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Abstract
Education has a crucial role to play in the Design Singapore Initiatives. It is hoped that design thinking as a way of life can be infused in the pre-tertiary educational programmes. The current study aimed to clarify the main design thinking processes in the learning of Design and Technology in Singapore. The study mainly examines the design journals done by nine secondary two students during the design coursework. The findings indicated the constant involvement of divergent-convergent thinking processes throughout the design coursework. But the potential limitations towards the development of design thinking skills may lie in the current approach towards ideation and development where exploration of solutions hinge more on sketches rather than a combination of sketches and prototypes.

design thinking; design thinking acquisition; design and technology; design education, design thinking teaching and learning frameworks

Education has a crucial role to play in delivering the quantity, quality and right type of professionals to support Singapore in aspiring to be the global city for design (DesignSingapore Council, 2009). As stated in the Design Singapore Initiatives II (DSG II), educational curriculums in pre-tertiary and tertiary education are identified for seeding projects to redefine and introduce design learning. It is hoped that design thinking as a way of life can be infused in pre-tertiary design educational programme which include the Design & Technology (D&T) curriculum in secondary schools and design studies in the School of Science and Technology (DesignSingapore Council, 2009). D&T as a form of general education, was already established in the secondary school curriculum as early as 1986 (Tan,

1996; Chia & Tan, 2012). Currently, D&T is a compulsory subject at lower secondary level and an elective subject at upper secondary level.

Although design education at pre-tertiary level is as an important gear in DSG II, few studies have been done to understand the potential and development of the subject in the design ecosystem in Singapore. At the same time, the potential of the D&T subject as a form of general education, the application of design thinking as a way of life and the potential of transferring design thinking from D&T to other disciplines has also not been clarified extensively.

The purpose of current study aimed to clarify the main design thinking processes during the integration of design and technology embedded within D&T learning in Singapore. Through this clarification, the study also aimed to be the first of a series of studies to identify and develop effective teaching & learning frameworks and strategies for design thinking acquisition at pre-tertiary level.

Design Thinking

The root term of design thinking emerged in the late 1960s (Hassi & Laakso, 2011). According to Georgiev (2012), the concept of design thinking was explicitly used by Lawson (1980) and was developed by Cross (1982) and Schön (1983). It seemed that design thinking may be viewed in at least two main viewpoints, i) an analysis of designer viewpoint and ii) a human-centred problem solving viewpoint (Georgiev, 2012). Where the former viewpoint can be seen as the study of the practices of working designers and the latter, the human-centred 'open' problem solving process decision makers used to solve real world wicked problems (Melles, 2010). From a historical point of view, there is a diverse understanding of design thinking (Georgiev, 2012). The ambiguous and constant evolving nature of design thinking make it seem impossible to provide a conclusive description of its scope (Georgiev, 2012). Nonetheless, design thinking may involve the following (Georgiev, 2012):

- Shifting attention to parts of the problem
- Way of knowing
- Reflective thinking approach
- Periodic and dialog style of inquiry
- Use of various specific types of thinking and media
- Wicked problems approach
- Abduction with unknown entities
- Activities beyond framework of problem solving
- Encompassing many types of skills and intelligence
- Practices
- Structured pattern of processing information
- Cognitive styles of processing information

- Strategies of addressing “ill-structured” and “wicked problems”

D&T Education in Singapore

General Perspectives of D&T

Although the D&T subject was modelled very closely to similar subjects offered in UK in the 1980s, the current D&T subject has moved away from the strong flavor of craft and vocational emphasis of Woodwork and Metalwork to a subject that focus on non-vocational and general education orientated curriculum that focus on students’ holistic education and development (Chia & Tan, 2012). According to Chia and Tan (2012), the philosophy of D&T practice as a form of general education seemed to be inspired by the different aspects of ‘designerly’ ways of knowing mentioned in Cross (2007). Chia and Tan (2012) further suggested that the definition of D&T as a form general education may be further justified by Cross (1980) where general education is in principal non-technical and non-vocational.

Teaching and Learning Strategies in D&T

The development of pupils in D&T as described by Tan (1996) could be seen to involve two major phases of teaching and learning, (i) formal lesson of understanding design method, principles in design, design tools, technology and design method and (ii) operationalization of the design method by pupils themselves. Tan (1996) went on to emphasize the importance of sketching and drawing abilities in students and explained that these abilities is far beyond that of communicating ideas, presenting ideas and construction drawings. The ability to sketch and draw promotes visual thinking between mind and paper in an interactive nature (Goldschmidt, 1994; Schon & Wiggins, 1992; Schenk, 1991). Drawing seemed to be vital to thought organization during the process of teacher-pupil discussion where pupil constantly shaped and reshaped design solution (Tan, 1996). This facilitates creativity and is important for the exploration and manipulation of ideas and assist in problem definition (Garner, 1990).

Design Thinking in D&T

As mentioned by Tan (1996), a major component of D&T is the operationalization of design methods during the process of designing. Chia and Tan (2007) looked into documenting design thinking in the form of digital design journal using the tablet PC via the software Tab-Sketch. Chia and Tan (2007) felt that the important role of doodling, sketching and drawing, and how it supports creative work in an intimate way ought to be clarified. This was further motivated by the findings in Cheng & Lane (2004) where the use of digital pen provided that ability to record and replay graphic marks with timeline. This ability of recording and replaying the act of design sketching and doodling provided the possibilities of understanding the designer’s way of thinking and visualization in action (Chia & Tan, 2007).

While, Chia and Tan (2007) focused on exploring possible design thinking tools in the area of sketching and doodling, Lim, Lim-Ratnam and Atencio (2013) explored the process of designing in the context of D&T. The design journals and graphic representations of two secondary four pupils were examined together with interviews with the students and supervising teachers (Lim et al., 2013). The graphic representations by the pupils were mainly line illustrations that represent the emotion and feeling of the pupils during the process of designing. Through the graphic representations, Lim et al. (2013) suggested that the process of designing is unique and there is no way to define or dictate how one should go about designing. Lim et al. (2013) further suggested that pupils may begin the design process by examining existing solutions then move on to refine the problem situations, explore some initial ideas through simple models and testing before conducting research to develop the idea further. Throughout the entire design process, the pupils may transit randomly from one design stage to another as the design evolves (Lim et al., 2013).

Methods

Scope of Study

The current study focus on a typical secondary two D&T programme in a local secondary school in Singapore. As mentioned in the previous section, D&T is a compulsory subject at secondary one and two level (lower secondary); and an elective subject in secondary three and four (upper secondary). At secondary one, all students do not have any prior knowledge about D&T, a typical D&T programme at secondary one level mainly touch on the foundation and basics of the design process. Since D&T is only an elective at the upper secondary level, the D&T programme at secondary two level may provide a better reflection on the full cycle of design process that most of the secondary school students would have gone through in their secondary school education.

Participants

The participants in this study came from a class of 41 secondary two students in Dunman Secondary School in Singapore. The D&T programme in Duman Secondary School is widely recognized by the local D&T fraternity to be well established among the secondary schools in Singapore. At secondary two level, the students are generally around the age of 14 and will have prior D&T knowledge. Throughout the design coursework, students were grouped to work in pairs although majority of the processes were to be done as individuals.

During a discussion with the teacher teaching the class for D&T, it was understood that not all of the work done by students present a good representation of D&T learning in the class. Some of the works were lacking in documentation on the processes that students had done. Some students were not able to produce good quality work due to heavy commitments in other school activities. Out of the 41 students, nine students' work were selected and analysed as representatives of the typical D&T work done in the class. The grouping were as

follow: Group A, Group B, Group C, Group D and Group E. It should be noted that Group E consisted of only one student. The grouping of students are as shown in Table 1.

Table 1: Grouping of Students in Each Group

Group	Student
Group A	S1A
	S2A
Group B	S1B
	S2B
Group C	S1C
	S2C
Group D	S1D
	S2D
Group E	S1E

Tasks

The secondary two D&T programme hinged on the design coursework that spread over 14 weeks with a 2 hour lesson each week. The students would engage the design coursework in pairs but due to the odd number of students in the class, one of the student actually worked as individual. The main stages in the design coursework include:

1. Identification of Problems
2. Idea Conceptualization
3. Design Development
4. Prototyping
5. Evaluation

Although students were grouped to work in pairs, they were required to work on stages 1, 2 and 5 individually. They were to submit their work related to the three mentioned stages as individual work.

During the design coursework, students often had individual consultation sessions with the teacher in-charge so as to allow the teacher to understand the challenges that the students were facing and also to provide guidance for the students.

Procedures

The current study is based on a qualitative approach that aimed to analyze and understand the design thinking trajectories that the students have taken, starting from the stage of problem identification to evaluation. The main piece of data analyzed in this study is based on the design journal supported by the feedback from students given to the teacher in-charge during the consultation sessions and the feedback provided by the teacher in-charge.

Findings

Exploring Design Problems

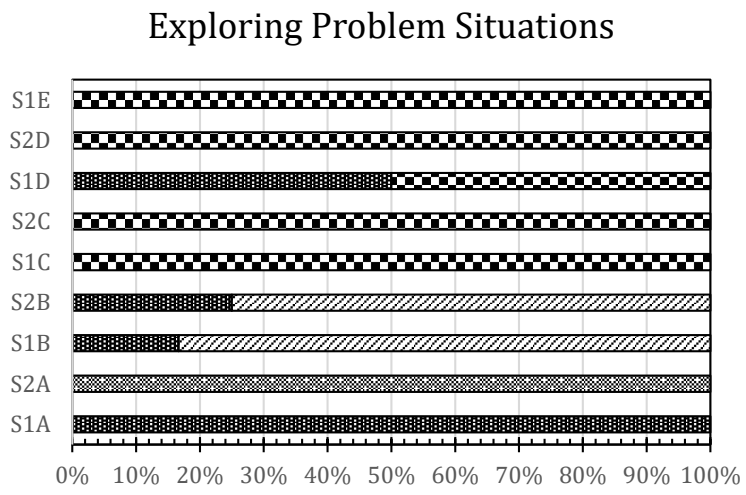
The design coursework started off with students given a theme for exploring and identifying possible related design problems, also known as problem situations. The main emphasis for this stage focused on students' ability to explore and justify possible design problems in breadth and depth.

