Sharpening Critical Thinking in Design Problem Selection in Design Project: A Perspective Based on Singapore Design and Technology

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出版情報：Journal of Technology and Engineering Education. 51 (1/2), pp.1-28, 2021. 國立台灣師範大學科技應用與人力資源發展學系
バージョン：
権利関係：

科技與工程教育學刊 2021，51(1/2)，1-28
DOI: 10.6232/JTEE.202106_51(1/2).0001

在設計專題活動中提升界定問題的批判思考能力：以新加坡「設計與科技」為例

摘要

本研究旨於釐清在設計專題活動中，學生對於界定問題的批判思考過程。本研究透過新加坡一所中學的高中學生撰寫的設計日誌，以不同推理要素分析學生的批判思考過程，並評估其推理質量。本研究得出以下結論：首先，使用決策矩陣等決策工具未必能幫助學生實現高質量推理。為提升界定問題時的推理質量，需要更系統化地資訊與證據的收集過程。為了讓學生更有目的地收集資訊或證據，應該在其進行探索前預先訂立問題篩選標準。如此一來，學生收集資訊的能力可獲得提升，從而加深對問題的理解，亦加強學生進行界定問題的決策能力。另外，學生在訂立篩選標準時應聚焦於倫理、重要性、合理性、相關性、情感和可行性等要素。

關鍵詞：設計與科技、批判思考、界定問題、設計教育

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Sharpening Critical Thinking in Design Problem Selection in Design Project: A Perspective Based on Singapore Design and Technology

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Abstract

The current study aimed to identify and clarify students' critical thinking processes when choosing a design problem within the problem identification process when engaging in a design project. Using design journals done by students at upper secondary level in a Singapore secondary school, the study broke down students' critical thinking processes based on various elements of reasoning to assess the quality of reasoning. From this study the following conclusion may be suggested. Firstly, the use of decision-making tools, such as decision matrix, does not necessary enable students to achieve quality reasoning. To enhance quality reasoning when choosing a problem, a more systematic process of information or evidence gathering is necessary. To facilitate purposeful gathering of information or evidence, the selection criteria for choosing a problem should be formed before students are engaged into problem exploration. In this way, it may sharpen students search for information to understand the problem better, which in turn sharpen decision-making in choosing a problem. In addition, when forming selection criteria, it is suggested that students should focus on factors such as ethical, significance, reasonability, relevance, emotions and achievability.

Keywords: Design and Technology, Critical Thinking, Problem Identification, Design Education

DOI: 10.6232/JTEE.202106_51(1/2).0001

1. Introduction

The framework for 21 Century Competencies (21CC) and Students Outcomes was formalised in 2010 as one of the most significant efforts in 21CC education in Singapore (Tan, 2013; Poon, Lam, Chan, Chng, Kwek & Tan, 2017). Critical thinking and inventive thinking are part of the three broad areas of emerging 21CC, where they are recognised as vital to helping Singapore's young people strive in the 21st century. Since its formalization in 2010, 21CC framework has been infused into the academic curriculum (Tan, Koh, Chan, Pamela & Hung, 2017). However, currently, few studies had been done to understand how critical thinking is being developed systematically through the implementation of pedagogy and practices in Design and Technology (D&T) in schools (Chia & Tan, 2007; Lim, Lim-Ratnam & Atencio, 2013; Loh, Kwek & Lee, 2015, 2017; Tan, 1996).

In the current national syllabuses for all lower secondary and upper secondary D&T courses published by the Singapore Ministry of Education (MOE), there are no clear standards to evaluate students' critical thinking during the process of designing (MOE 2016a, 2016b, 2016c, 2016d). The evaluation standards are mainly to evaluate students' design process. Thus, it is necessary to articulate clear standards to guide students on achieving good critical thinking and also to allow teachers to evaluate students' critical thinking process with clarity.

The current study is part of a research to identifying and clarifying students' critical thinking processes during the problem identification process in D&T projects using Singapore as the context. This study will focus on a specific stage in the problem identification process where students make decisions to choose a design problem to solve. Thus, the main purpose of the study will be to identify and clarify students' critical thinking processes when choosing a design problem to work on further in the design process. The findings will contribute to the understanding of how critical thinking may be systematically developed through D&T and also contribute to the international practices in D&T education.

2. Literature Review

The literature will first attempt to explore the general accepted definitions of critical thinking. This will be followed by reviewing the methods of evaluating critical thinking. The final part of the literature review will determine the working definition of critical thinking for this study.

2.1 Defining Critical Thinking

Conceptualizing critical thinking may be divided by the generalist (domain-general) or the subject-specific (domain-specific) approach (Butler, 2017; Moore, 2004; Davis, 2006). The generalist

DOI: 10.6232/JTEE.202106_51(1/2).0001

approach conceptualises critical thinking as a set of skills that may be applied across subjects and disciplines (Moore, 2004), whereas, the subject-specific approach believes that critical thinking is closely tied to the subject or domain which it is applied. This is because, the set of critical thinking skills varies among the different domains or situations in which it is applied to (Moore, 2004).

While the definitions of critical thinking remain varied, they tend to have similarities with considerable overlaps (Halpern, 2014; Butler, 2017). Based on a study of literature review on critical thinking by Fischer & Spiker (2000), most definitions of critical thinking include reasoning/logic, judgement, metacognition, reflection, questioning and mental process. Butler (2017) mentioned that most definitions of critical thinking involved the attempt to achieve a desired outcome by thinking rationally in a goal-oriented fashion. Other studies also seemed to have obtained a consensus among policy makers, employers and educators who agreed that critical thinking involves constructing a situation and supporting the reasonings that form a conclusion (Jones, Dougherty, Fantaske, & Hoffman, 1995; Jones et al.,1995). In a way, this "common consensus" on critical thinking definitions tend to tie critical thinking with reasoning.

One of the mainstream concepts of critical thinking was developed by Ennis (1991, 1993, 2018), where "critical thinking means reasonable reflective thinking that is focused on deciding what to believe or do" (Ennis, 1991, p.8). Taking the generalist approach in defining critical thinking, Ennis (1991) considered critical thinking as an important part of problem solving. To provide more clarity on the nature of critical thinking, Ennis (1991) explained the conceptualization of the critical thinking definition through the decision-making process. Decisions about belief or action that generally occur in problem solving should have some basis. This basis may consist of observations, information and/or some previously accepted propositions. A decision is made through the inferences of this basis. Thus, when making and checking decisions independently, an ideal critical thinker should exercise a group of critical thinking dispositions where any decision made should be justifiable and able to be articulated to others (Ennis, 1991, 2015). According to Ennis (2018), other well-known definitions such as the one by Scriven and Paul (1987), as well as definitions by Seigel (1988), Facione (1990), Fisher and Scriven (1997) and Kuhn (2015) are not significantly different from his or from each other.

Scriven and Paul (1987) described critical thinking as a disciplined process that actively and skilfully conceptualize, apply, analyse, synthesize, and/or evaluate information gathered from/or generated by observation, experience, reflection, reasoning or communication, to guide one's belief and action. In other words, critical thinking is a self-directed, self-disciplined, self-monitored and self-correcting thinking process that involves analysing and evaluating thought processes with the intention of improving them (Paul & Elder, 2002, 2019). The conceptualization of the definition of critical thinking by Scriven and Paul (1987) and Paul and Elder (2002, 2019), rest on the basis that

DOI: 10.6232/JTEE.202106_51(1/2).0001

thinking can be analysed and evaluated by first taking thinking apart and then applying standards to those parts. Paul and Elder (2002) explained that whenever thinking occurs, reasoning occurs. This is based on the concept that thinking always occurs for a purpose within a point of view based on assumptions that lead to implications and consequences (Paul & Elder, 2002, 2019). Concepts, idea and theories are used to interpret data, facts and experiences in order to answer questions, solve problems and resolve issues (Paul & Elder, 2002, 2019). As such, all thinking processes involve generating purposes, raising questions, using information, utilizing concepts, making inferences, making assumptions, generating implications and embodying a point of view (Paul & Elder, 2002, 2019). These eight areas form the eight basic structures of thinking, which Paul and Elder (2002, 2019) also called the elements of reasoning that are present in reasoning across subjects and cultures. By deconstructing thinking into the elements of reasoning, each element of reasoning may then be assessed.

2.2 How Critical Thinking can be Displayed and Evaluated?

To further clarify critical thinking, this section reviewed the type of skills and abilities a person may display when critical thinking is exercised. Ennis (1991, 2018) conceptualized a set of general critical thinking dispositions and abilities of an ideal critical thinker. Expanded from the list published in 1991, the latest list included 12 dispositions and 18 abilities (Ennis, 1991, 2018). Mainly using examples from his experience as a juror, Ennis (1991) exemplified and elaborated on each of the dispositions and abilities to explain his conception of an ideal critical thinker. Similarly, Halpern (2014) provided a list of 15 generic skills that a critical thinker will possess. In addition to acquiring skills, it is necessary to develop the attitude or disposition of a critical thinker. Thus, Halpern (2014) included 8 attitudes or dispositions that a critical thinker should exhibit, and just to name a few, willingness to plan, flexibility, and persistence. Among the skills and dispositions suggested by Ennis (2018) and Halpern (2014), some of the overlapping skills and dispositions are the use of existing knowledge, metacognition, understanding and using math, graphs and diagrams for communication, judging creditability of information, making justifiable decisions, open-mindedness, taking a position when there is sufficient evidence and an ability to employ critical thinking skills and dispositions.

