Sharpening Critical Thinking in Problem Identification in Design and Technology Education

LOH, Wei Leong
Faculty of Design, Kyushu University

出版情報：pp.899-925, 2020. Design Research Society(DRS)
バージョン：

Aug 11th, 12:00 AM

Sharpening Critical Thinking in Problem Identification in Design and Technology Education

Wei Leong Loh
Kyushu University, Faculty of Design, Japan

Citation
Loh, W. (2020) Sharpening Critical Thinking in Problem Identification in Design and Technology Education, in Boess, S., Cheung, M. and Cain, R. (eds.), *Synergy - DRS International Conference 2020*, 11-14 August, Held online. https://doi.org/10.21606/drs.2020.358

DRS2020
BRISBANE, 11–14 AUG
SYNERGY

Sharpening Critical Thinking in Problem Identification in Design and Technology Education

Wei Leong LOH

Kyushu University, Faculty of Design, Japan
leon@design.kyushu-u.ac.jp
doi: https://doi.org/10.21606/drs.2020.358

Abstract: The current study aimed to identify and clarify students' critical thinking processes when understanding the design problem towards formulating design specifications within the problem identification stage when engaging in a design project at upper secondary level. Using design journals done by students 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, a set of general guidelines can be proposed for students to achieve good reasoning standards in order to understand the problem and to determine appropriate design specifications. To achieve good reasoning standards when breaking down the design problem, research in three basic related areas such as environment, users and products are necessary to form important background knowledge.

Keywords: PedSIG; critical thinking; design education; design and technology

1. Introduction

In responding to the effects of globalization and the knowledge-based economy, a major curriculum review was undertaken in 1997 by the Ministry of Education, Singapore (MOE) to rethink its goal and direction for the future (Poon, Lam, Chan, Chng, Kwek & Tan, 2017). The knowledge-based economy has shifted the efficiency driven education into an ability driven education, where ability for life-long learning by its people is kegiy to the sustainability and economic growth of Singapore (Goh & Gopinathan, 2008). The major curriculum review in 1997 led to the inception *Thinking School Learning Nation* (TSLN) in the same year (Poon et al., 2017). TSLN was considered as the pivotal policy shift toward 21 Century Competencies (21CC) education and the defining moment that aimed to systematically educate 21CC by concentrating resources on teachers, infrastructure and technology with the aim to prepare Singapore's students with the necessary knowledge and skills for the future (Poon et al., 2017).

The importance of critical thinking as part of the 21CC required of a student can be articulated with the policies and initiatives that came after the TSLN. To enhance the pedagogical change that set out in TSLN, the *Teach Less, Learn More* (TLLM) initiative was introduced in 2004 and subsequently launch in 2005. The TLLM set out to enhance the quality of education through reduction in syllabus content to encourage active learning and independent learning; and also, to enhance critical thinking and inquiry-based learning among students (Tan, Koh, Chan, Pamela & Hung, 2017; Koh, 2013). The revision in the *Desired Outcomes of Education* in 2009 further emphasized the importance of critically thinking in the four desired outcomes of the student (Tan et al., 2017).

Supporting the revised *Desired Outcomes of Education* in 2009 was the formalization of the *Framework for 21CC and Student Outcomes* in 2010 that represented one of the most significant developments in Singapore's efforts for 21CC education (Tan, 2013; Poon et al., 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 et al., 2017). However, currently, few studies had been done to understand how critical thinking and creativity 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).

The current study is part of a research to enhance critical thinking of students studying D&T by first identifying and clarifying students' critical thinking processes in D&T projects using the Singapore context. In this study, the main focus is to identify and clarify students' critical thinking processes in understanding a chosen design problem that lead to the determination of design specifications within problem identification stage. 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. Critical Thinking

2.1 What is 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 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 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 Exercising and Assessing Critical Thinking

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 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; Paul & Elder, 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, 2013a; Paul & Elder, 2008, 2014). Words such as clarity, accuracy, relevant, significant, logical and so forth are identified as intellectual standard words (Paul & Elder, 2008, 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, 2013a; Paul & Elder, 2008, 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 & Elder (2002, 2008, 2019).

2.3 Adopting a working definition and a mode of assessing quality 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, 2008, 2019) 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 choosing a problem to solve, how do students exercise critical thinking to clarify the problem and determine the necessary design specifications?