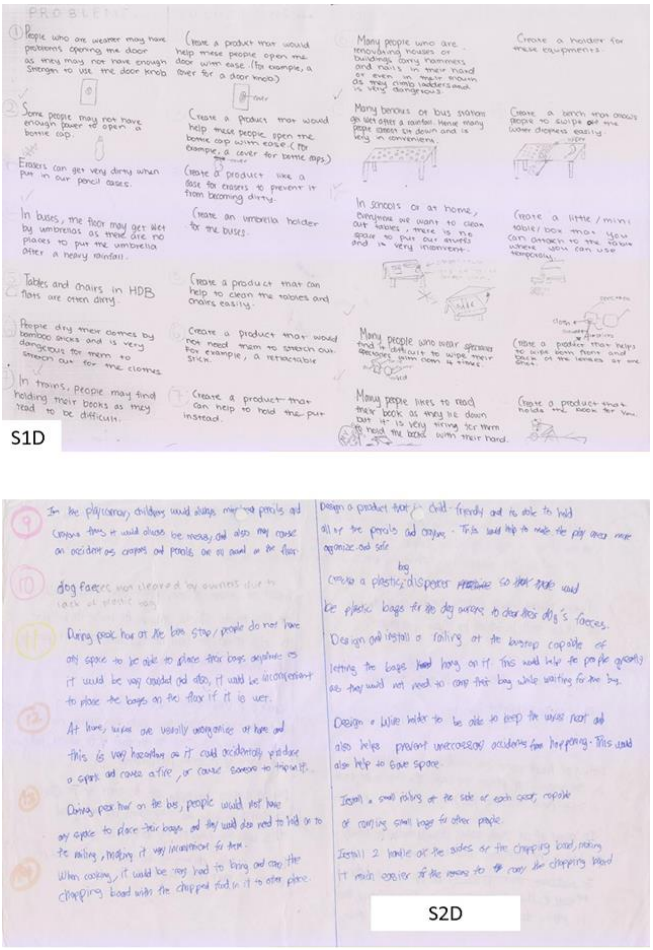
The main challenge for D&T teachers during this stage of the design process is to guide the students to explore and identify authentic design problems. It was believed that, due to their limited exposure and experience in life, most students often tend to explore design problems revolving around their home context or have a superficial understand of the design problems that they come in contact with.

In order to allow students to explore and identify design problems in a wider range other than home context, students were taught various brainstorming methods like mind-mapping, note-listing and 5Ws 1H (Why, What, When, Where, Who and How). Students may choose to use any of these methods to explore possible design problems. To ensure that students explore a variety of design problems, at least four design problems need to be identified.

During the initial stage of problem identification, it was observed that slightly more than half of the 9 participants preferred to explore and brainstorm possible problem situations using note listing method, refer to Figure 1.

In note-listing, students described problems that they could think of in words. Some sample journal pages of students using note listing style is shown in Figure 2a and 2b. From the journal pages, it was evident that some students had tried to provide some form of evidences to rationalize their claims on the identified design problems, even though research was not necessary to be conducted at this stage. Students S1D and S2C made used of simple sketches in addition to written notes to articulate the design problems. While student S1C provided pictures obtained from the internet to supplement the written information.





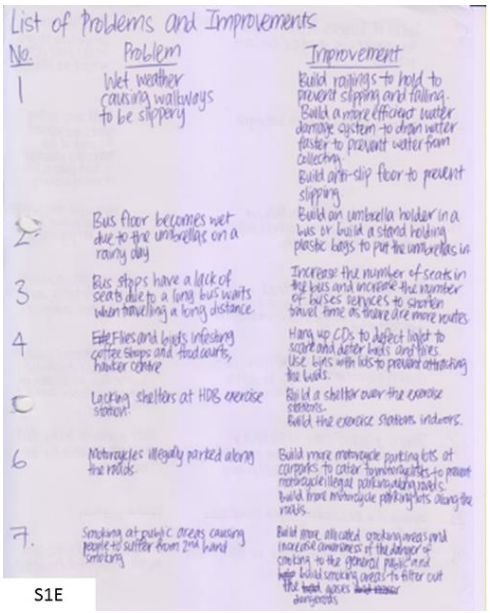


Figure 2a: Brain storming using note listing.

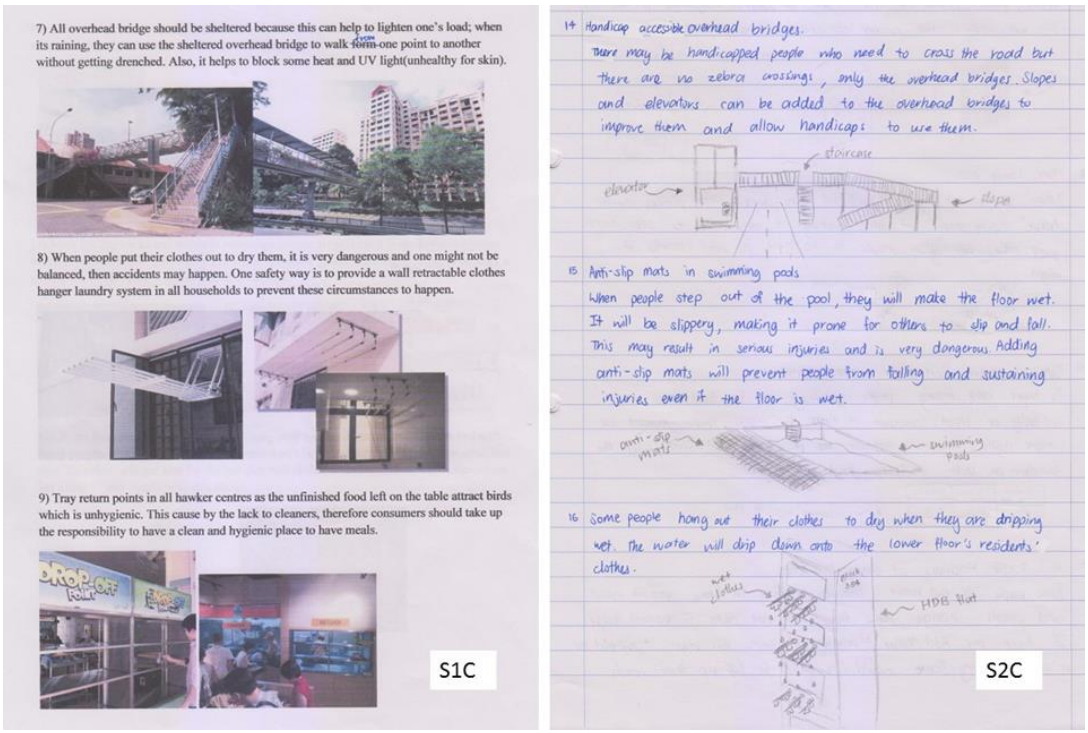


Figure 2b: Brain storming using note listing.

Another common method for brainstorming, based on Figure 1, was mind-mapping. In mind-mapping, students were taught to focus on a main area/problem and then further explain the problem by linking relevant points/details. Refer to Figure 3. During the process, some students went on to identify possible solutions. Only one student made use of 5Ws 1H during the brainstorming process, refer to Figure 4. During this process, students clarify the design problems through questions.

At this stage, students were allowed to use a combination of methods to explore and identify problems, thus bringing the important message that there is no fix method in problem identification. But it was pretty consistent among all the students that the design problems presented in the journals were superficial in nature. The descriptions of the problems, which might not reflect the actual cause of the problems, were mainly based on the students' interpretation and understanding of the problem. Though some students attempted to include sketches to further explain the problem situations, the illustrations were of a low resolution

To provide some scaffolds for students to think deeper and provide good rationale in choosing authentic design problems further engagement, the 'critical thinking' template was provided to all the students. The template contains five different sections that touch on 1) Problem/Needs Identified, 2) Is the problem or needs clear, 3) Is my thinking accurate?, 4) Is my thinking only from my point of perspective? and 5) Redefine problem or needs identified. Within each section, students were required to come out with relevant questions to question their own thinking and then they were required to provide the relevant responses.

Through this process, it was observed that students were able to clarify whether the problems that they identified were indeed problems, and at the same time they were able to describe and explain the problems clearer. Aside from writing down notes, students also conducted research to find out more about the problems. Some students took pictures of the

environment that the problems occur, thus conducting simple field survey, refer to Figure 5. Whereas some students preferred to conduct interviews with mainly people they know, refer to Figure 6.

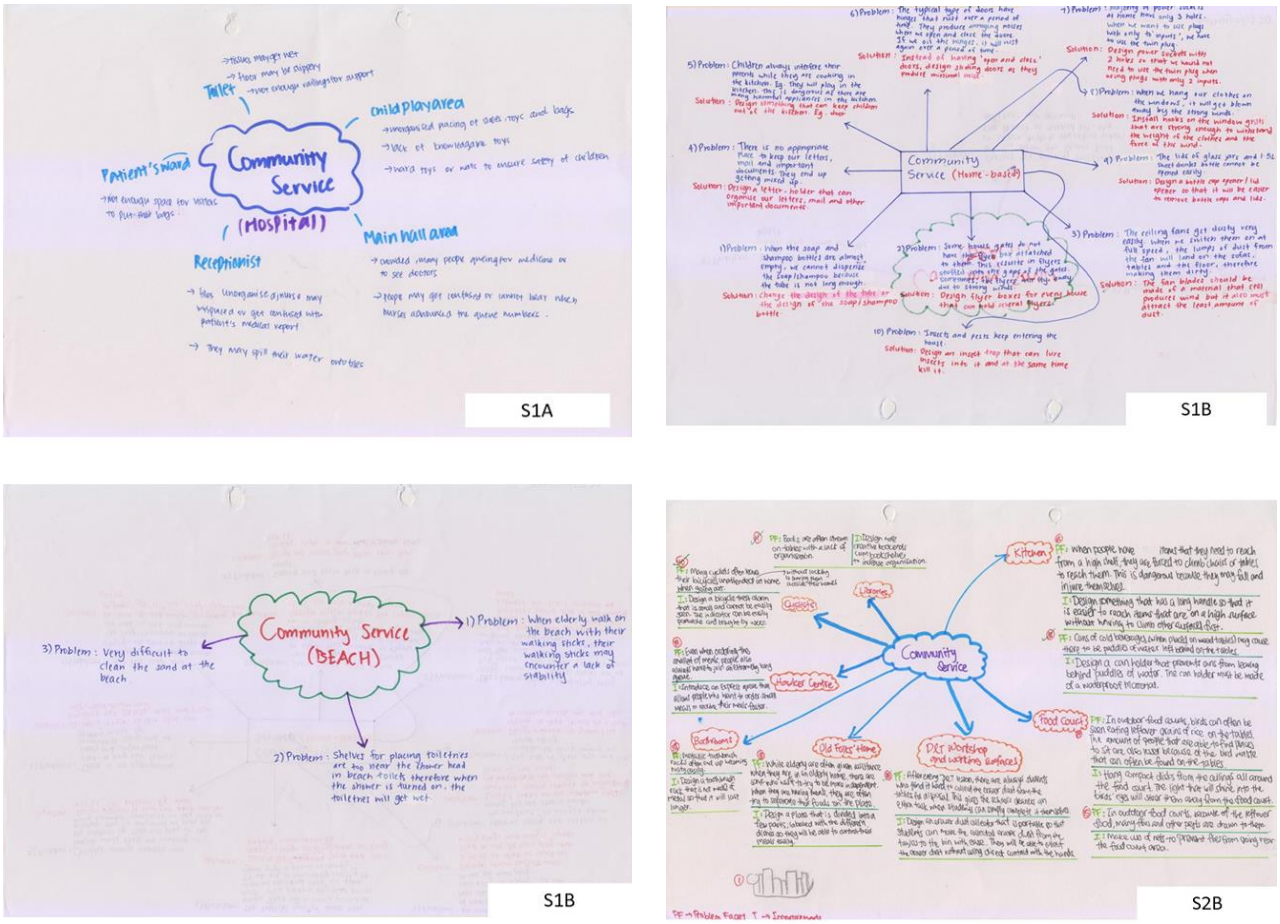


Figure 3: Brain storming using mind-maps.