In order to exercise critical thinking, possessing the skills may not necessarily mean that critical thinking has been achieved. For example, the ability to analyse evidence and make justified decisions does not mean that a good decision is made based on the quality analysis of the information at hand. In determining if a person has exercised critical thinking, Bailin (1999) emphasized that it is the quality of thinking, not the process of thinking, that differentiate critical thinking from ‘uncritical thinking’. As such, not all thinking activities that aimed at decision making can be considered as

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critical thinking and the quality of thinking has to fulfil a certain level of acceptable standard (Bailin, 1999). In assessing critical thinking skills, many such assessments come in the form of a critical thinking test.

According to Ennis (1993), no subject-specific tests were found but a list of general-oriented-based tests could be consolidated during a study on critical thinking assessment. Almost all the tests were multiple choice test which were good for efficiency and cost, but not comprehensive enough in effective testing for many significant aspects of critical thinking such as being open-mindedness and drawing warranted conclusions cautiously (Ennis, 1993). Ennis (1993) further suggested that open-ended critical thinking tests were necessary for comprehensive assessment, unless appropriate multiple-choice tests were developed. In a recent study, Butler (2017) provided a brief review on the reliability and validity of critical thinking assessments that measure critical thinking skills and those that measure critical thinking dispositions. These tests are used mainly to assess student learning outcomes so as to provide formative feedback to improve instructional methods. In fact, much of these tests may also be seen as an advocate for teaching of critical thinking explicitly rather that implicitly.

While critical thinking skills and dispositions can be assessed using test-based assessment, Paul and Elder (2002, 2019) provided an alternative model for assessing the quality of critical thinking. Paul and Elder (2002, 2019) suggested that a well-cultivated critical thinker should exhibit the following characteristics:

- Raises vital questions and problems, formulating them clearly and precisely
- Gathers and assesses relevant information and effectively interprets it
- Comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards,
- Thinks open-mindedly within alternative systems of thought, recognizing and assessing as need be, their assumptions, implications, and practical consequences
- Communicates effectively with others in figuring out solutions to complex problems

The formation of these characteristics is based on a conceptual framework where the basic structures of thinking, also called elements of reasoning, can be assessed using a set of standards (also called intellectual standards). Intellectual standards can be conceptualized as standards necessary for making sound judgements and rational understanding (Elder & Paul, 2013b; Elder & Paul, 2008). The intellectual standards are formed based on the argument that all modern natural languages (such as English, German, Japanese, etc.) provide their users with a wide variety of words that, when used appropriately, serve as plausible guides in the assessment of reasoning (Elder & Paul, 2008, 2013a; Paul & Elder, 2014). Words such as clarity, accuracy, relevant, significant, logical and so forth are

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identified as intellectual standard words (Elder & Paul, 2008; Paul & Elder, 2013, 2014). Though the focus on determining intellectual standard words are based on the availability in English language, it is hypothesized that similar web of intellectual standard words exist in every natural language, though perhaps with differing nuances (Elder & Paul, 2008, 2013a; Paul & Elder, 2014). Paul and Elder (2002, 2019) suggested that there are at least 9 intellectual standards (also called intellectual standard words), recently expanded to 10. The intellectual standards are clarity, accuracy, precision, relevance, depth, breadth, logicalness, significance and sufficiency (Paul & Elder, 2002, 2019). Using questions to deconstruct reasoning, a framework of how intellectual standards can be applied to these questions to assess quality of critical thinking has been further explained by Paul and Elder (2002, 2019), and Elder and Paul (2008).

2.3 Adopting a Model to Assess Critical Thinking

The different ways of defining critical thinking seems to be just different ways of cutting the same pie. The main concept of critical thinking process revolved around the process of reasoning. With this assumption, Paul and Elder provided a clear structure to unpack reasoning into parts. Without the need for a standardized critical thinking assessment test, Paul and Elder had also created a model to allow the quality of reasoning to be assessed using the intellectual standards, through questioning techniques. Furthermore, this model is flexible in application across different subject areas and provides a great potential for the application in this study. With above considerations, the current study adopts the definitions of critical thinking conceptualized by Paul and Elder (2002, 2019) and Elder and Paul (2008), and at the same time, attempts to apply the concept of elements of reasoning and intellectual standards to achieve the objectives of this study.

3. Research Question and Methodology

3.1 Research Question

This study sought to answer the following main question.

- After an initial brainstorming and exploration of problems, how do students exercise critical thinking to choose a problem to work on further in the design process?

3.2 Research Approach and Method

The current study employed a qualitative research methodology to gain insights on students' application of critical thinking to choose a design problem. The method used for the current study

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was the collective case study, as described by Goddard (2010). The current study will be conducted within a single site, which is a government secondary school in Singapore. The considerations for choosing the site are shown in Table 1. Singa Secondary School (the school name used is a pseudonym), was identified as a potential site for the study. The selection of Singa Secondary School was based on the following reasons in Table 2.

Table 1
Criteria for choosing a study site

Criteria for Selection of Study Site	
1.	School should be recognised to implement a progressive D&T programme
2.	D&T teachers are active in professional sharing in the Singapore D&T fraternity.
3.	Profile of students studying D&T consists of a mix of academic abilities

Table 2
Reason for choosing the current study site

Reasons to select Singa Secondary School as Study Site	
1.	As a pilot school for implementing Framework for 21CC in 2010, the school will have more experience with the review and implementation of pedagogy and practices to develop critical thinking.
2.	Widely recognised by the D&T fraternity in Singapore, for the last 15-17 years, for innovation in pedagogy and teaching practices, and the ability to achieve excellent student outcomes. D&T teachers from different parts of Singapore often seek opportunities to visit the school to learn from the teachers.

3.3 Objects of Study

The objects, or cases, for this study are the design journals done by upper secondary students in Design Project A for a D&T Express course. Design Project A is a major design project that all upper secondary school students in the Express course (between the age of 15 and 16) have to go through in Singa Secondary School. In Design Project A, students will complete the project on their own. Each student will produce a design journal. As such, each case for this study is represented by a design journal done by one student.

The main purpose of Design Project A is to allow students to exercise their knowledge and skills learned in D&T up till the point of Design Project A to engage in a full design process that starts with a given theme and ends with a proposed working prototype. In this project, students take main control of the design process as teachers supervise. The given theme for Design Project A differs yearly, but the tasks required, and assessment criteria are consistent.

In Design Project A, students are required to record any forms of explorations, research, ideation, experimentation and evaluation processes related to problem identification, ideation, idea development and prototyping into the design journals. Thus, the used of design journals as objects of study is based on the assumptions that design journals are a detailed collection of students' thinking and decision-making processes during the design process. In the selection of design journals for study, the following considerations were made. (Refer to Table 3)

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Table 3
Considerations for design journals selections as study cases

Considerations for Selecting Design Journals as Cases	
1.	The design journals should be done by students who were conscientious in completing their work. This is to ensure that any deficiency in their performance in the design journals are due to their abilities rather than the lack of effort.
2.	The design journals should be done by students who had gone through similar D&T curriculum before attempting Design Project A. This is to reduce the disparity of student performance due to the difference in terms of content knowledge and skills.
3.	The design journals should be representative samples that reflect the quality of work done by majority of the D&T students in Design Project A. The design journals selected for study should not be the outliers in terms of performance.

In a pilot school for 21CC, the D&T department had reviewed the curriculum for the lower and upper secondary D&T Express course. Started in 2012, critical thinking is taught more explicitly in lower secondary D&T. Thus, upper secondary students engaging in the Design Project A from 2014 onward would have gone through a similar D&T programme starting from lower to upper secondary. Using available archives of design journals produced between 2014 and 2016, 15 cases based on the design journals that were supervised by two teachers were selected for this study. (Refer to Table 4)

Table 4
The number of journals used for study between 2014 and 2016

Year:	No. of Archived Journals Used	Supervised by:
2014	8	Teacher A
2015	1	Teacher A
2016	6	Teacher B

Based on class deployment, the academic profile of students supervised by the two teachers were similar. Throughout the year, it is a practice in the school that all D&T teachers will often share and discuss about teaching and learning, and students' progress for all levels (secondary 1 to 4) of D&T learning. These forms of meeting provide professional development for all D&T teachers and also reach consensus on what to expect for student outcomes for each level. Though the selected design journals for this study were supervised by two D&T teachers, the disparity in the quality of supervision, teaching and student academic abilities related to this study were considered to be minimum.

3.4 Research Design

The primary set of data was collected via students' documentations in the design journals. The scope of data collection covers students' documentation during the process of decision making to select a design problem. Students' documentations will include written and printed text, sketches and photos. The general process undertaken by students during the process in focus can be described as

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follow. The process of decision making to select a design problem comes after the brainstorming process to explore a range of possible problems related to the given theme. When making a decision to select a problem to work on further, students would evaluate the various problems identified during the brainstorming process.

To design a method to interpret the students' documentation, firstly, the author consulted the teachers and collected the expectations for students to achieve in the process within the scope of study (refer to Table 5). These expectations were in line with the assessment rubrics for Design Project A. Though the critical thinking model by Elder & Paul (2008) can be applied to all reasonings across different fields, the importance of some intellectual standards may be different in different fields. Thus, it is necessary to contextualize the intellectual standards within the field and then to articulate the intellectual standards that are most important for reasoning (Elder & Paul, 2008). Table 5 and 6 provided the context for the author to contextualize the intellectual standards relevant to the current study.

Based on Table 5, questions were used to deconstruct reasoning for the decision-making process in selecting a problem and then after, intellectual standards were applied to answer these questions (Elder & Paul, 2008). By answering the questions, the intellectual standards essential to good reasoning related to the processes in the current study can be articulated (refer to Table 6). Using Table 6, the author was able to observe students' critical thinking processes by interpreting the documentations in the design journals. To increase validity of the interpretations, any queries related to the documentations were clarified with teachers before further interpretations. In addition, all observations were provided to the D&T teachers for clarification so that any misinterpretations could be corrected.