3.2 Research Approach and Method

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

	Reason 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. 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)

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 is 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 the 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, 15 design journals completed between 2014 and 2016, and supervised by two teachers were selected as study samples. (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 B
2016	6	Teacher C

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 problem clarification, problem re-define and determining design specifications. Students' documentation will include written and printed text, sketches and photos. The general processes undertaken by students during the processes in focus can be described as follow. After deciding on a problem to solve, students would conduct research to clarify the problem with the aim of having a thorough understanding of the problem. Sometimes, students might be required to re-define the problem after they gained deeper understanding of problem. During the research process, students will identify potential design considerations for the solution. Based on the design considerations surfaced, students would then determine the design specifications necessary for the design solution.

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 processes within the scope of study (refer to Table 5 and 6). These expectations were in line with the assessment rubrics for Design Project A. Though the critical thinking model by Paul and Elder (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 (Paul & Elder, 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 and 6, questions were used to deconstruct reasoning for clarifying the problem, re-defining problem and determining the design specifications and then after,

intellectual standards were applied to answer these questions (Paul & Elder, 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 7 and 8). Using Table 7, and 8, 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.

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 for problem clarification, problem re-define (if any) and determining design specifications. Then after, using Table 7 and 8 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.

Table 5 Teachers' expectations for students during the phase of understanding the problem and re-defining the problem.

Teachers' expectations of student in understanding the chosen problem and re-defining problem when necessary
Student needs to come up with a research plan on what they need to find out in order to understand the chosen problem.
Student needs to clarify the problem through research in related areas such as environment, user, product and others when any additional information is required.
Student needs to explain the objectives for each research to show the relevance or importance to understanding the issues in the problem.
Student needs to conduct at least one relevant site visit to observe the issues in the problem. If the sites are not accessible, student needs to conduct research on the sites and issues based on internet, books, newspaper, etc.
Student needs to observe user(s)-environment and/or user(s)-product interaction and behaviour, take photo, note down details and draw connections of how and why problem arise.
Student may interact with relevant products as a form of immersion in order to obtain insights on possible problems.
Student needs to take photos of the problem issue on the site or to find reliable photos on the internet, books, newspapers to justify the existence of the problem.
Student needs to conduct questionnaire surveys and/or interviews with users or relevant stakeholders to understand the users and problem better.
Student needs to prepare the questions for the questionnaire surveys and interviews with rationale stated for each question.
Student needs to analyse results from the questionnaire surveys and/or interviews to identify trends or varied responses, justified by logical and valid reasons.
If the relevant users are not accessible, student needs to research about the users and issues based on the internet, forums, books, newspaper, etc.
Student needs to research existing products, any form of make-shift/homemade solutions that can solve the problem or possibly solve the problem.
Student needs to analyse the existing products, any form of make-shift/homemade solutions to find out the parts required to make the product and the purpose of each part. This will help them understand what they need to consider for their solutions.
Student needs to draw relevant insights from the analysis of the research with respect to the chosen problem and the users involved.
Student needs to research on relevant information to achieve a deeper understand of related concept(s).
Student needs to draw relevant conclusions based on the findings in their research.
If student's research findings showed that the problem that they have stated initially is not accurate, they have to re-define the problem and brief.
If student realised after/during the research that the scope of the problem is too wide, they can narrow the scope of the problem and re-define the problem and brief.
After re-defining the problem and brief, the student needs to assess the relevance of the initial research and determine if they need to do new research to understand the problem better.
Student needs to find out new information that they need with objectives of research stated and provide conclusions at the end of the research.

Table 6 Teachers' expectations for students during the phase in determining design specifications.

Teachers' expectations of student in determining design specifications
Student needs to identify important and relevant design specifications with respect to the chosen problem based on the research done.
Student needs to write the design specifications clearly and logically.
Student needs to provide relevant, justified and logical reasons for the design specifications that they have stated.

Table 7 Deconstructing reasoning and articulating intellectual standards for understanding the chosen problem and re-defining the problem.