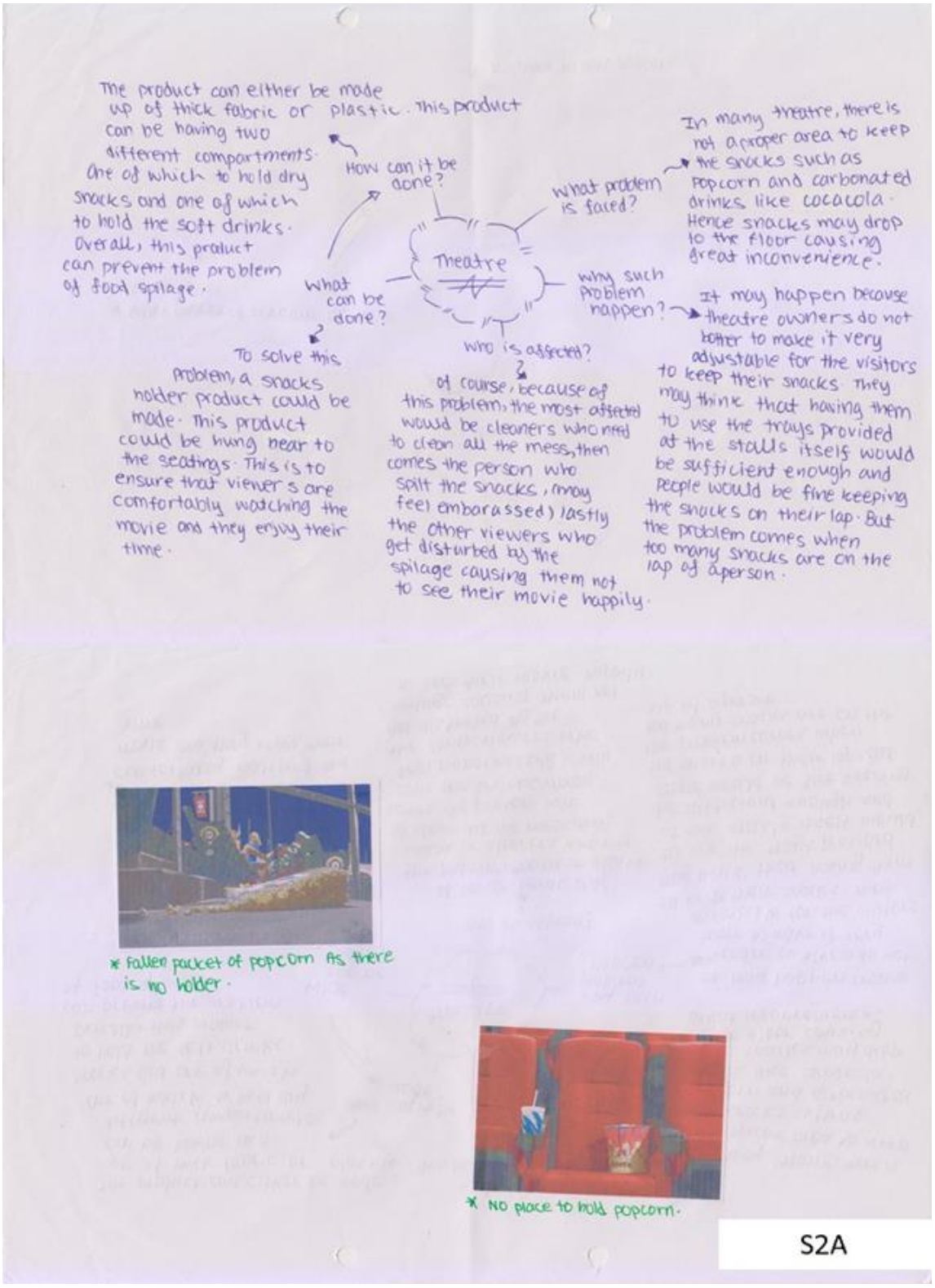
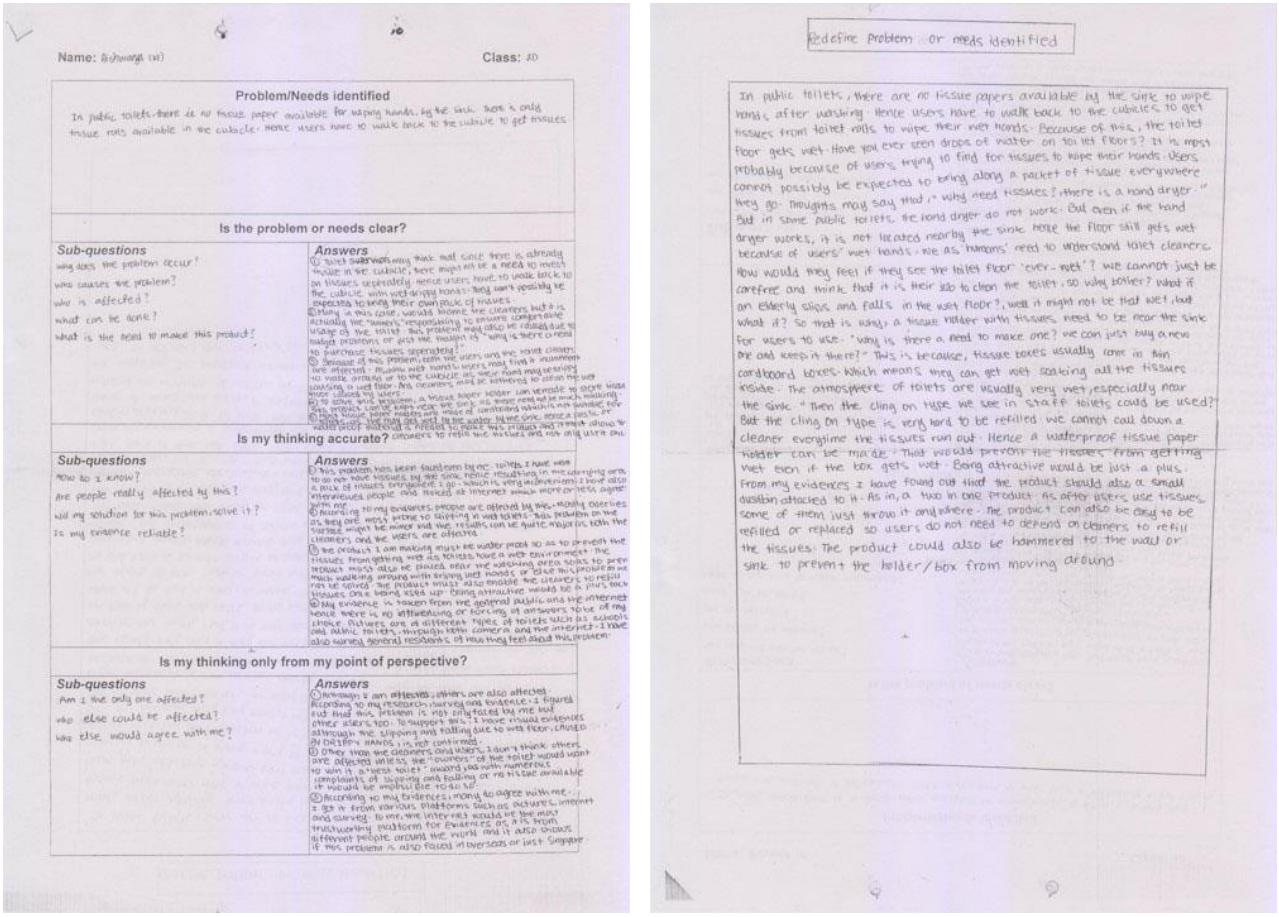


Figure 4: Brain storming using 5Ws 1H by student S2A.



Student clarifying the problem using the template

Supporting the clarification of problem with field survey and internet search

Figure 5: Sample work done by student S2A when clarifying selected design problem supported by research.