Table 5
Teachers' expectations for students during the process of choosing a problem

Teachers' expectations of student in choosing a problem to work on
Student is encouraged to choose a problem of their interest, from a context that they are familiar with, or easy access to research for information.
Student needs to give a reasonable and logically explanation for the rationale of choosing the problem.
Student needs to choose a problem that will make a positive impact to people' lives.
Student needs to choose a problem that can be solved with a physical product.

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Table 6

Deconstructing reasoning and articulating intellectual standards for good reasoning when choosing a problem

Elements of Reasoning when Choosing a Problem	Questions to deconstruct reasoning	Intellectual Standards for good reasoning in Choosing a Problem
Purpose	□ Is the student able to adopt realistic purposes and goals when choosing a problem? □ Is the student able to choose a problem based on significant purposes and goals?	□ The ***achievability*** of the problem is ***clearly*** articulated. □ Display ***clarity*** in purpose by choosing a problem related to the theme. □ The significance of solving the chosen problem is ***justified*** and ***clearly*** articulated.
Questions	□ Is the student able to use relevant questions to evaluate the problems?	□ Formulate ***relevant*** and ***clear*** questions and apply them to evaluate the problems that lead to the chosen problem.
Point of View	□ From what point of view do student use to choose the problem?	□ The problem is chosen based on other points of view to achieve ***fairness*** and ***clarity***.
Information	□ To what extend is the student's decision on the chosen problem supported by relevant and fairly gathered information?	□ The evaluations of the different problems are supported by ***reliable*** and ***adequate*** source of information. □ The decision for choosing a problem is supported by ***reliable*** and ***adequate*** source of information.
Concepts and Ideas	□ Are the key ideas and concepts that guide students' reasoning to choose a problem clear, accurate or deep?	□ Display ***clarity*** and ***depth*** in concepts and ideas used to ***justify*** research conclusions.
Assumptions	□ Are the student's assumptions justifiable and reasonable based on evidence or past experience when choosing the problem?	□ The reasons given for choosing a problem based on the student's assumptions which are ***justified*** and ***clear***.
Implications and Consequences	□ Is the student able to clearly and precisely articulate the possible implications and consequences in choosing the problem?	□ The reasons given for choosing a problem is articulated ***clearly*** and ***logically*** based on the implications and consequences in choosing the problem.
Inference	□ Is the student able to make inferences that are reasonable, clear and logical to support the problem chosen?	□ Inferences and interpretations made to support the problem chosen are ***reasonable***, ***clear*** and ***logical***.

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3.5 Research Implementation

During the implementation of the study, to gain a holistic view, the documentations in each design journal were first studied to understand the processes embarked by students to select a problem. Then after, using Table 6 to interpret the documentations, observations of each student's good reasonings and weak reasonings with respect to each of the elements of reasoning were recorded. After all the 15 design journals were interpreted and observations recorded, common and different patterns in students' reasoning for each element of reasoning could be identified and clarified.

4. Findings: Critical Thinking in Choosing a Problem

Before students make decision to choose a problem, students will explore a range of possible problems that are related to the theme. During the problem exploration process, students mainly focus on brainstorming and exploring relevant problems (Loh, 2020). Students did not conduct any forms of evaluation on the problems that might assist their decision-making process in choosing a problem. When making a decision to select a problem after problem exploration, students were free to use any methods they had learned to evaluate their choice of problems and assist their decision-making processes.

4.1 Observations of Good Reasoning

A general observation in the journals during the process of choosing a problem can be described as follow. It was evident that nine students used a decision matrix to assist their decision making in choosing a problem (refer to Figure 1). In a typical decision matrix, the left most column of the decision matrix are criteria set by students and the top row of the matrix are the headings of problems identified during problem exploration. Students would evaluate all the problems based on the criteria they set. A score will be given to each problem against each criterion. The scoring system is usually based on the number of problems (n) available. With the lowest ranked problem given 1 point and the highest given n points. Then after, the total score for each problem is tabulated in the lowest row of the matrix.

For students using the decision matrix, seven of the students chose the problem with the highest score. While the other two students could not decide on their choice of a problem went on to seek teacher's opinion. The teacher then advised the two students to conduct more research for those problems in the decision matrix with higher scores so that it may help them in their decision making.

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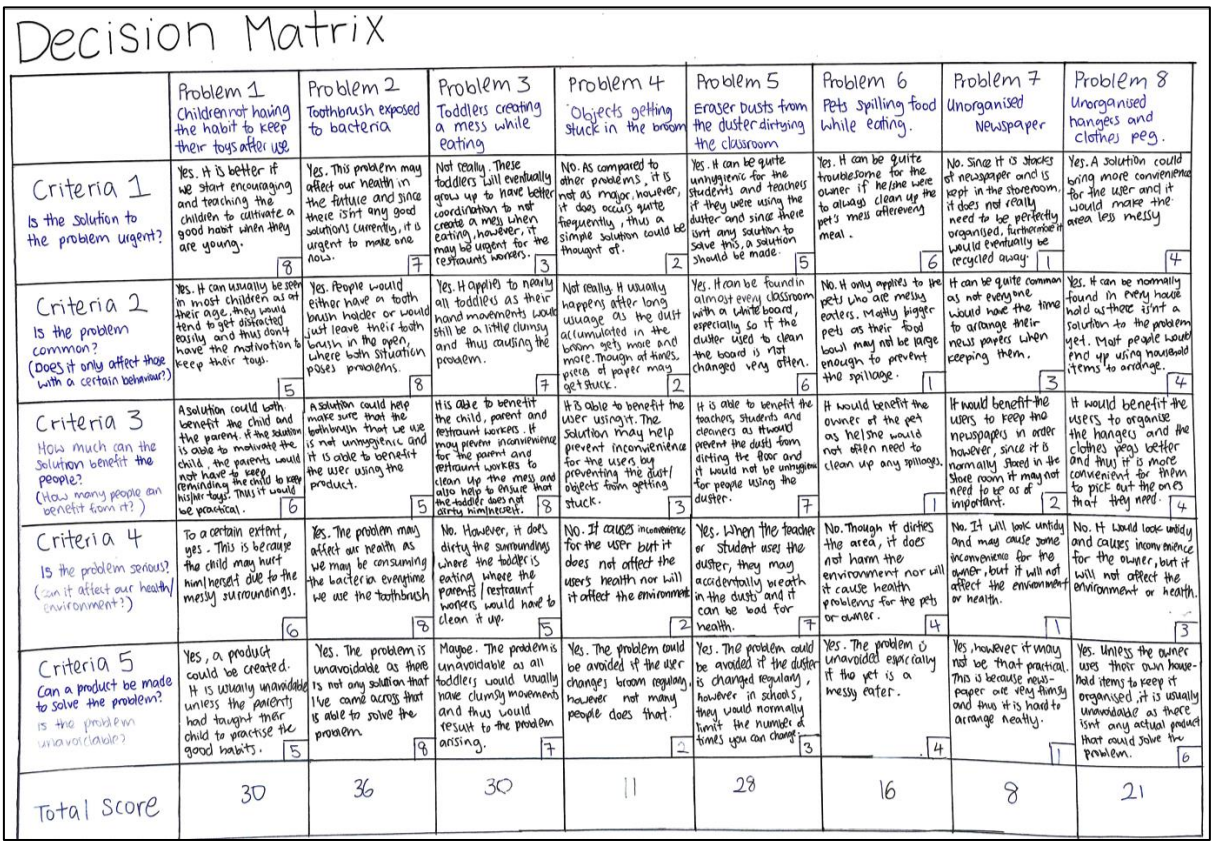
In six students who did not use the decision matrix, five of them provided reasons in their journals to explain their choice of the chosen problem. But one of student did not provided any reasons as to why she chose the problem. But this particular student did provide reasons for modifying her chosen problem immediately after choosing the problem.