Elements of Reasoning during Understanding the Chosen Problem and Re-defining Problem	Questions to deconstruct reasoning	Intellectual Standards for good reasoning in Understanding the Chosen Problem and Re-defining Problem
Purpose	▪ Is the student clear about the purpose of research to understand the chosen problem?	▪ The objectives and ***significance*** of each research conducted are ***justified*** and ***clearly*** articulated. ▪ Display ***clarity*** and ***consistency*** in purpose by identifying and conducting relevant research in areas that provide better understanding to the problem. ▪ The objectives and ***significance*** of the questions used in the questionnaire survey are ***justified*** and ***clearly*** articulated. ▪ The need for re-defining the problem is ***justified*** and ***clearly*** articulated.
Questions	▪ Is the student able to use relevant questions when planning research? ▪ Is the student able to use relevant questions to clarify the problem? ▪ Is the student able to breakdown the main question into useful sub-questions to clarify the problem?	▪ Formulate ***relevant*** and ***clear*** questions and apply in planning of research. ▪ Formulate ***relevant*** and ***clear*** questions and apply in the analysis of existing products related to the problem. ▪ Formulate ***relevant*** and ***clear*** questions and apply in understanding the problems that users faced through questionnaire surveys and interviews. ▪ Ability to breakdown the main question into sub-questions to achieve a more ***precise*** clarification of the main question. ▪ Sub-questions are used to break down the problem to achieve ***clarity*** and ***precision*** in understanding the problem.
Point of View	▪ From what point of view did student look at the problem?	▪ Understanding of the problem based on other points of view to achieve ***fairness*** and ***clarity***.
Information	▪ To what extend is student's reasoning about the problem supported by clear, relevant, accurate and adequate information? ▪ Did the student manage to present or state the evidence clearly and fairly in the research?	▪ Source of information in understanding the problem is ***reliable*** and ***accurate***. ▪ Multiple sources of information are ***fairly*** gathered to achieve an ***accurate*** claim. ▪ Research conclusions are supported with ***reliable***, ***adequate*** and ***accurate*** evidence. ▪ Findings from research are ***clearly*** and ***fairly*** reported without distortion.
Concepts and Ideas	▪ Are the key ideas and concepts that guide students' reasoning clear, accurate or deep?	▪ The concepts and keys ideas used by student to clarify the problem are ***clearly*** articulated and displayed ***depth of thinking***.
Assumptions	▪ Are the student's assumptions justifiable and reasonable based on evidence or past experience? ▪ Is the student clear about the assumptions that he/she is making?	▪ Research conclusions are based on the student's assumptions which are ***justified*** and ***clear***.
Implications and Consequences	▪ What implications and consequences follow student's reasoning? ▪ Is the student able to clearly and precisely articulate the possible implications and consequences?	▪ Inferences on research findings based on the evidence ***clearly*** and ***precisely*** articulated the possible implications and consequences. ▪ Able to articulate ***clear*** and ***logical*** implications on the need to re-define the problem when necessary.
Inference and Interpretations	▪ Is the student able to make inferences and interpretations that are justified, reasonable, clear and logical?	▪ Inferences and interpretations of the problem are ***consistent*** with evidence from the research findings. The inferences and interpretations are ***logically***, ***reasonably*** and ***clearly*** articulated. ▪ Decisions on the necessity of possible considerations for design solutions (design considerations) are ***logically***, ***reasonably*** and ***clearly*** explained.

Table 8 Deconstructing reasoning and articulating intellectual standards for determining design specifications.

Elements of Reasoning during Design Specifications	Questions to deconstruct reasoning	Intellectual Standards for good reasoning in Design Specifications
Purpose	▪ Is the student able to distinguish significant and relevant design specifications that are necessary for the design solution to solve the problem?	▪ Design considerations identified in research are examined and selected as design specifications based on the ***significance*** and ***relevance*** to solving the problem.
Point of View	▪ Did student seek different points of view when determining the design specifications?	▪ Design specifications that are adopted are ***justified*** and ***fair (unbiased)*** based on points of view from related target users.
Concepts and Ideas	▪ What are the main concepts and ideas used in articulating the design specifications?	▪ ***Relevant*** concepts and ideas used to determine the design specifications are ***clearly*** articulated.
Implications and Consequences	▪ What implications and consequences follow student's reasoning? ▪ Is the student able to clearly and precisely articulate the possible implications and consequences?	▪ ***Significant*** potential implications and consequences of adopting the design specifications are ***clearly*** articulated based on earlier research.
Inference and Interpretations	▪ Is the student able to make inferences that are justified, reasonable, clear and logical?	▪ The decision for adopting each design specification is ***clearly*** and ***logically*** articulated and ***justified*** based on the earlier research.