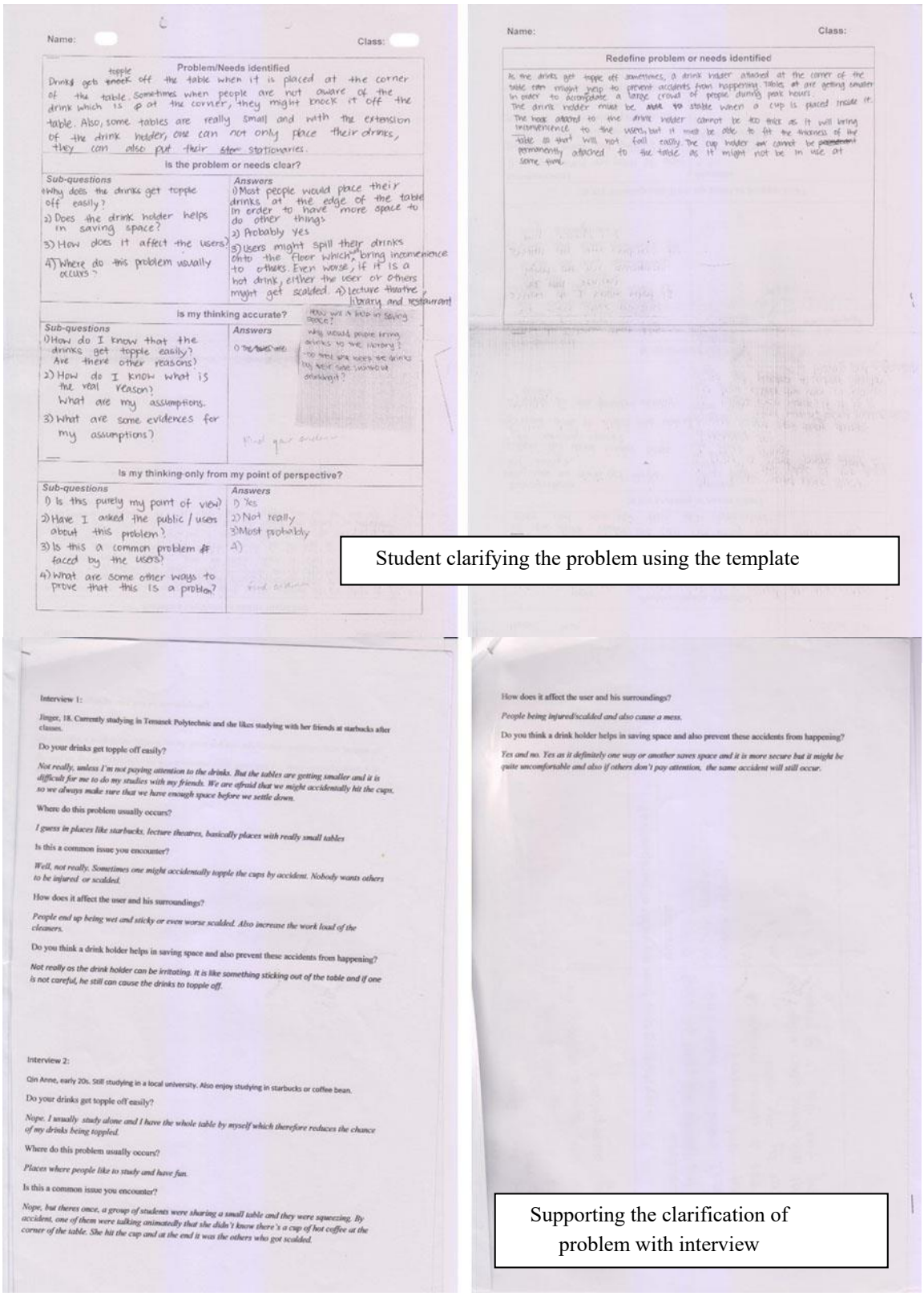


Figure 6: Sample work done by student S1C when clarifying selected design situation support by research.

Research – Clarifying Design Problems

During the process of the clarifying design problems, as mentioned earlier, research is an important component to deepen the understanding of the problem. Students were advised to research on meaningful areas (such as existing solution, the environment involved, user habits etc.) pertaining to design problems that they would like to work on. Besides, information gathered during research would also lead to the formation of design specifications. Students were highly encouraged to survey the environment where the problems of interest occur and to understand the problem better via the people involved. Thus, to fulfill the tasks required in the area of research, research methods such as photo journalism, interviews, product analysis and internet search were taught to the students.

Product analysis was mandatory for all students so as to ensure that all students were aware of existing solutions to the respective problems. Besides, students were discouraged to conduct the research by just plugging information from the World Wide Web (WWW). The rationale was that information plugged from WWW may not be 100% accurate. Besides, the background context of the information may not match the context which the students are researching. Thus, students should cultivate the habit of conducting research based on their own findings and observations.

Referring to Figure 7, interviews and photo journalism became the second most common research methods in the clarifying of design problems during the design coursework. With the availability of technology, such as smart phones (all students in this study owned a smart phone), photo journalism could be easily conducted by students. While a small handful of students would still prefer to use internet search as a means to clarify problems, two students also attempted to present their findings through sketching, which is referred as situational sketching in this study.

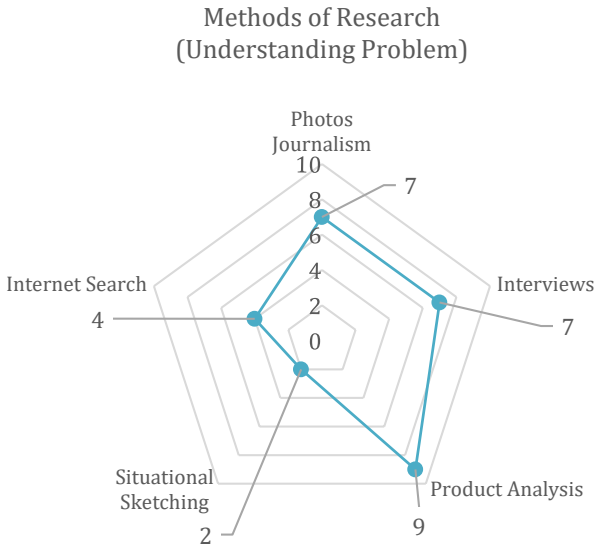


Figure 7: The type of research conducted by students when understanding the problem.

Evaluating Design Problems

Towards selecting a final problem, evaluation method such as the decision matrix was taught to the students so that students could narrow down their choices to select the most relevant or suitable problem based on their own set of selection criteria. The set of criteria aimed to facilitate the decision making process of students where students examined factors such as the impact of problem to people, existing solutions in the market which may related to the urgency of the solution and constraints (time, resources and technology) etc. Figure 8 and 9 show the design matrix for group A and D respectively. During the evaluation process, it was observed that the ability of student to evaluate critically seem to depend on the student's ability to articulate their thinking and argument on paper.

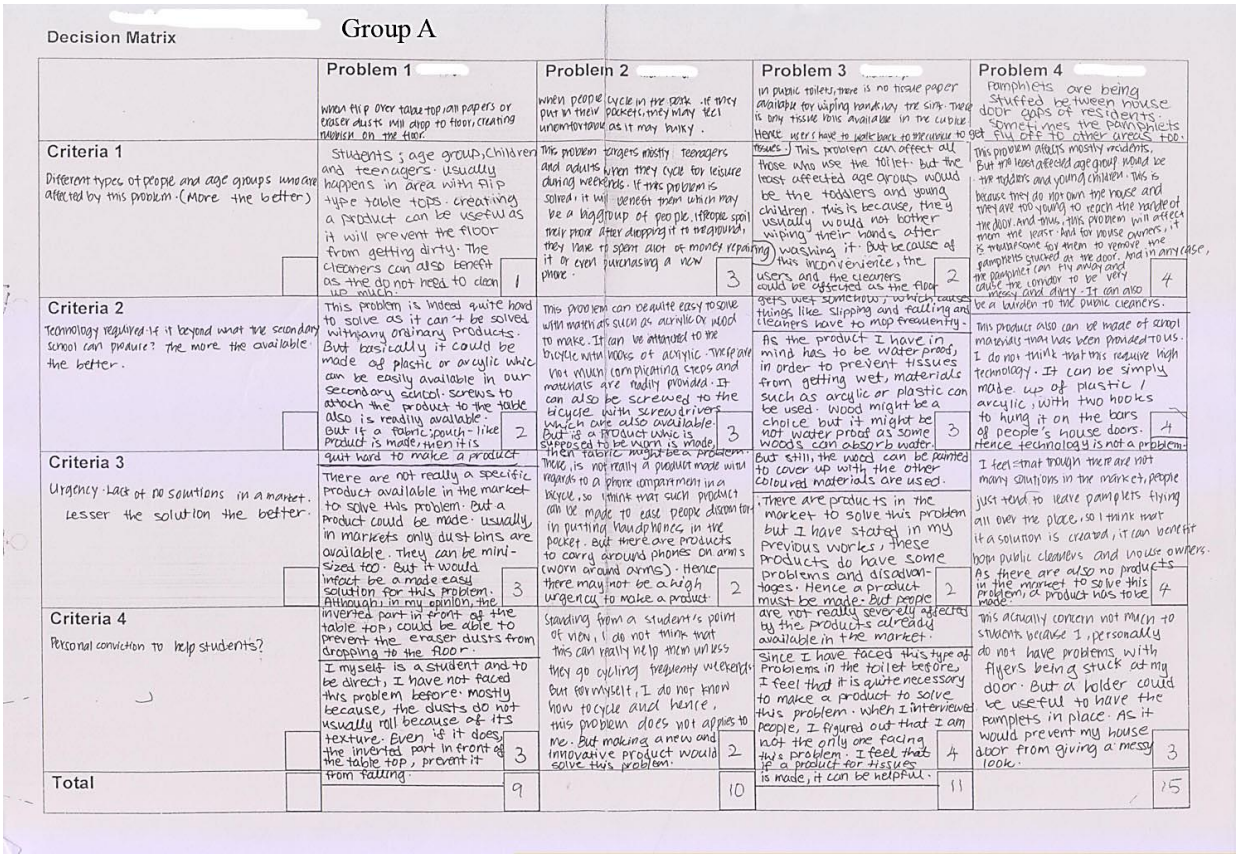
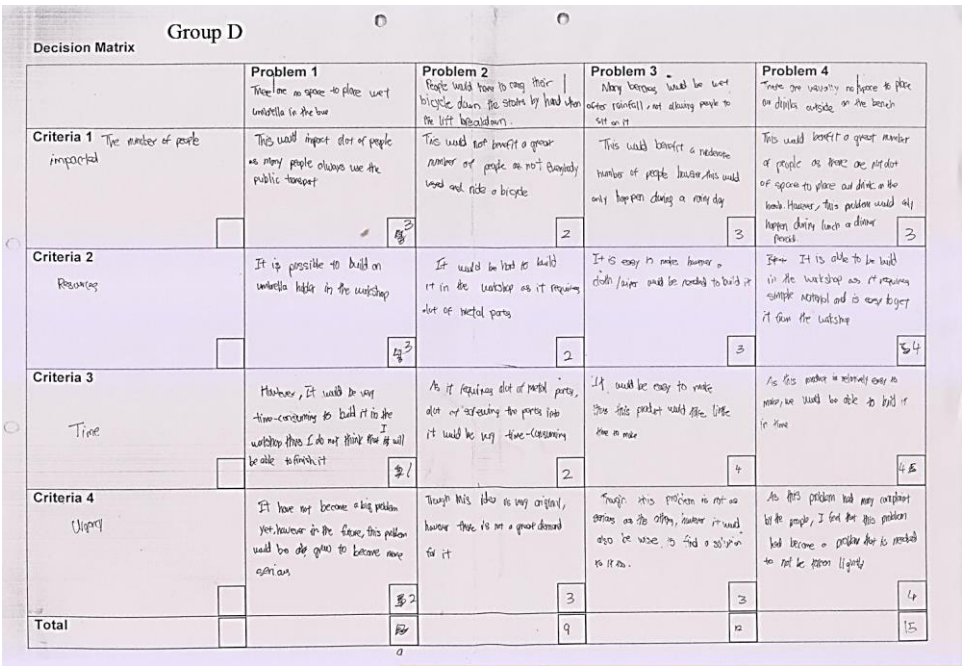


Figure 8: Decision matrix on problem evaluation by Group A.