Decision Matrix

	Problem 1 Children not having the habit to keep their toys after use	Problem 2 Toothbrush exposed to bacteria	Problem 3 Toddlers creating a mess while eating	Problem 4 Objects getting stuck in the broom	Problem 5 Eraser dusts from the duster dirtying the classroom	Problem 6 Pets spilling food while eating.	Problem 7 Unorganised Newspaper	Problem 8 Unorganised hangers and clothes peg.
Criteria 1 Is the solution to the problem urgent?	Yes. It is better if we start encouraging and teaching the children to cultivate a good habit when they are young. 8	Yes. This problem may affect our health in the future and since there isn't any good solutions currently, it is urgent to make one now. 7	Not really. These toddlers will eventually grow up to have better coordination to not create a mess when eating, however, it may be urgent for the restaurants workers. 3	No. As compared to other problems, it is not as major, however, it does occurs quite frequently, thus a simple solution could be thought of. 2	Yes. It can be quite unhygienic for the students and teachers if they were using the duster and since there isn't any solution to solve this, a solution should be made. 5	Yes. It can be quite troublesome for the owner if he/she were to always clean up the pet's mess afterevery meal. 6	No. Since it is stacks of newspaper and is kept in the storeroom, it does not really need to be perfectly organised, furthermore it would eventually be recycled away. 1	Yes. A solution could bring more convenience for the user and it would make the area less messy 4
Criteria 2 Is the problem common? (Does it only affect those with a certain behaviour?)	Yes. It can usually be seen in most children as at their age, they would tend to get distracted easily and thus don't have the motivation to keep their toys. 5	Yes. People would either have a tooth brush holder or would just leave their toth brush in the open, where both situation poses problems. 8	Yes. It applies to nearly all toddlers as their hand movements would still be a little clumsy and thus causing the problem. 7	Not really. It usually happens after long usuage as the dust accumulated in the broom gets more and more. Though at times, piece of paper may get stuck. 2	Yes. It can be found in almost every classroom with a white board, especially so if the duster used to clean the board is not changed very often. 6	No. It only applies to the pets who are messy eaters. Mostly bigger pets as their food bowl may not be large enough to prevent the spillage. 1	It can be quite common as not everyone would have the time to arrange their news papers when keeping them. 3	Yes. It can be normally found in every house hold as there isn't a solution to the problem yet. Most people would end up using household items to arrange. 4
Criteria 3 How much can the solution benefit the people? (How many people can benefit from it?)	A solution could both benefit the child and the parent. If the solution is able to motivate the child, the parents would not have to keep reminding the child to keep his/her toys. Thus it would be practical. 6	A solution could help make sure that the toothbrush that we use is not unhygienic and it is able to benefit the user using the product. 5	It is able to benefit the child, parent and restaurant workers. It may prevent inconvenience for the parent and restaurant workers to clean up the mess and also help to ensure that the toddler does not carry maintenance. 8	It is able to benefit the user using it. The solution may help prevent inconvenience for the users by preventing the dust/ objects from getting stuck. 3	It is able to benefit the teachers, students and cleaners as it would prevent the dust from dirting the floor and it would not be unhygienic for people using the duster. 7	It would benefit the owner of the pet as he/she would not often need to clean up any spillages. 1	It would benefit the users to keep the newspapers in order however, since it is normally stored in the store room it may not need to be as of important. 2	It would benefit the users to organise the hangers and the clothes pegs better and thus it is more convenient for them to pick out the ones that they need. 4
Criteria 4 Is the problem serious? (Can it affect our health/ environment?)	To a certain extent, yes. This is because the child may hurt him/herself due to the messy surroundings. 6	Yes. The problem may affect our health as we may be consuming the bacteria everytime we use the toothbrush 8	No. However, it does dirty the surroundings where the toddler is eating where the parents / restaurant workers would have to clean it up. 5	No. It causes inconvenience for the user but it does not affect the users health nor will it affect the environment 2	Yes. When the teacher or student uses the duster, they may accidentally breath in the dusts and it can be bad for health. 7	No. Though it dirties the area, it does not harm the environment nor will it cause health problems for the pets or owner. 4	No. It will look untidy and may cause some inconvenience for the owner, but it will not affect the environment or health. 1	No. It would look untidy and causes inconvenience for the owner, but it will not affect the environment or health. 3
Criteria 5 Can a product be made to solve the problem? Is the problem unavoidable?	Yes, a product could be created. It is usually unavoidable unless the parents had taught their child to practise the good habits. 5	Yes. The problem is unavoidable as there is not any solution that I've came across that is able to solve the problem 8	Maybe. The problem is unavoidable as all toddlers would usually have clumsy movements and thus would result to the problem arising. 7	Yes. The problem could be avoided if the user changes broom regularly, however not many people does that. 2	Yes. The problem could be avoided if the duster is changed regularly, however in schools, they would normally limit the number of times you can change 3	Yes. The problem is unavoidable especially if the pet is a messy eater. 4	Yes, however it may not be that practical. This is because news-paper are very flimsy and thus it is hard to arrange neatly. 1	Yes. Unless the owner uses their own house-hold items to keep it organised, it is usually unavoidable as there isn't any actual product that could solve the problem. 6
Total Score	30	36	30	11	28	16	8	21

Figure 1. An example of decision matrix to evaluate all problems against criteria.

Based on the 15 design journals, the critical thinking processes exercised by students to choose a problem can be broken down by elements of reasoning. By applying the intellectual standards articulated in Table 6, the quality of students' critical thinking could be assessed through the documentations in their design journals. In this section, Table 7 consolidates the observations of common and different patterns of good reasoning exercised by students. When necessary, the observations may be accompanied by an example extracted from part of a design journal and be presented via a figure indicated at the end of the respective observations.

DOI: 10.6232/JTEE.202106_51(1/2).0001

Table 7

Observations of good reasoning when choosing a problem

Elements of Reasoning during Choosing a Problem	Observations of Good Reasoning in Choosing a Problem [1,2] [1]The number in the bracket [ ] represents number of design journals with similar observation [2] When necessary to present the observation clearer, an example from a journal may also be provided as a figure
Purpose	□ One student was observed to have decided on the problem based on the accessibility for research, her own willingness to try, the time and cost needed to invest in the research and current available solutions in the market. The reasons given are ***clear***, ***logical***, ***achievable*** and ***realistic***. [1] (refer to Figure 2) □ A handful of students gave ***clear*** and ***logical*** reasoning to ***justify*** the significant positive impact of solving the problems they have chosen. [4] (refer to Figure 3) □ More than half of the students evaluated all the problems based on frequency of occurrence, number of people impacted, urgency, importance and/or personal conviction of solving the problem. The evaluations were ***clear*** and ***logical*** to ***justify*** the significant of solving the problem. [8] (refer to Figure 1) □ One student inserted a criterion to evaluate the ***achievability*** of all the problems based on whether a product can be designed to solve the problem. The evaluations for this criterion were articulated ***clearly*** and ***logically***. [1] (refer to Criteria 5 found in Figure 1) □ One student took an unusual path in choosing a problem based on ***significance***. Initially, this student did not provide any reasons to explain why a problem was chosen. But based on her conversation with stakeholders, she realised that the problem that she focused on was not significant for the stakeholders. Instead, the stakeholders provided some other problems that are more crucial to solve. Thus, led to her modifying the initial problem. As a final chosen problem, this student was able to ***justify*** the choice of problem based on the creating positive ***significant*** impact to stakeholders. [1] (refer to Figure 4) □ As one of the evaluation criteria, one student evaluated the ***significance*** of the problem ***clearly*** based the frequencies of the problems that he, or his families and friends faced commonly. [1]
Questions	□ A handful of students used ***relevant*** questions as criteria to guide their evaluation of problems in order to decide on one problem. [5] (refer to Figure 1)
Point of View	□ One student sought ***relevant*** viewpoints from teacher to verify the problems identified. Through this, she got to know that there are existing good solutions are available for one of the problems she hoped to choose. Student had displayed ***fairness*** in accepting opposing viewpoints that are not in favour of her findings. Through seeking ***relevant*** viewpoints, she later to identify another possible related problem related to the same context. [1] (refer to Figure 5) □ One student sought ***relevant*** viewpoints from friends to evaluate the viability of solving the problem. [1] □ One student sought ***relevant*** viewpoints from dog owners (stakeholders) with regards to her chosen problem and realized that the chosen problem is not that significant. She managed to ***clarify*** the more significant aspects of the problem faced by the stakeholders related to the same context. [1] (refer to Figure 4) □ Some students displayed ***flexibility*** by seeking other viewpoints, such as from teachers, when they faced difficulties in choosing the problem. [3]
Information	□ Student gathered ***adequate*** information through stakeholders to claim that none of the stakeholders are willing to assist her in conducting research to understand the problem. Student stated this information ***clearly*** as evidence to support her decision of not choosing a problem. [1] (refer to Figure 6)

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Concepts	□ More than half of the students displayed ***clarity*** in applying the concept of objective decision-making by using criteria and points via a decision matrix. [9] (refer to Figure 3) □ For some instances, students were able to think ***deeply*** about the concepts used as criteria to evaluate the problems in the decision matrix. This was evident as students were able to articulate most, but not all, of their evaluations of the problems ***clearly*** and ***with relevance*** to the respective criteria. [8] (refer to Figure 1)
Assumptions	□ In general, students were able to articulate their assumptions ***clearly*** and ***logically*** to ***justify*** their reasons for choosing the problem. [14] (refer to Figure 7) □ Two students made decisions in selecting problems based on assumptions that were ***justified*** by information gathered through seeking other points of view. [2] (refer to Figure 4)
Implications and Consequences	□ When making the decision to choose a problem, one student articulated ***clearly*** the potential negative consequences if the problem was not addressed. [1] (refer to Figure 8) □ Most students articulated the implications and consequences ***clearly*** and ***logically*** to support their decisions in choosing a problem. [13] (refer to Figure 7)
Inferences	□ A few students who gathered information from teacher, friends and/or related stakeholders were able to articulate their inferences of the information ***accurately*** to ***justify*** their problem selection or decision-making process that leads to next course of action to select a problem. [5] (refer to Figure 9)