4. Findings: *Critical Thinking in Understanding the Chosen Design Problem*

In the process to understand the chosen problem, students conducted research to clarify the problem. To clearly understand the problem, students engaged into different areas of research which can be categorised into, 1) environment related, 2) users related, 3) product related, and/or 4) any other additional information. In each research, after achieving a conclusion from the findings, students would identify a number of possible design considerations and constraints for the design solutions.

Within an area of research, the common modes of inquiry can be presented as follow. For 11 students who conducted environment related research, the main mode of inquiry was making observations about the environment. For 13 students who conducted users related research, the modes of inquiry were 1) questionnaire survey [conducted by 6 students], 2) interviews [conducted by 2 students], 3) observations on user behaviour at the site [conducted by 9 students], 4) internet search [conducted by 5 students] and 5) immersion into actual situation [conducted by 2 students]. All students conducted products related research and product analysis was mainly done.

Based on the 15 design journals, the critical thinking process exercised by students to clarify the problem through research can be broken down by elements of reasoning. By applying the intellectual standards articulated in Table 7, the quality of students' critical thinking could be assessed through the documentations. In this section, Table 9 consolidates the observations of common and different patterns of good reasoning exercised by students. When necessary, the observations may be accompanied by an example presented via a figure indicated at the end of the respective observations.

Table 9 Observations of good reasoning during research to clarify the chosen problem

Elements of Reasoning during Understanding the Chosen Problem	**Observations of Good Reasoning in Understanding the Chosen 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, a picture of the journal may also be provided as a figure
Purpose	▪ All students started the process by making a research plan to identify ***relevant*** research areas to clarify the problem. In most cases, the methods for investigation were also stated and were ***clearly*** and ***logically*** articulated. [15] (Refer to Figure 1) ▪ When conducting their research, students stated the research objectives with ***clarity*** and ***relevance*** to the problem. [15] (Refer to Figure 2) ▪ Students stated the rationales to the questions used in questionnaire surveys and interviews ***clearly***, ***logically***, and with ***relevance*** to understand the chosen problem. [8] (Refer to Figure 3) ▪ During the process of research, some students surfaced evidence which suggested some inaccuracy in the initial hypothesis of the problems, such as the related users, the leading cause of the problem, scope of the problem, etc. Students stated ***clearly*** the purpose of their problems to be re-defined and ***justified*** by their research findings. [5] (Refer to Figure 4)
Questions	▪ Most students used ***relevant*** questions as a guide to identify relevant research areas and formulate a research plan. [11] (Refer to Figure 1) ▪ Only a handful of students used ***relevant*** sub-questions to breakdown the main questions in the research plan to clarify the problem with depth and precision. [3] (Refer to Figure 1) ▪ Students who conducted questionnaire surveys used ***relevant*** questions to gain clear and accurate understandings of the problem faced by users or related stakeholders. [6] (Refer to Figure 3) ▪ A few students conducted interviews and used ***relevant*** questions to have a clear and deeper understanding on the problem faced by target users or related stakeholders. [2] ▪ One student used ***relevant*** questions as a guide to analyse more clearly and precisely on existing products or "make-shift" solutions used by target users that may solve the problem. [1]
Point of View	▪ A handful of students sought teacher's opinions to obtain different ***relevant*** viewpoints when finalising the research plans. [2] (Figure 1) ▪ A handful of students sought teacher's opinions to obtain ***broader*** viewpoints when formulating questions for questionnaire surveys. Students were also able to ***clearly*** articulate viewpoints from teachers. [2] ▪ Almost half of the students used questionnaire surveys to sought other points of views in order to obtain a ***clear*** and ***fair*** understanding of the problem faced by users and/or relevant stakeholders. [7] ▪ A handful of students sought other points of views through interviews to obtain a ***clear***, ***fair*** and ***deeper*** understanding of the problem faced by users and/or relevant stakeholders. [2] ▪ A handful of students seek ***broad*** viewpoints from teachers and/or stakeholders when making decisions in re-defining the problems. [2]
Information	▪ About half of the students went to at least one ***relevant*** site to collected ***relevant*** information in order to clarify the problem. While two of these students collected information from two or more ***relevant*** sites to ensure ***fair*** and ***adequate*** information collected. (7) (Refer to Figure 5) ▪ Most students took ***relevant*** photos of the sites related to the problem and/or users' behaviour with respect to the problem as evidence for analysis. For students who made observations related to uses, they may only focus on users' behaviour without considering the environmental influence on the users. [11] (Refer to Figure 2) ▪ Most students noted ***clearly*** the observations of how users and related stakeholders interact with the environment and the products related to the problem. [11] (Refer to Figure 2) ▪ Students sourced for ***relevant*** pictures, videos and articles from the internet to understand the users and environment better, especially for students who are not able to visit the site and talk to the target users. [9] ▪ Students conducted questionnaires surveys with more than one ***relevant*** user and/or related stakeholders to ensure ***adequate*** and ***fair*** information collected. [7] (Refer to Figure 6) ▪ A handful of students conducted interviews with more than one ***relevant*** user and/or related stakeholders to ensure ***adequate*** and ***fair*** information collected. [2] (Refer to Figure 2) ▪ One student went to experience the problems faced by users by using the products related (***seeking relevance***) to the problem to surface potential issues. [1] (Refer to Figure 7) ▪ Student played the role of a stakeholder to obtain ***accurate*** insights on possible problems. [1] (Refer to Figure 8) ▪ Students identified ***relevant*** products for product analysis. [15] (Refer to Figure 9) ▪ A few students collected information from ***relevant*** product based on product descriptions to analyse accurately. [3] (Refer to Figure 9) ▪ A few students collected information on ***relevant*** existing "make-shift" solutions that users used to solve the problem. [3] (Refer to Figure 10) ▪ Quite a number of students collected ***relevant*** information from the internet and research journals to gain in depth understanding of the concepts related to the problem. [6] ▪ All students generally presented the research information ***fairly*** (without distortion), ***clearly*** and ***logically***. [15] (Refer to Figure 2) ▪ To obtain ***clarity*** and ***accuracy*** on different aspects of the problem, most students conducted more than two different areas of research such as environment related, user related, product related, or any others to ensure ***fair*** and ***adequate*** information collected. [14] ▪ One student conducted different modes of inquiry related to target users to obtain ***clarity*** and ***accuracy*** on claims related to target users. [1] (Refer to Case Example A in the text of findings)

