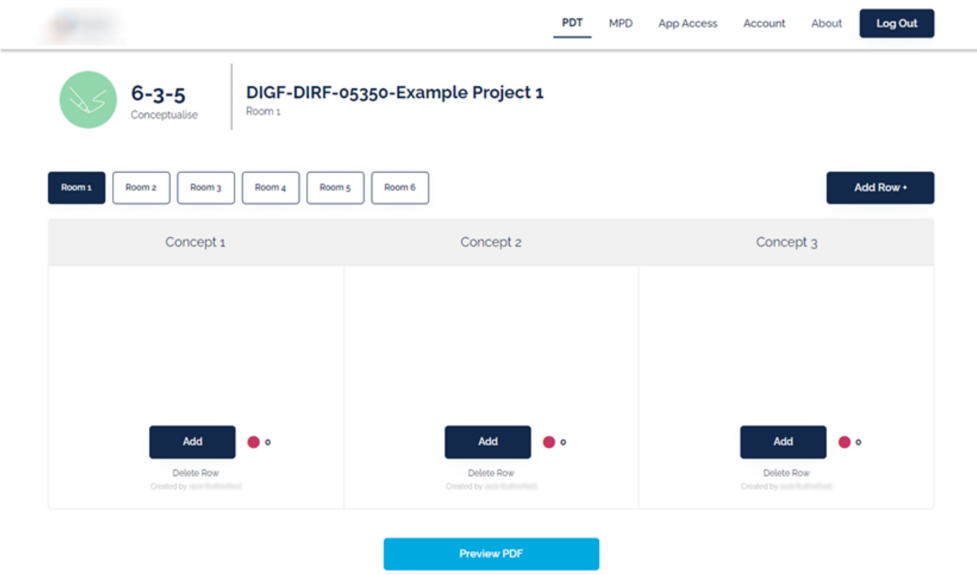

Figure 19. NMIS online PD toolkit: 6-3-5 digital tool

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.

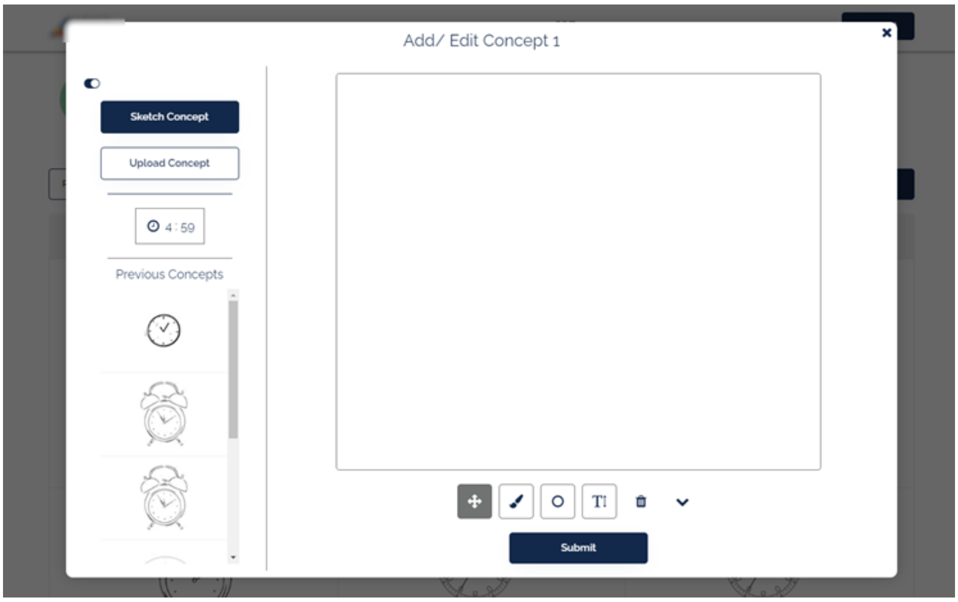

Figure 20. NMIS online PD toolkit: digital sketching

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).