Group D

Decision Matrix

	Problem 1	Problem 2	Problem 3	Problem 4
	There is no space to place wet umbrella in the bus	People would have to carry their bicycle down the stairs by hand when the lift breakdown.	Many benches would be wet after rainfall, not allowing people to sit on it	There are currently no space to place or display outside on the bench
Criteria 1 The number of people impacted	This would impact alot of people as many people always use the public transport	2	This would benefit a reasonable number of people however, this would only happen during a rainy day	This would benefit a greater number of people as there are not alot of spaces to place out drinks in the hands. However, this problem would only happen during lunch or dinner periods.
	3		3	3
Criteria 2 Resources	It is possible to build an umbrella holder in the workshop	It would be hard to build it in the workshop as it requires alot of metal parts	It is easy to make however a cloth/layer would be needed to build it	It is able to be built in the workshop as it requires simple materials and is easy to get it from the workshop
	3	2	3	4
Criteria 3 Time	However, It would be very time-consuming to build it in the workshop thus I do not think that I will be able to finish it	As it requires alot of metal parts, alot of screwing two parts too it would be very time-consuming	It would be easy to make thus this product would take little time to make	As this product is relatively easy to make, we would be able to build it in time
	1	2	4	4
Criteria 4 Usage	It have not become a big problem yet, however in the future, this problem would be able grow to become more common	Though this idea is very original, however there is not a great demand for it	Though this problem is not as serious as the others, however it would also be wise to find a solution to it as.	As this problem had many complaint by the people, I feel that this problem had become a problem that is needed to not be taken lightly
	2	3	3	4
Total		9	12	15

Figure 9: Decision matrix on problem evaluation by Group D.

Idea Conceptualization and Prototyping

The process of idea conceptualization proceeded after the design specifications had been decided based on the problem identification and research processes. Idea conceptualization in the design project can be viewed in three phases: 1) Ideation, 2) Development and 3) Mock-up and Testing. After that, prototyping completes the design coursework.

Shape borrowing and SCAMPER were two main techniques used by the students during ideation. The ideation process mainly focused on exploring ideas through sketching where students transferred the ideas they had in mind through sketches. Among the 9 participants, two distinct observations may be observed. Firstly, when coming out with ideas, some students seemed to rely a lot on their previous exposure to images rather than functions that might solve the problem. This can be observed through their drawings where ideas first take the shape of organic shapes, cartoon characters or other shapes etc. and morph into the solution to solve the problem. Some examples are shown in Figure 10, 11 and 12.

A closer observation on the drawings suggested that whether the function practically solve the problem was not much considered in the first place. A more detail exploration of functions mostly followed after the initial exploration of ideas. It appeared that the students would considered the shape and aesthetics of the solution first instead of the function that may solve the problem. On the other hand, some students explored solutions to the problem by focusing on the functional features first before considering the shapes and aesthetics of the solutions. Some examples are shown in Figure 13 and 14.

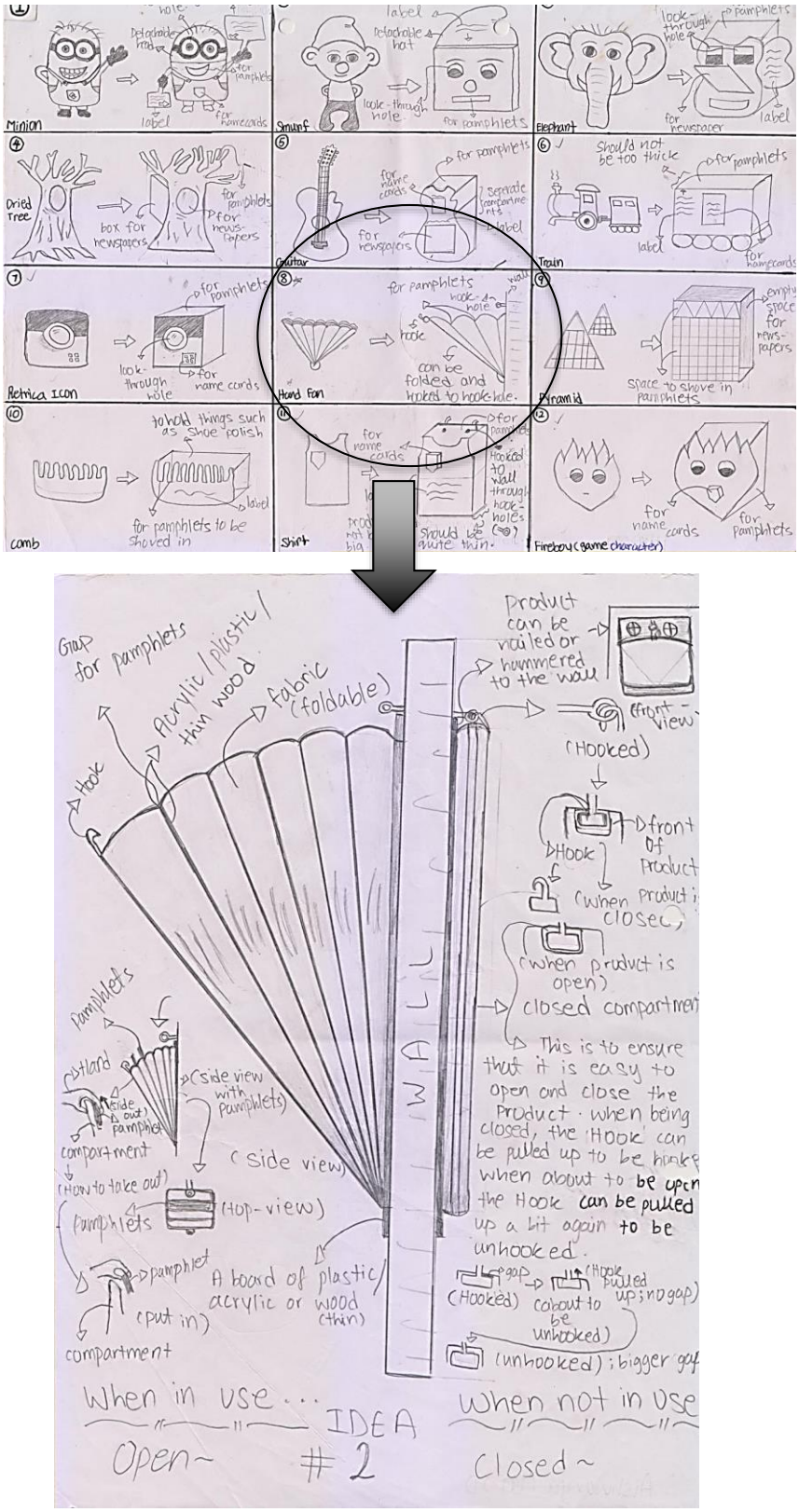


Figure 10: Ideation by student S2A showed initial exploration through organic shape (circled area) and then further elaborated in detail for a pamphlet holder for the main gate of the house.

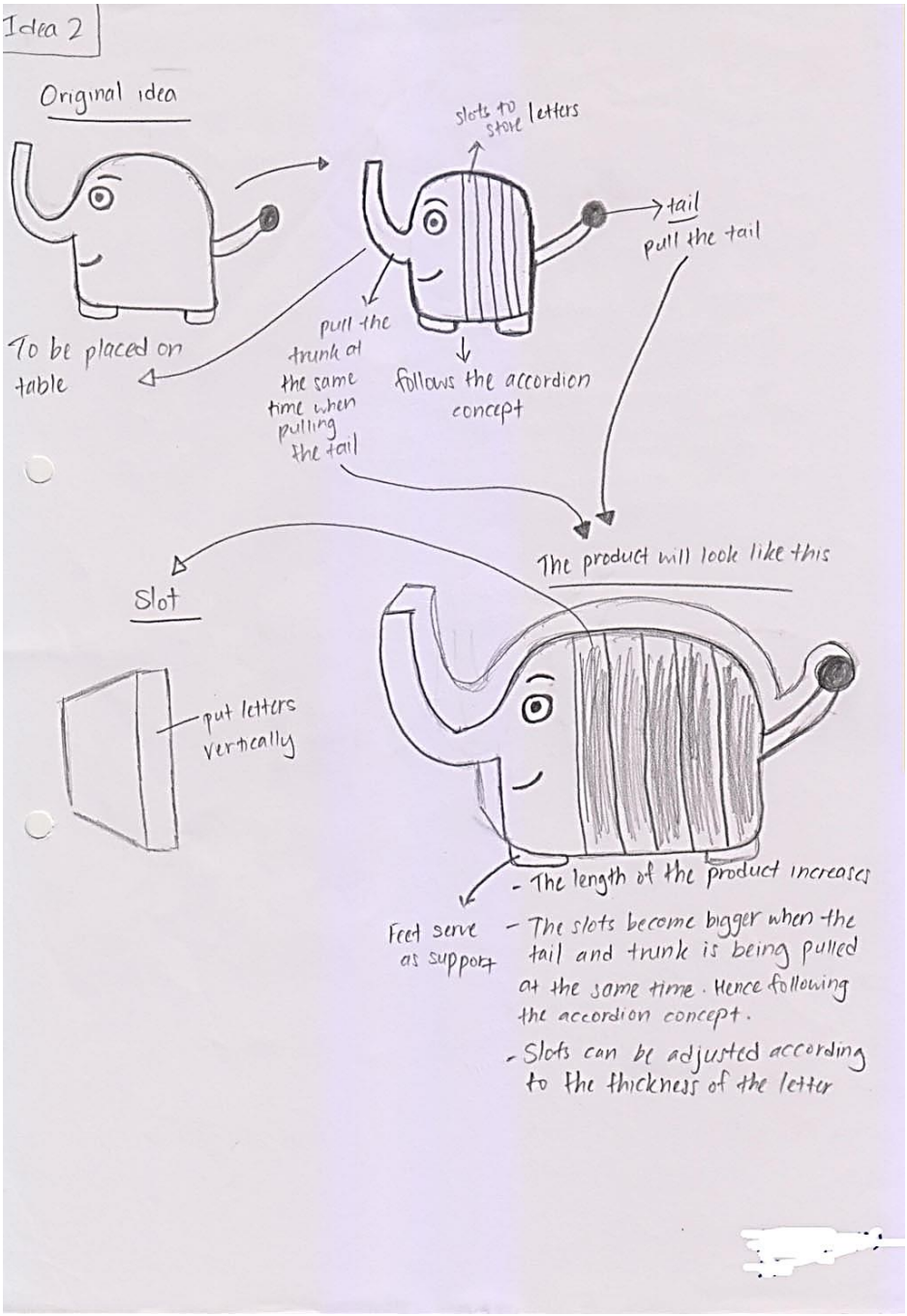


Figure 11: Ideation by student S1B showed initial exploration through the shape of animal followed by adaptation of function for a letter holder.