Concepts and Ideas	▪ Several students were able to use concepts and key ideas to explain the issues inherent in the problem ***clearly*** and ***accurately***. [6] (Refer to Figure 11) ▪ One student thought ***deeply*** about the concepts on hygiene as she was able to explain ***clearly*** the concepts in relationship to the hygiene issues that signalled the need to re-define the problem. [1] (Refer to Figure 4)
Assumptions	▪ Students generally made ***reasonable*** assumptions in analysis of information collected as they can explain ***clearly*** and ***logically*** on the implications presented by the information. [15] (Refer to Figure 10) ▪ Students generally made ***reasonable*** assumptions about the problem as they can present ***clear*** and ***logical*** claims about the problem based on the research. [14] (Refer to Figure 4)
Implications and Consequences	▪ Several students articulated ***clearly*** on the implications of the questions formulated for the questionnaire surveys and interviews, and how these questions may enhance understanding on the related users. [6] (Refer to Figure 3) ▪ Most students articulated the implications and consequences ***clearly*** and ***logically*** when concluding certain parts of their research based on the interpretations from research findings. [11] (Refer to Figure 11) ▪ After achieving a clear, accurate and deep understanding of the problem based on research, students articulated ***clear*** and ***logical*** implications that lead them to re-define the problem. [5] (Refer to Figure 4)
Inferences	▪ Students articulated ***justified*** inferences ***clearly*** and ***accurately*** based on information collected from site visits. [7] (Refer to Figure 2) ▪ Students interpreted the data from the survey and interview results ***logically*** and ***reasonably***. [8] (Refer to Figure 6) ▪ Inferring from questionnaire survey findings, students identified ***relevant*** design considerations and articulated the reasons ***clearly*** and ***logically***. [6] (Refer to Figure 6) ▪ Most students made inferences from the photos and information collected related to users ***logically*** and ***reasonably***. [12] ▪ Inferring from observation surveys and interviews related to users and stakeholders, students identified the design considerations and articulated the reasons ***clearly*** and ***logically***. [8] ▪ Students articulated their inferences of relevant products ***clearly***, ***logically*** *and* ***reasonably*** based on relevant pictures and information. [15] (Refer to Figure 9) ▪ From the product analysis, students identified relevant design considerations and articulated the reasons ***clearly*** and ***logically***. [9] (Refer to Figure 9) ▪ Most students made inferences from information gained from the different areas of research to triangulate ***accurate***, ***clear*** and ***justifiable*** understanding of problem and derived ***relevant*** design considerations. [14] ▪ Student made ***justified*** inference based on evidence from the research that resulted in the need to re-define the problem. [5] (Refer to Figure 4)