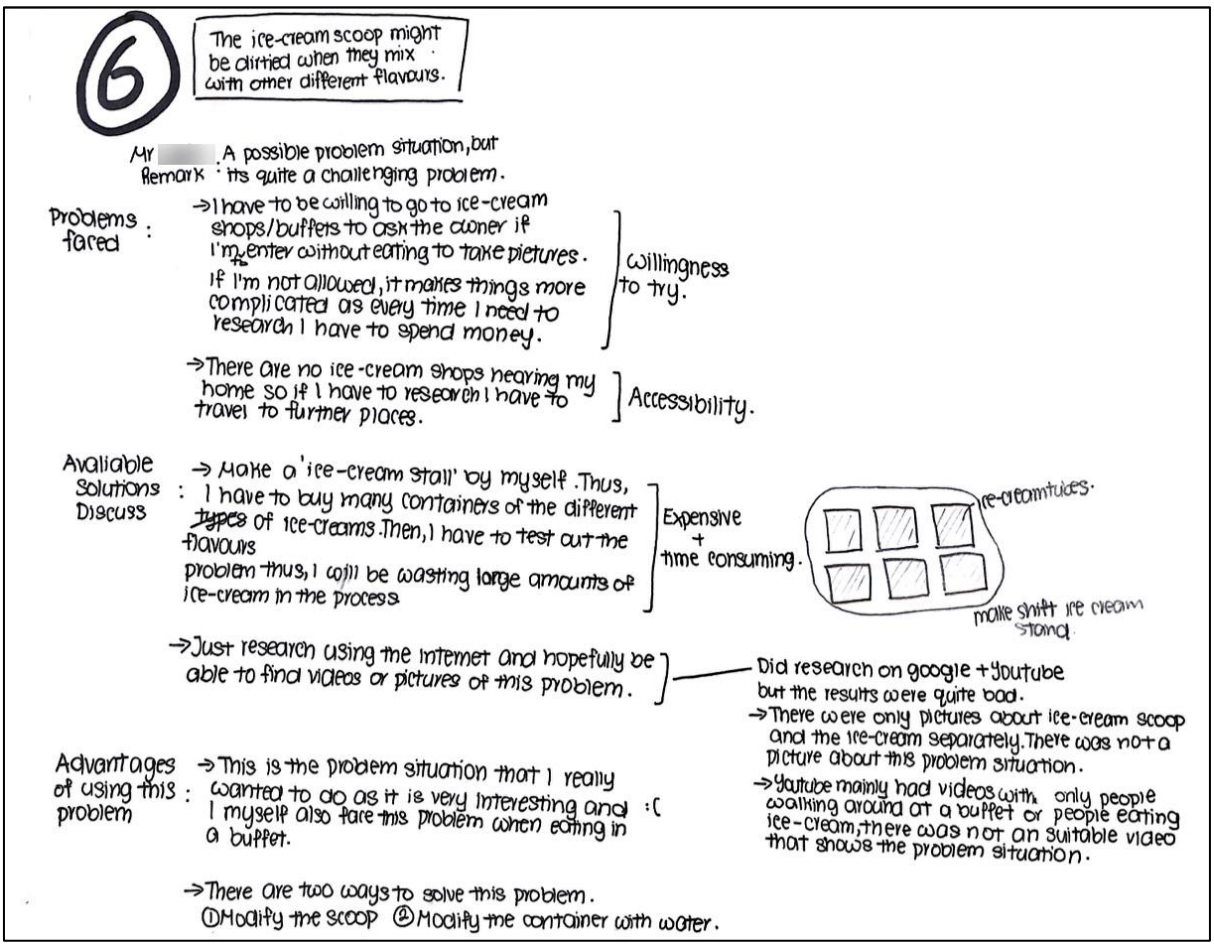

Figure 2. An example of a student who did not use a decision matrix but displayed purposeful selection of problem.

DOI: 10.6232/JTEE.202106_51(1/2).0001

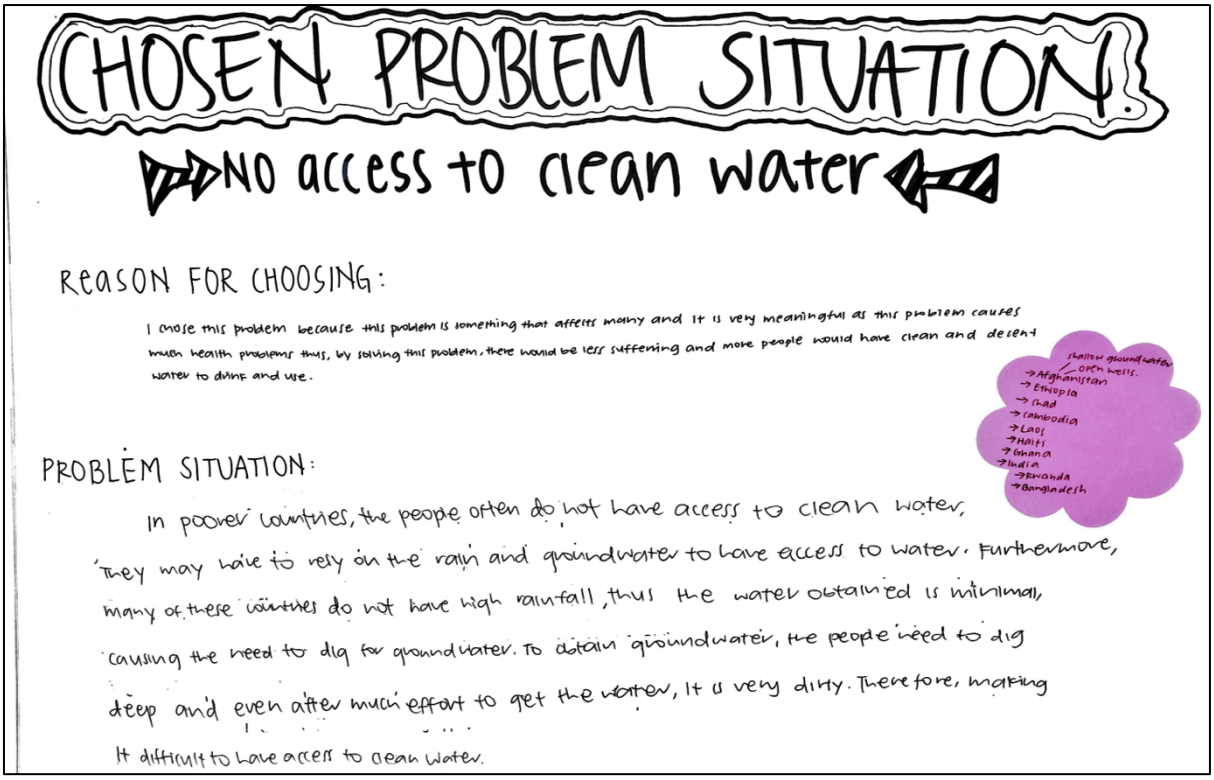

Figure 3. An example of a student who displayed clear and logical reasoning in justifying significantly positive impact for solving the chosen problem.

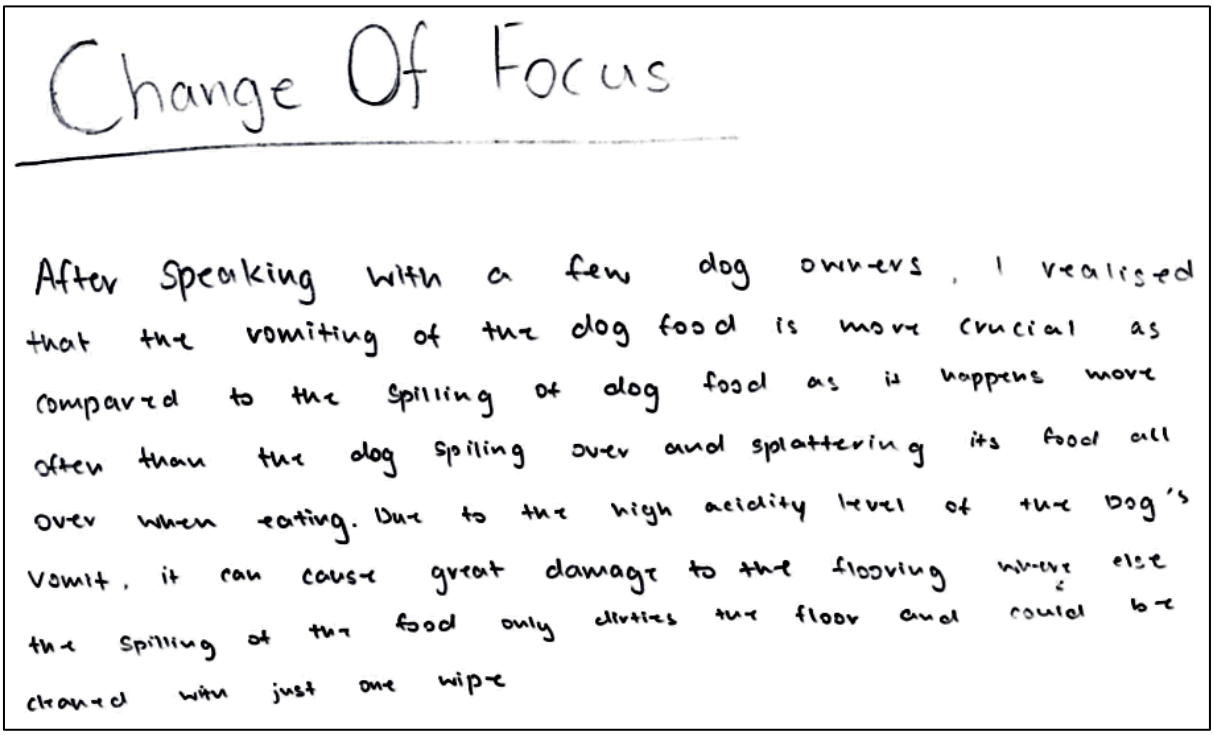

Figure 4. An example of a student displaying the willingness to modify her purpose in solving a problem based on other significance identified through seeking other points of view.