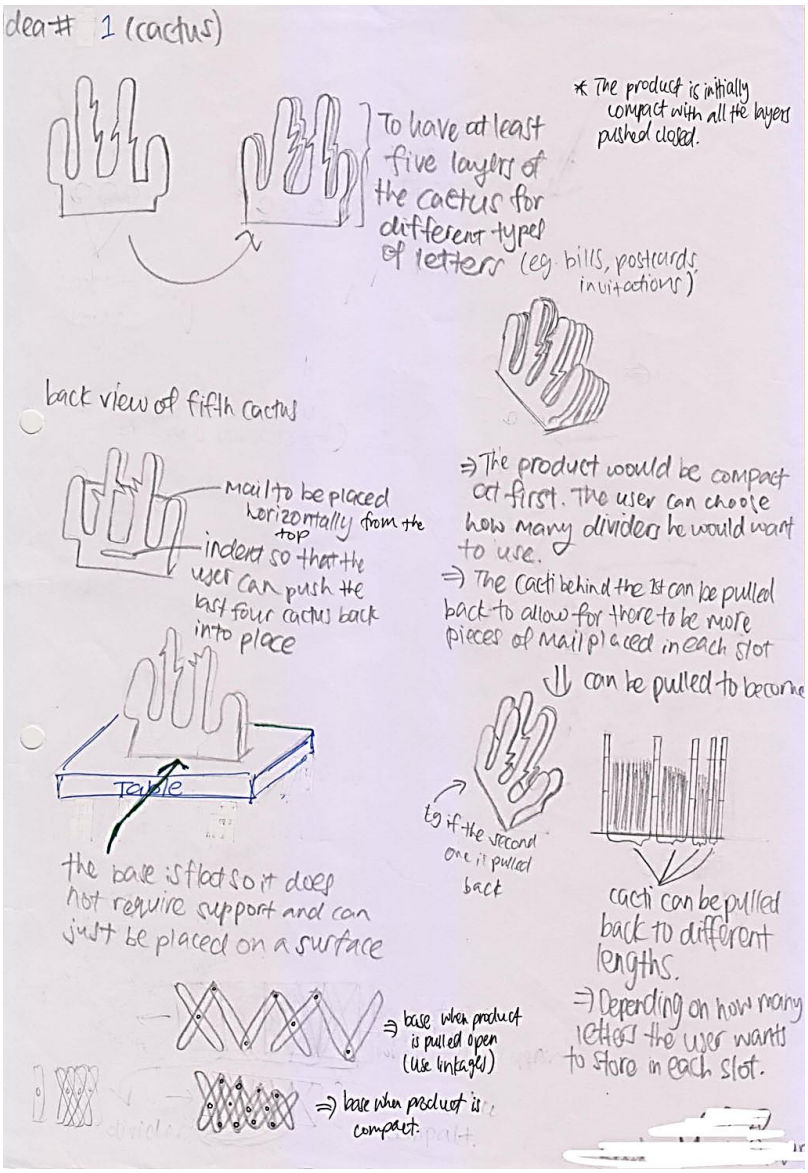


Figure 12: Ideation by student S2B showed initial exploration through the shape of plant followed by adaptation of function and technology (linkages) for a letter holder.

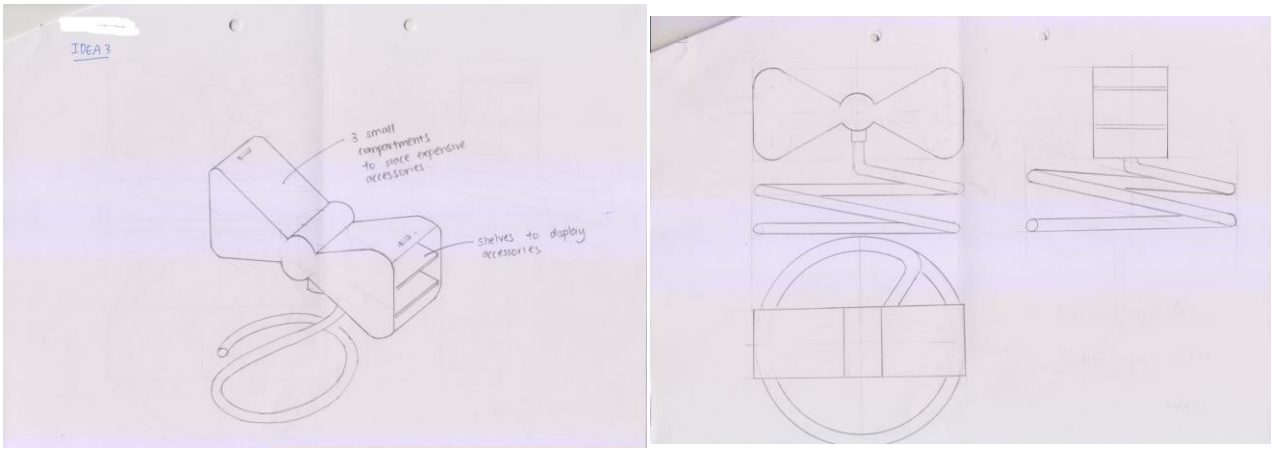


Figure 13: Ideation by student S1C explored the function of solution for an accessory holder.

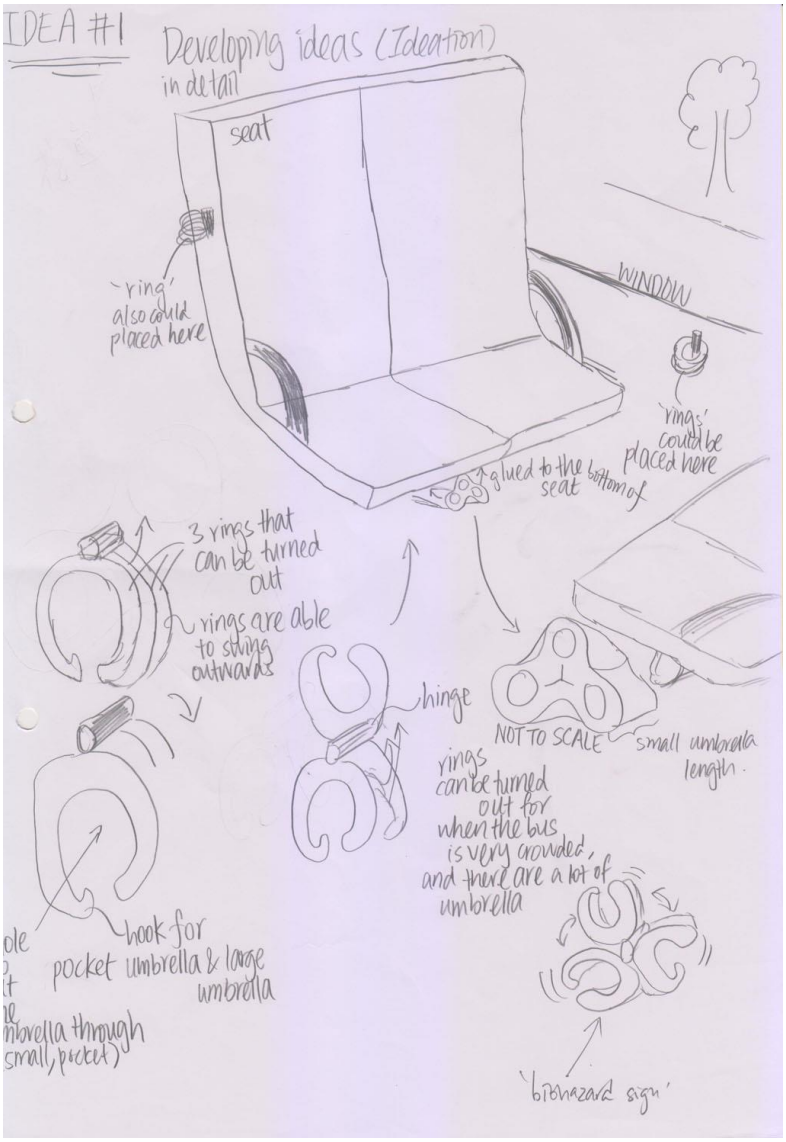


Figure 14: Ideation by student S1E explored the function of an umbrella holder in a public bus.

From Figure 13 and 14, it can be observed that student S1C and S1E both focused on exploring the function of the product first before considering the shapes and forms. Student S1C also made use of orthographic projection to visualize the different views of the idea.

The ideation process provided a platform for students to brainstorm and explore a variety of design ideas. In order to evaluate the feasibility and usefulness of these ideas, the Plus, Minus and Interesting (PMI) technique was taught to students as a converging tool for decision making to select a design idea for further development. Figure 15 shows a sample of the PMI table done by one of the students. Similar to the decision matrix, the PMI evaluation required students to evaluate the design ideas using the three respective aspects: Plus (advantageous factors), Minus (disadvantageous factors) and Interesting (Unique factors). Based on the sketches for the design ideas, the evaluations will depend on the students' ability to visualize the sketching in 3D form and the ability to articulate this visual information into written form.