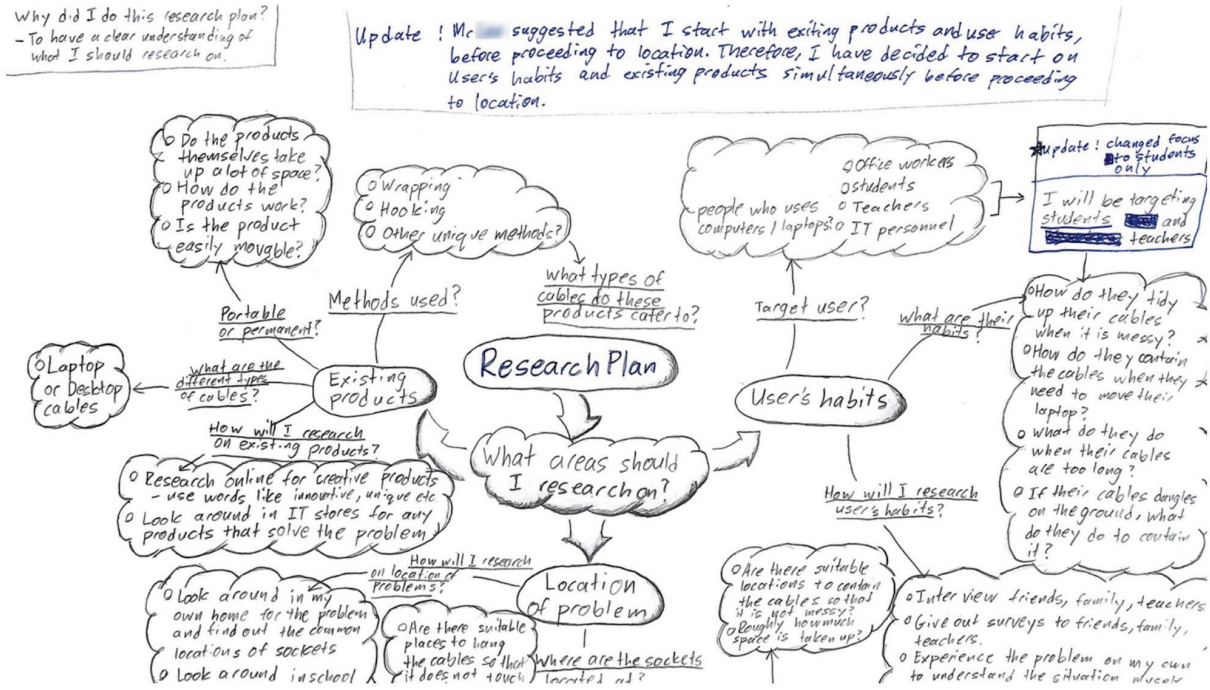

Figure 1 Example of a research plan.