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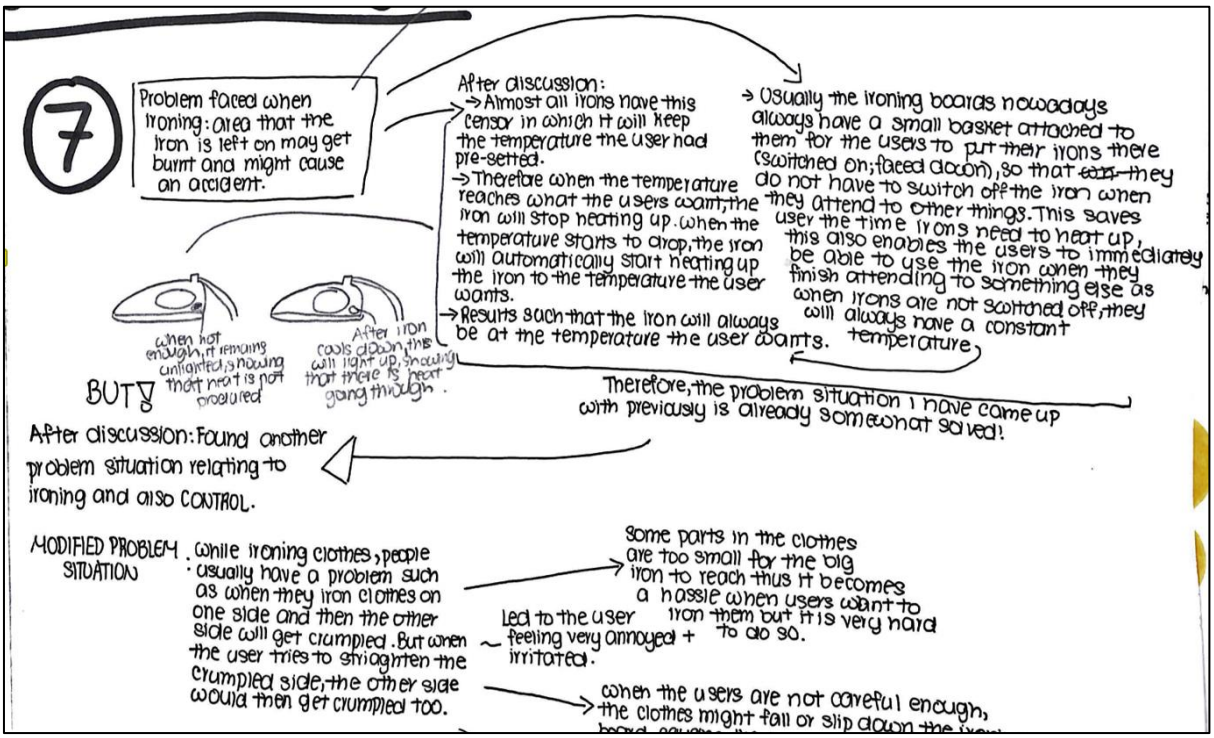

Figure 5. An example of a student who documented the outcomes of the discussion with teacher who gave opposing viewpoints which lead to the modification of problem.

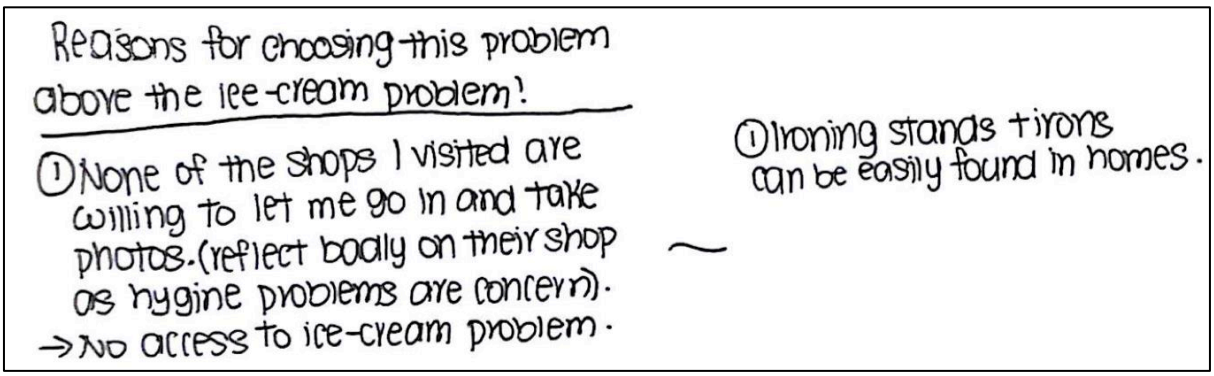

Figure 6. An example of a student who gathered adequate information before making a decision in her problem selection.

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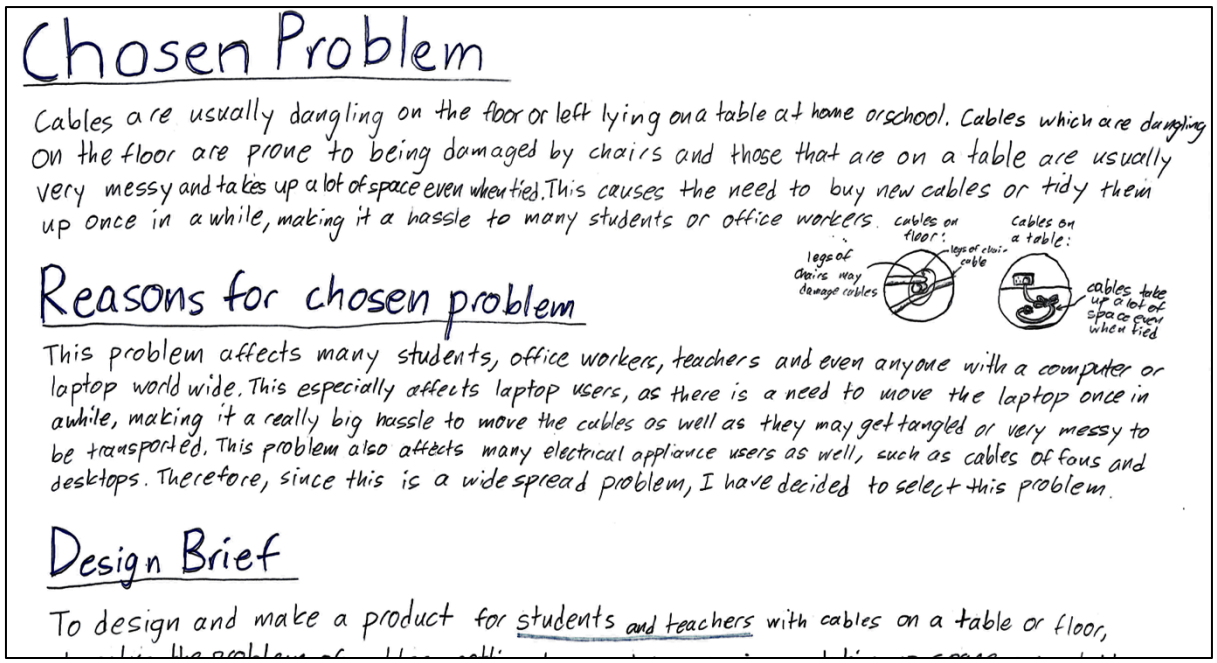

Figure 7. *An example of student being able to articulate his assumptions clearly and logically to form a decision.*

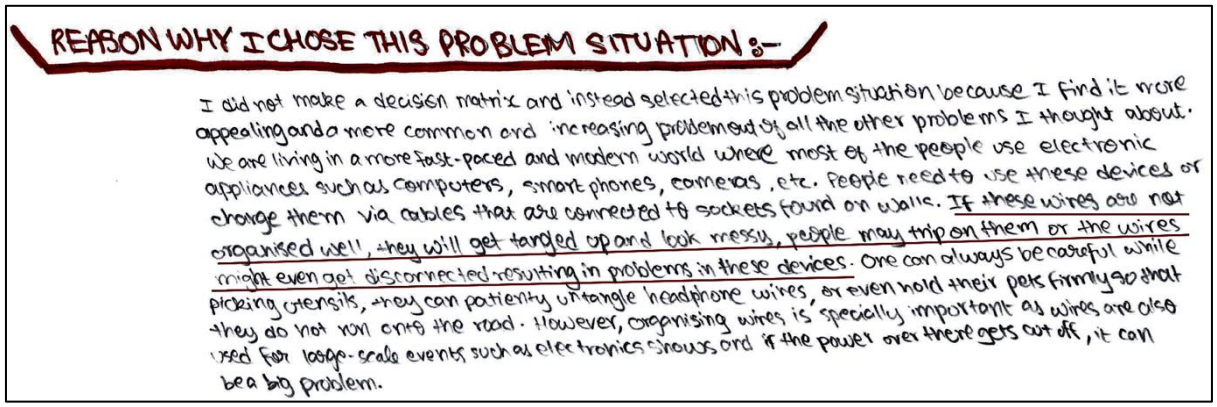

Figure 8. An example of a student articulating clearly the potential negative consequences.