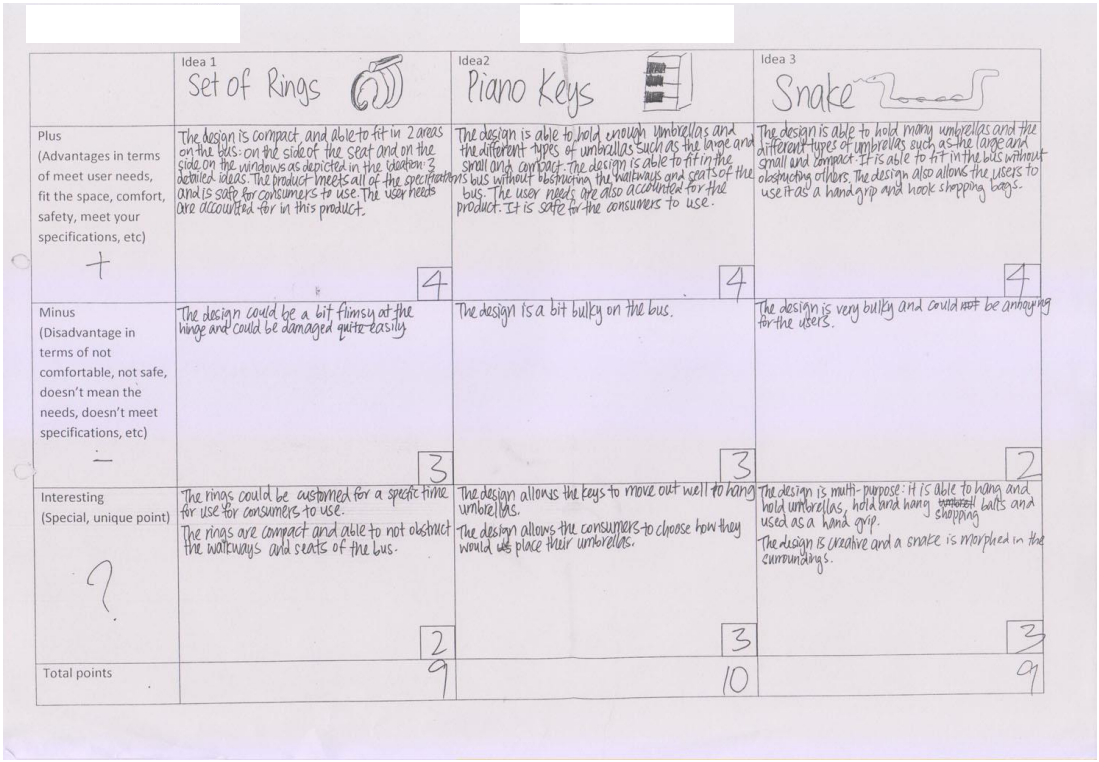
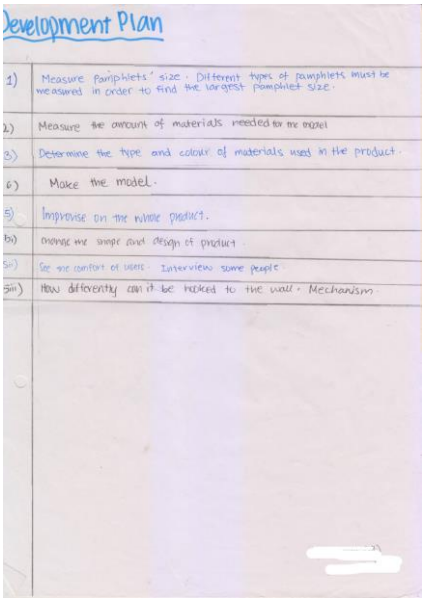


Figure 15: Evaluation through the PMI technique done by student S1E.

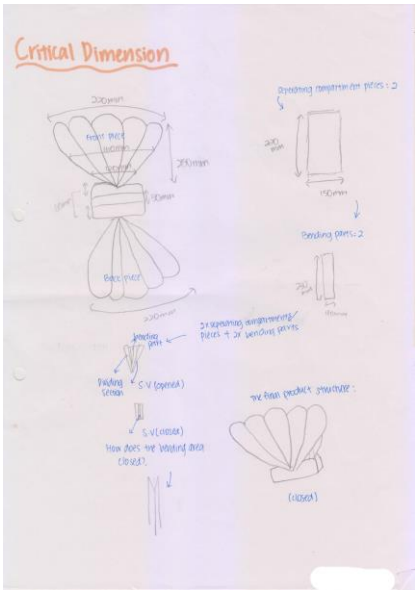
During the ideation process, it was clear that students diverge their ideas through wide exploration of ideas through mainly two approaches, 1) by first morphing the shape of the solution then consider the function and 2) by considering the function of the solution and then considering the shape and form.

But no matter which approaches they adopt, all students would have to develop one selected idea into a working prototype. The trajectory towards a working prototype would see students explore all details of the solution; form, shape, technology used (which included material selection), colour considerations, critical dimensioning, anthropometry analysis (only for some groups who required) to testing solution with a mock-up model and finalizing working drawings. Throughout the development process, although mini iteration processes could be observed when students made adjustments to the details of the solution, the whole development process may still be considered to be a linear process towards the final outcome. As observed from the development, students would considered most of the details of the solution first (mainly on paper) before setting out to test the solution using a mock-up model made of styroform or cardboard. Once necessary adjustments or improvements were made using the mock-up, students set out to manufacture the actual prototype in the workshop. A sample of the development work in the journal and the final prototype done by Group A is presented in Figure 16 (a) to (p).

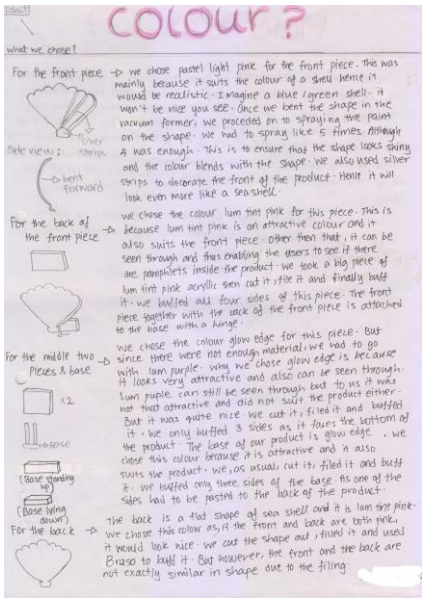


(a)

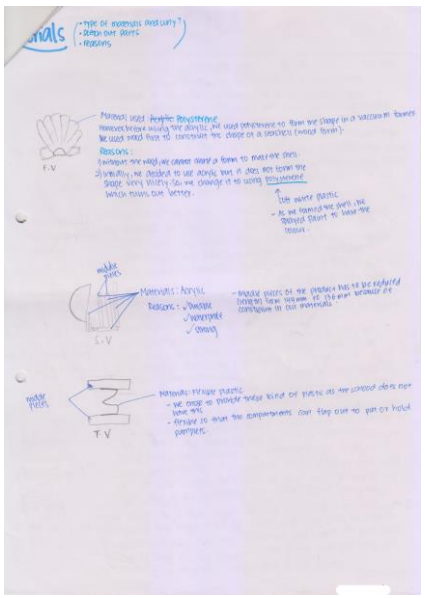
(b)



(c)



(d)



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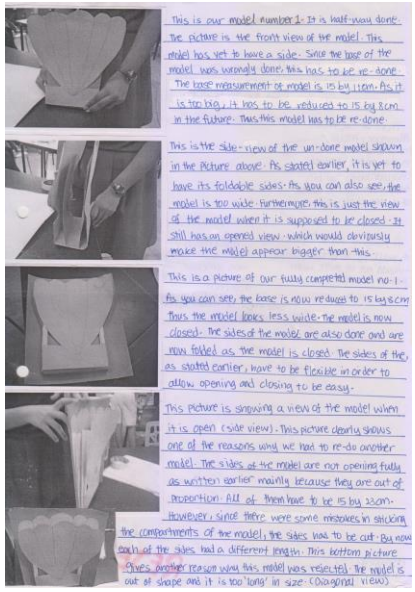
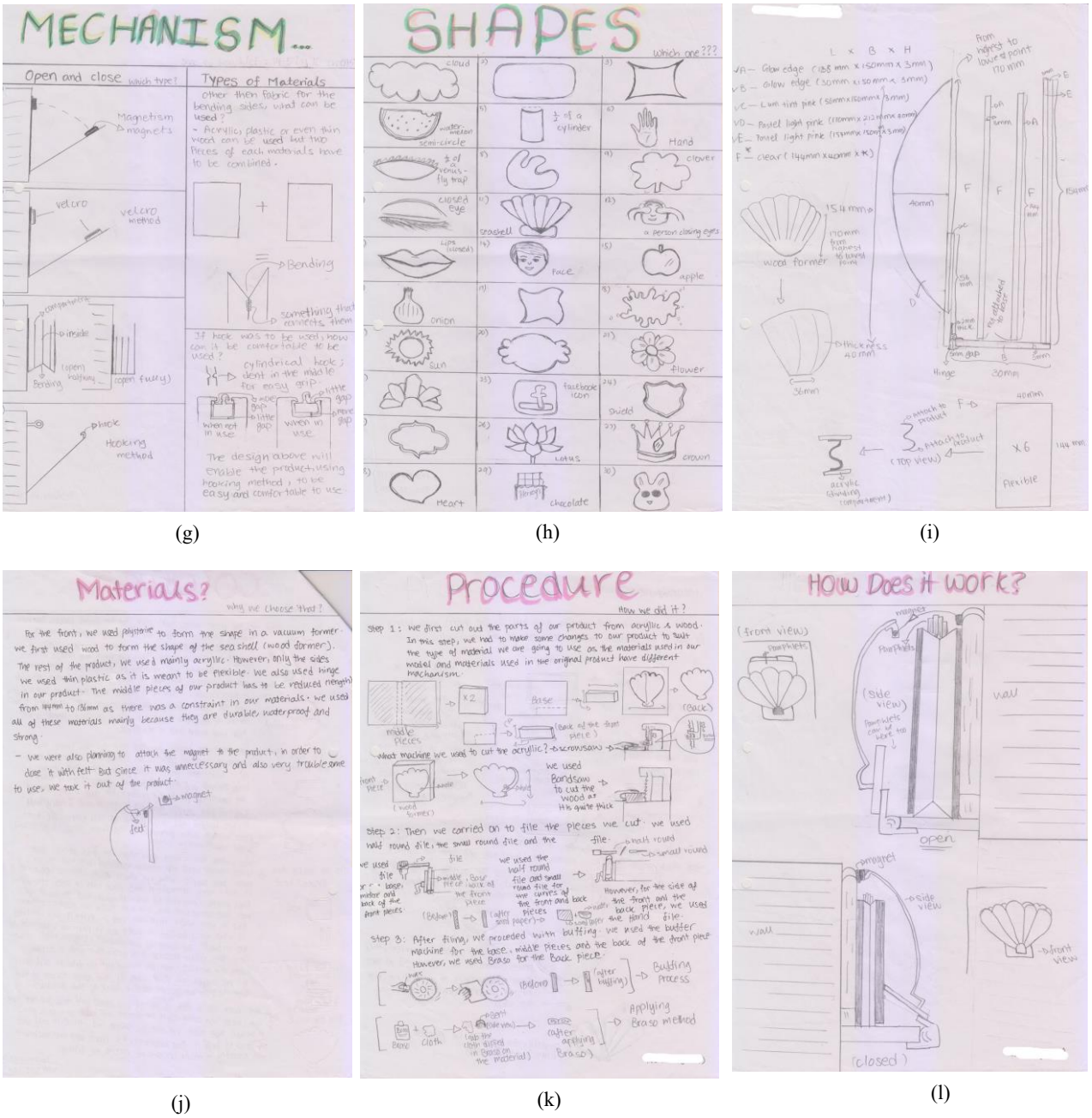