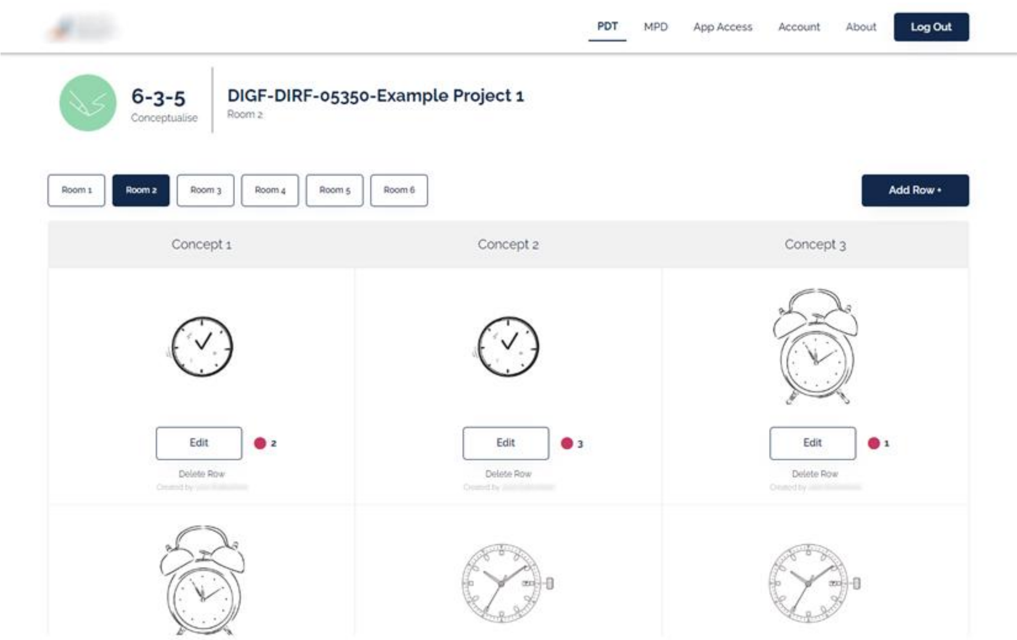

Figure 22. NMIS online PD toolkit: Dot sticking activity

Appendix B. Decision Trees

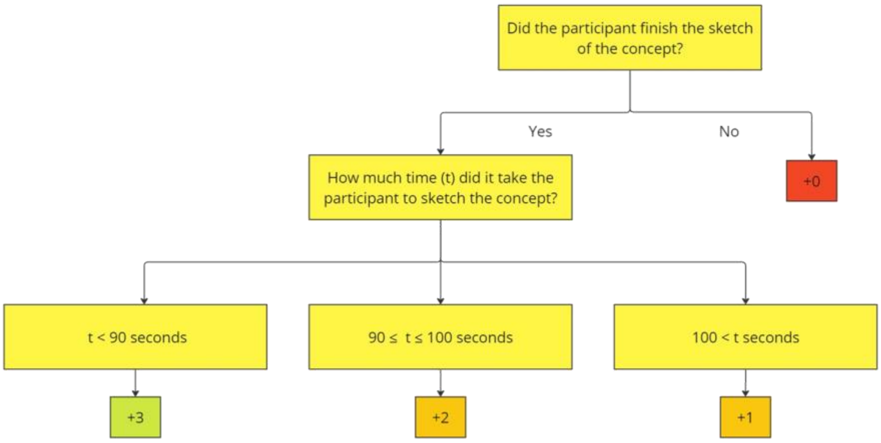

Figure 23. Decision tree to determine efficiency

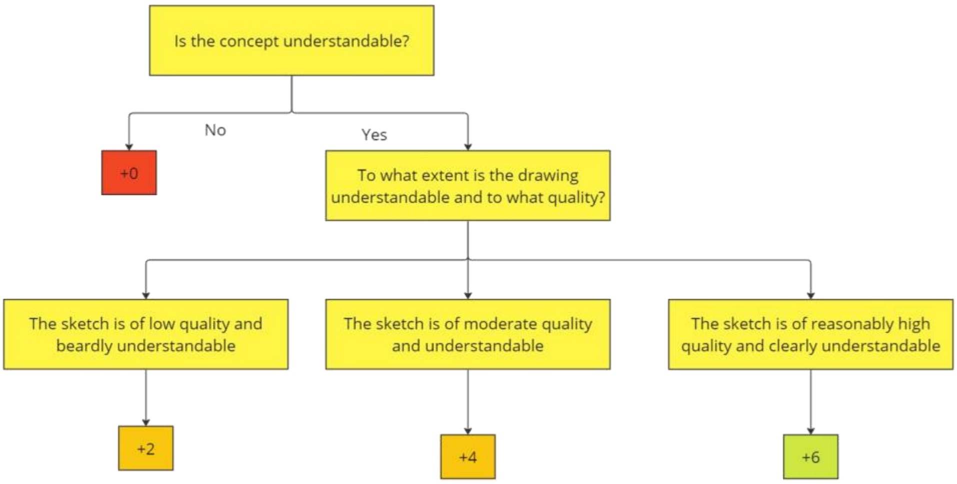

Figure 24. Decision tree to determine sketch quality

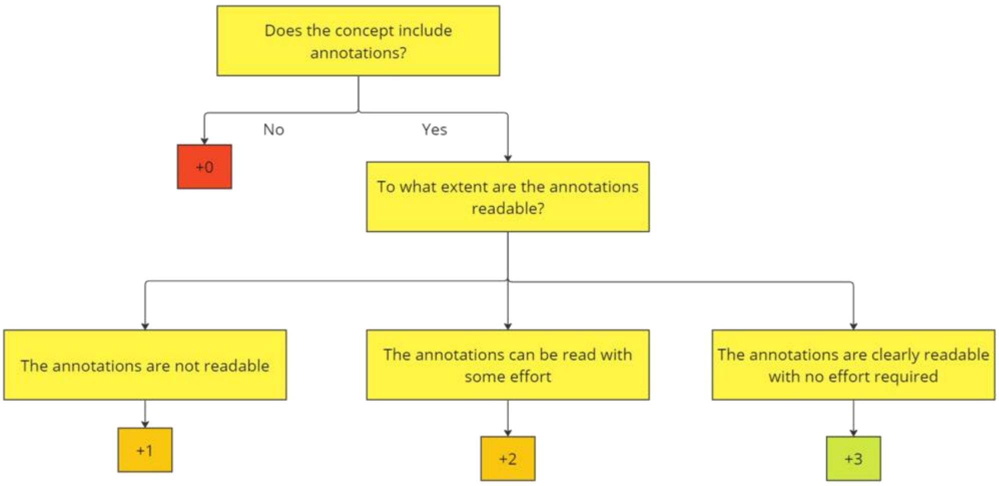

Figure 25. Decision tree to determine the detail of annotations