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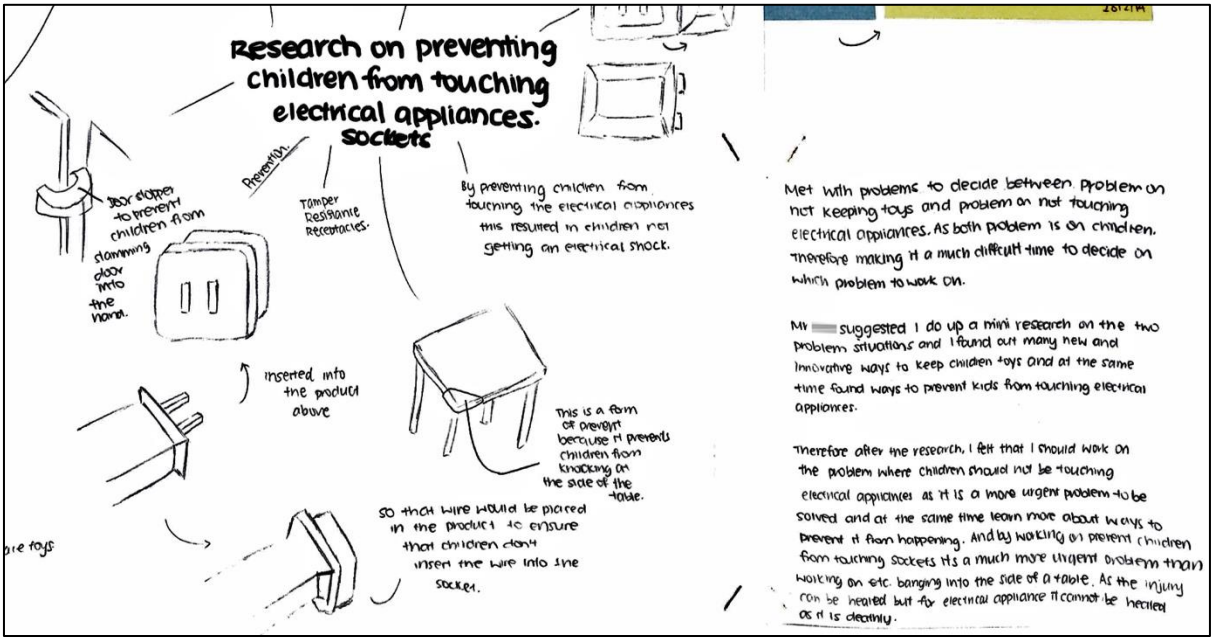
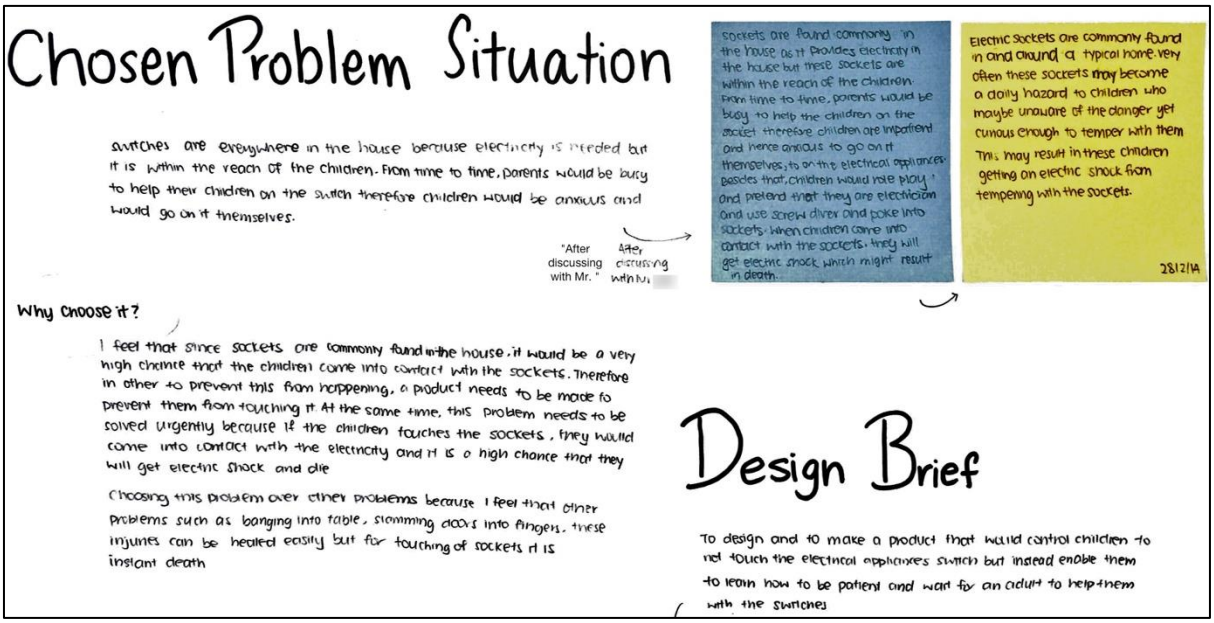


(a)



(b)

Figure 9. (a) An example of student who was able to articulate her inferences clearly based information gather during a discussion with teacher that called for the need for further research before choosing a problem; (b) Same student later was able to further articulate the problem clearly based on what seems to be a discussion with teacher but the decision to choose the problem is mainly based on her assumptions.

4.2 Observations of Weak Reasoning

Using Table 6, areas of weak reasonings displayed by students can also be observed based on the documentations in the design journals and can be presented in Table 8. In general, most students were able to articulate clearly and logically to justify their assumptions towards their decision-making

DOI: 10.6232/JTEE.202106_51(1/2).0001

processes in the selection of problem. But one major issue observed was that, although students can clearly and logically justify their assumptions, most of the assumptions made were not accurately justified with evidence. In other words, very often there was no evidence provided to support their assumptions. Thus, almost all fourteen students did not support their decision of choosing a problem based on any form of data or information as evidence. This was especially evident for students who did not use the decision matrix. Although they have stated their reasons in choosing a problem, but nothing was provided in the journals that support their reasons. Although more than half of the students used the decision matrix as a structure to assist them in their decision-making processes, their evaluations of each criteria were mostly based on their own assumptions. Thus, students may have gone through the process of systematic decision-making, but the quality of reasoning during the decision-making process was weak.

Table 8

Observations of weak reasoning when choosing a problem

Elements of Reasoning during Understanding the Chosen Problem	**Observations of Weak Reasoning in Choosing a Problem [1,2]** [1]The number in the bracket [ ] represents number of design journals with similar observation [2] When necessary to present the observation clearer, an example from a journal may also be provided as a figure
Purpose	Some students evaluated the problems based on personal convictions as a criterion. However, they were ***not able to articulate and explain with clarity*** how decisions were made based on personal conviction to select the problem as a goal for this design project. In some cases, justification to choose the problem based on personal conviction were ***shallow***. [4] (refer to Figure 10)
Information	When choosing a problem, most students did not gather adequate information to support their decision-making processes. Their decision-making processes are mainly based on their own assumptions of the problems but may be ***inaccurate*** which further make ***unfair evaluations*** to some extent. [14] (refer to Figure 11)
Concepts	One student clearly displayed ***a lack of depth in thinking*** about the concept related to criteria to evaluate the problems in the decision matrix. This is evident in his /her ***superficial*** evaluations of all the problems. [1] (refer to Figure 10)
Assumptions	As a whole, for students using the decision matrix, the evaluations made with regards to the problems were mainly based on their assumptions that ***may not be accurately justified*** by evidence. [9] (refer Figure 1)
Implications and Consequences	For students using the decision matrix, some of the evaluations were made based on ***unclear*** implications and consequences. [2] (refer to Figure 10)
Inferences	In general, most students did not seek to figure out their assumptions of the problems that lead to their inferences related to the problems. Thus, this led to making inferences based on ***unjustified*** and ***faulty*** assumptions related to the problems that may influence their decision-making processes to choose a problem. [14]

DOI: 10.6232/JTEE.202106_51(1/2).0001

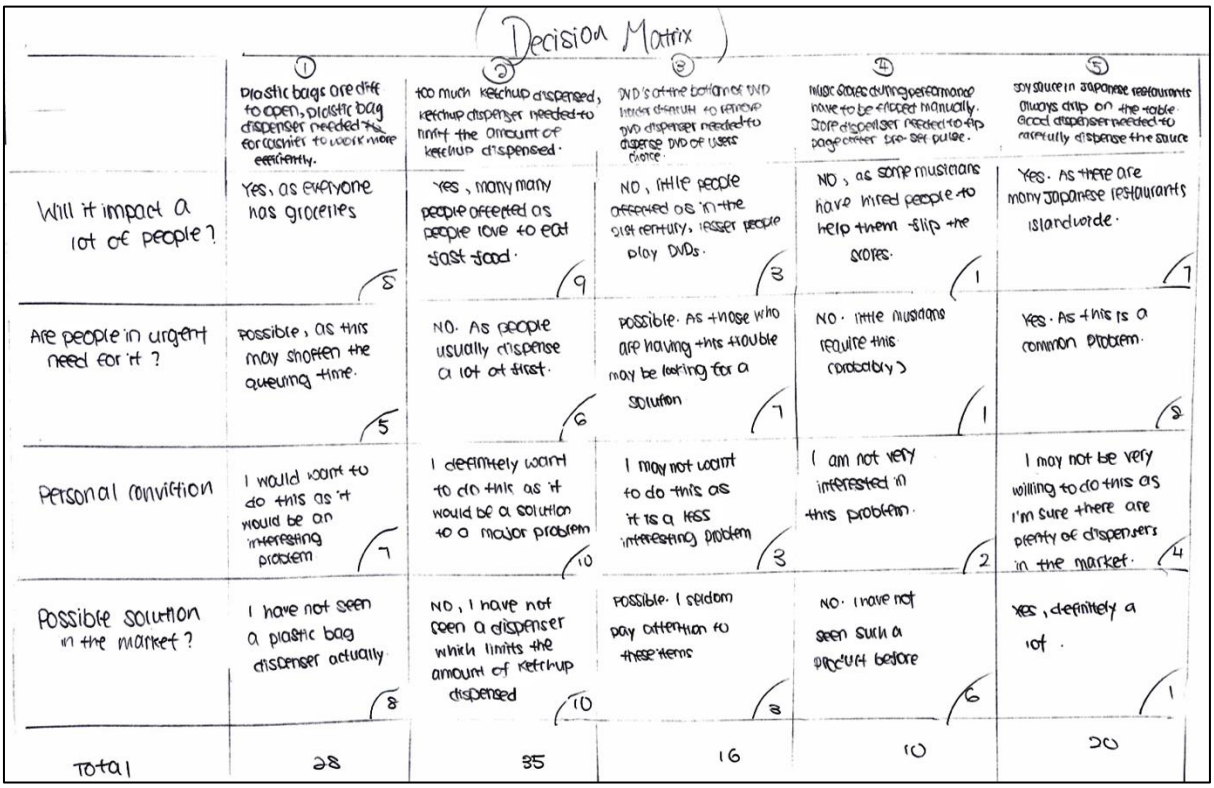


Figure 10. An example of a student's vague evaluations that clearly displayed weak reasoning in elements such as purpose, concepts and implications.