(f)

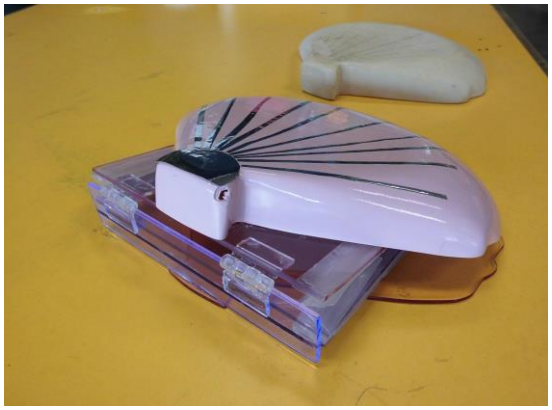
Figure 16: (a) Students developed a plan before the idea development process; (b) Data Collection (Pamphlet Size); (c) Determining Dimensions for Solution; (d) Colour Considerations for Solution; (e) Material Considerations for Solution; (f) Mock-up Model for Testing



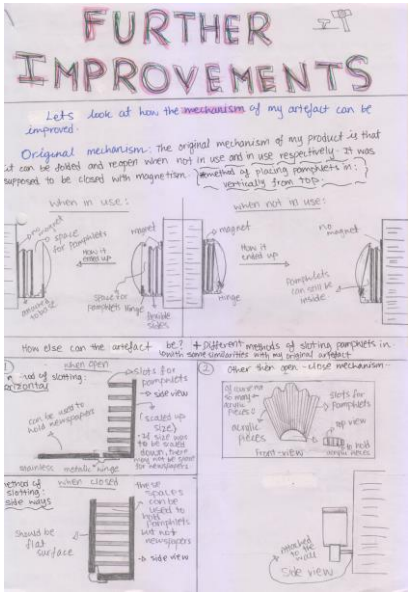
(g) (h) (i)

(j) (k) (l)

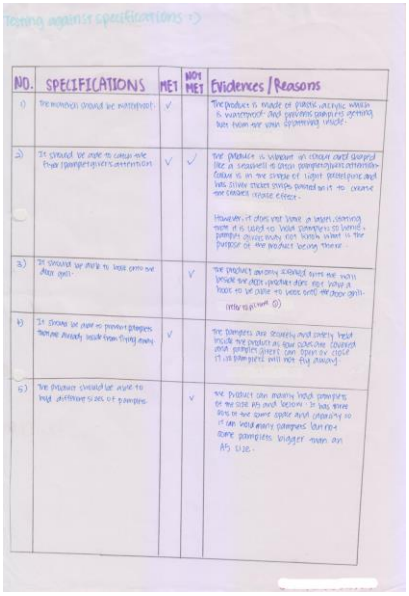
Figure 16: (g) Determining Appropriate Use of Technology; (h) Exploring Shapes and Forms; (i) Working Drawings; (j) Finalizing Materials; (k) Manufacturing Procedures for Prototype; (l) Keeping track of working functions during prototyping



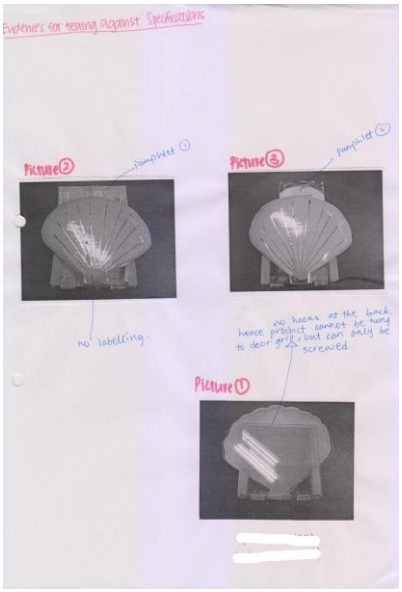
(m)



(n)



(o)



(p)

Figure 16: (m) Final Prototype with Former; (n) Evaluation for Improvements; (o) Evaluation against Specifications; (p) Evaluation against Specifications

Discussion

The aim of this study is to clarify the design thinking processes during the design coursework of nine secondary two students in D&T learning. If design thinking is always considered an interplay between diverging exploration of problem and solution space and converging processes of synthesizing and selecting according to Lindberg, Meinel and Wagner (2011), then the design coursework in D&T may provide ample potential and opportunities for the development of design thinking skills. The findings in this study suggested that the development of design thinking skills in the design coursework focus heavily on the development of reasoning and reflective thinking skills.

Development of Reasoning and Reflective Thinking Skills

In the design coursework, the divergent-convergent thinking processes take place right from the start. While students explored a wide range of problems through mind mapping or note listing, it is important for students to be able to rationalize and explain why a problem is a genuine problem. The 'critical thinking' template is designed to help students reason through questions. Questioning emerges as the beginning steps of any design process in the problem definition phase (Dym & Little, 2003). The problem identification process involved exercising critical thinking skills where the primary focus is to determine if the arguments are sound based on true premises and logical strength (Hughes, Lavery & Katheryn, 2010). Through research, students support their arguments with evidence. According to Butterworth and Thwaites (2013) the reasoning process will advance students from what they already know to new knowledge and understanding; and using this understanding to make decisions and form judgements with confidence.

Critical thinking, problem solving and decision making are all forms of reflective thinking (Butterworth & Thwaites, 2013). When students are engaged in reflective thinking, they do not base their decisions on impulse but require careful consideration of alternatives, think about consequences, weigh up available evidence, draw conclusions, test hypothesis and so on (Butterworth & Thwaites, 2013). The decision matrix and PMI approaches that featured in the design coursework provide platforms for reflective thinking so that evaluations can be done. In these two approaches, students make use of questions to crystalise their thoughts. Although, the limitations to these approaches may rest on the students' ability to articulate their thoughts or evaluations clearly in words, students may improve with practice and perhaps be able to apply this thinking skill in daily life.

Divergent and Convergent Questions

The development of reasoning and reflective thinking skills in the design coursework is mainly supported by the iterative process of diverging and converging questioning in the trajectory towards sharpening the final solution. When exploring for possible problems related to the theme, the question that students first need to answer is "what type of problems are related to the theme?". This set off a general exploration of possible problems where some problems may hold true and some may not. Dym, Agogino, Eris, Frey and Leifer (2005) stated that questions asked in design problems exist multiple alternative known answers, regardless of being true or false, as well as multiple unknown possible answers. When the questioner intends to disclose the alternative known answers and to generate the unknown possible ones, such questions are characteristics of divergent thinking where there is an attempt to diverge from facts to the possibilities that can be created from them (Dym et al., 2005). Similarly, in the ideation process, students explores the question of what shape and form, technology, colour, manufacturing techniques etc. fits the required functions of the proposed solution.

In between each diverging thinking process, students follow-up with an attempt to achieve a conclusion through converging questions that sieve out facts to evaluate the most appropriate problem and solution. This can be evident through the design matrix table and the PMI table done during the problem identification and ideation phase respectively. Dym et al. (2005) explained that converging questions attempt to converge on and reveal facts and is a characteristic of converging thinking. Answers to converging questions are expected to hold truth value that can be verifiable (Dym et al., 2005). Thus, through the design matrix and the PMI table, together with a combination of research justifications, students clarify and verify the facts, so as to update their assumptions and hypothesis.

Limitation of the Design Coursework

In the exploration of solution, Lindberg et al. (2011) explained that design thinking ask for a great number of alternative ideas in parallel and elaborates them with sketching and prototyping techniques. This study suggests that the development of design thinking skills through the design coursework may encounter limitations in the solution space, if the exploration of alternative ideas required a combination of sketching and prototyping of proposed solutions. In this study, it is evident that students only explored ideas on paper through sketching. Although evaluations are done to converge onto a selected idea for further developmental work, this evaluation is only based on the assumptions of what can be understood from the sketches and annotations provided by the students. The current approach in ideation and development may cut short potential ideas that may provide possibilities to the solutions. Besides, the mock-up done by each group of students to test feasibility of the idea only came after much developmental work to finalize the shape and form, the technology to be used, the colour and function of the solution etc. on paper and iterations, if any, were done based on the single selected idea. The open ended nature of design problems often required designers to imagine and try out alternative solutions (Buxton, 2007; Kelly, 2002). Without sufficient exploration, students may fixate on potential solutions (Duncker, 1954; Jansson & Smith, 1991) and overlook key insights (Kershaw & Ohlsson, 2004).

Conclusion

In conclusion, the study suggested that the development of reasoning and reflective thinking skills, coupled with the application of divergent and convergent questions is critical to the development of design thinking skills in D&T learning. The design coursework provided ample opportunities for divergent and convergent thinking which characterized the design thinking process. But the potential limitation to the development of design thinking skills in D&T may lie in the current approach towards ideation and development where exploration of solutions hinge more on sketches rather than a combination of sketches and prototypes.

The limitations to this study lies on the limited scope that only touches on the main design thinking process within the design coursework at secondary two level. The study has not yet

establish the detail mechanics of design thinking and the types of teaching and learning approaches within each specific phase between problem identification and idea conceptualization and prototyping. The room for further study will provide much motivation for future research and may provide a rich understanding on design thinking acquisition in pre-tertiary design education.

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Grace has been serving as a secondary school teacher in Singapore for 14 years. During this period, she has taken on leadership and mentoring roles such as Subject Head, Head of Department and Lead Teacher. She has received a Master of Design with the University of New South Wales in 2005. Her current work engagements involve mainly staff development and mentoring programmes. She is also a member in the Academy of Singapore Teachers (AST) D&T Subject Chapter core team. Her research interest revolves around the development of thinking skills and experiential learning in Design & Technology subject.

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