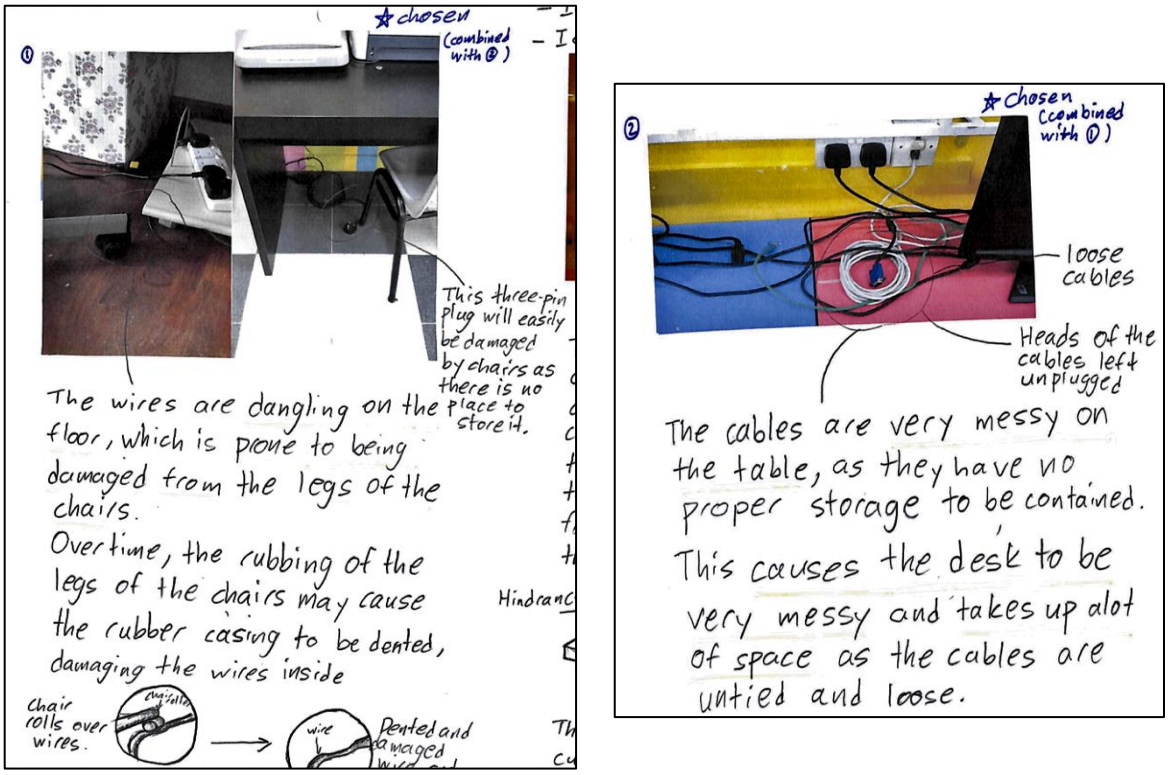


Figure 11. An example of a student who chose the problem based on his own interpretation of the problem through field observation, but his decision was not supported by other forms of data or information.

DOI: 10.6232/JTEE.202106_51(1/2).0001

5. Discussions

The current study presented an approach to dissect students' critical thinking into the various elements of reasoning and then assessing these elements of reasoning using the intellectual standards that are contextualised for the current study. Although current study is based on Singapore context, the findings may provide the following implications for critical thinking development in D&T design projects with respect to choosing a design problem.

5.1 The Need to Strengthen the Quality in Critical Thinking Process

The collective cases formed based on the analysis of documentations in the design journals in this study provided important insights to understand how students exercise critical thinking when choosing a design problem. From the documentations in the design journals, it is clear that students do go through a process of critical thinking to evaluate the problems so that a decision can be made when choosing a design problem. Such systematic decision-making process can be seen in the form of the decision matrix.

Although students went through a systematic decision-making process, their decisions were often justified based on their assumptions. In decision matrix, students were able to articulate their evaluations of the problem clearly and logically, but these evaluations were mainly based on assumptions that were inaccurate or not justified by sufficient evidence. Thus, the final decision to choose a design problem may not be fully justified. For students who did not use the decision matrix to evaluate their options when choosing a design problem, most seem able to provide reasons to support their choice of problems, but their reasons were mainly based on assumptions made without any evidence to support such assumptions. Thus, the observations in the design journals shown that though students may have gone through the critical thinking process, but that do not equate to achieving the desired quality of the critical thinking process. One of the main reasons is that students do not conduct much research to verify their evaluations of the problems when choosing a problem. Thus, mostly falling back on their own assumptions.

5.2 Suggestions to Strengthen the Quality in Critical Thinking Process

In order to sharpen students' critical thinking to achieve quality reasoning during the process of problem selection, the suggestions in this section may provide educators with useful insights when teaching the problem identification process for D&T design projects.

Firstly, a more systematic process of information or evidence gathering to support decision-making may be necessary. For example, in the use of the decision matrix, the selection criteria for

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choosing a problem may be formed early in the problem identification process. In other words, before students engage into the process of problem exploration, the selection criteria necessary for decision-making when choosing a problem should be formed. In fact, when forming the selection criteria, students should also justify the need for each criterion with support or evidence instead of just resting on their assumptions. Once the selection criteria are formed, students can systematically research on required information or evidence with respect to the selection criteria during the problem exploration process. This will provide the basis for decision-making when choosing a problem. While this process does not mean to restrict students' exploration of problems during the divergent thinking process; but by knowing the selection criteria in advance, this will sharpen students search for information to understand the problem better and in turn form important background knowledge that is necessary to perform quality reasoning during the problem selection process. This in-turn may sharpen critical thinking.

The decision-making process in choosing design problems formed an excellent opportunity for the development of ethical reasoning in the critical thinking process (Sternberg, 2017). In the face of a list of design problems, students are confronted with deciding on which problem should be solved instead of the others. Such decision-making process touch on ethical considerations in reasoning. For example, choosing a design problem that affects the lives of many people as compared to problems that affect individuals; or addressing a need rather than a want; or addressing sustainable issues rather than promoting consumerism and wastage. Perhaps, through this process students may be able to think much deeper how design can contribute to natural environment and mankind, and experience the ethical struggle in design, rather than just considering the commercial aspect of design.

In addition, students should also evaluate the possible problems based on their personal emotions such as conviction and interest in the problem, which may be affected by their values. By going through such a process, students may be more aware of how their own emotions affect decision-making, especially in choosing the types of problems to solve. It should not be discounted that students are usually more motivated in solving problems that they are interested in and have personal conviction. Finally, students can also be taught to choose realistic goals in the form of design problems that can be solved within their means. Thus, when forming selection criteria for choosing problems, it is suggested that students should focus on factors such as ethical, significance, reasonability, relevance, emotions and achievability.

5.3 Infusing the Elements of Reasoning into the Curriculum for Design-Based Learning

Taking D&T in Singapore as an example, the current national syllabus and assessment criteria mainly focus on assessing students' competencies in the design process. Although critical thinking is

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expected to be developed when students go through the design process, how critical thinking can be evaluated is still not well defined. In order to evaluate the quality of critical thinking displayed by students, methods to articulate the standards for quality critical thinking need to be developed.

The current study provides a possibility of an approach to deconstruct reasoning required for a particular stage in the design process. Using critical thinking model by Paul and Elder (2002, 2019), the standards for good reasoning required for a particular stage in the design process can be articulated based on expected student outcomes. Using the set of standards articulated specifically for a particular stage in the design process, it is possible to evaluate the quality of students' critical thinking at every major juncture in the design process.

Based on the expected student outcomes defined in the national syllabus, which will translate into the curriculum of each school, curriculum developers at school level may develop a set of standards that can be applicable to evaluate students' critical thinking in the design projects. On the other hand, curriculum developers at national level may consider the approach presented in this study to develop a set of relevant standards that may be used by schools to evaluate the quality of critical thinking in students during design-based learning.

In the aspect of developing students with skills to achieve good reasoning during the design process, the standards for good reasoning will also be useful to teach students how to reason through the different elements of reasoning. As there are eight elements of reasonings, D&T programmes in school curriculum may need to scaffold learning activities that can develop students with the different elements of reasoning by stages and with different intensity. This is because, it may not be possible for students to internalise all eight elements of reasoning at one go.

6. Limitations of Study

As limitations to this study, current findings are based on evidence from the design journal. However, what goes into the discussion between students-teachers, students-users and students-stakeholders, that may influence students' decision-making are not able to be clarified, although some students did note some of the discussions. In a way, how students derived the selection criteria in the decision matrix are mostly unknown. There may have been formed after certain discussions with teachers, stakeholders, friends. To cover such possibilities, any queries about the documentations in journals were clarified with the teachers as much as possible.

7. Conclusion

The current study aimed to identify and clarify students' critical thinking processes when choosing a design problem by using Singapore D&T as a context. Breaking down students' critical

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thinking into elements of reasoning, the quality of reasoning can be assessed using intellectual standards. From the study, the follow main points may be summarised.

Firstly, the use of decision-making tools does not necessary enable students to achieve quality reasoning. While students may be able to articulate clearly and logically their choice of the problem, but in most cases, their decisions are mainly based on assumptions which may not be well justified. Thus, a more systematic process of information or evidence gathering is necessary.

Secondly, the selection criteria for choosing a problem should be formed early in the problem identification process, before students engage into problem exploration. By doing this, students may be able to know the selection criteria in advance, this will sharpen students search for information to understand the problem better and in turn form important background knowledge that are necessary to perform quality reasoning during the problem selection process.

Thirdly, the process of choosing problems may be a good opportunity to touch on students' ethical and emotional considerations towards the problems. Thus, when forming the selection criteria to choose a problem, it is suggested that students should focus on factors such as ethical, significance, reasonability, relevance, emotions and achievability.

Finally, the current study may provide curriculum developers with some fruits for thoughts on the possibilities to develop relevant assessment standards that may be useful in evaluating and developing quality critical thinking in design-based learning.

8. Acknowledgements

The author would like to thank all the school leaders and teachers who have kindly contributed to this study. This work was supported by JSPS KAKENHI Grant Number JP18K13168.

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