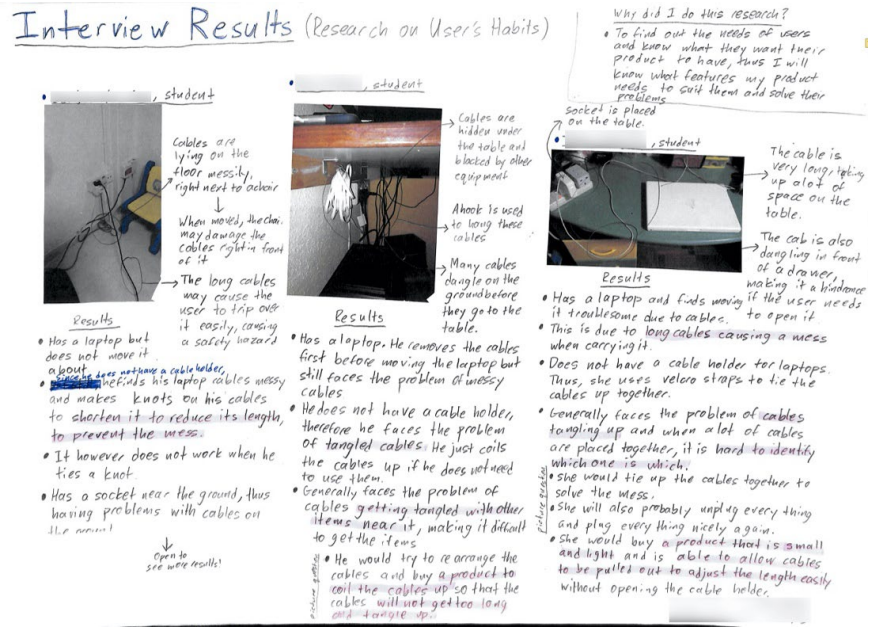

Figure 2 An example of student who showed a clear purpose for the research conducted.

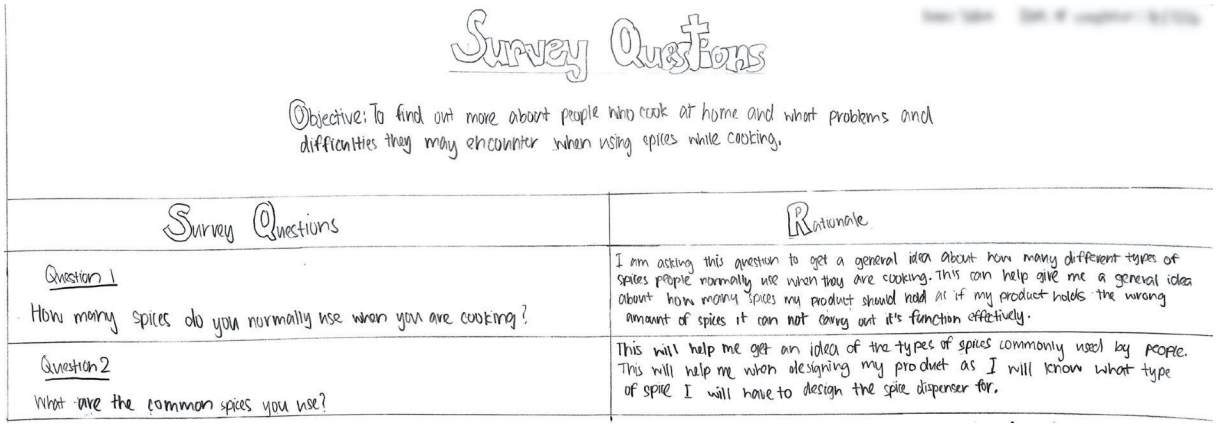

Figure 3 An example of student providing the rationale for each question used for surveys.

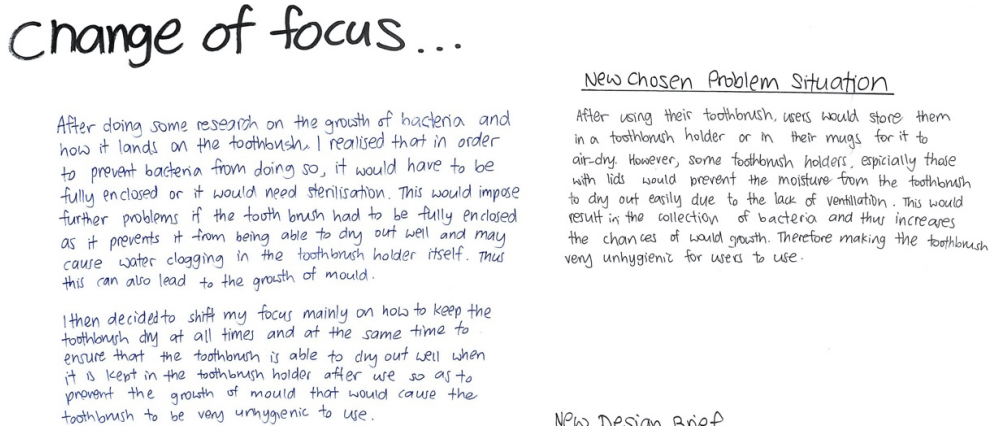

Figure 4 An example student who re-defined the design problem and re-stated the design brief.

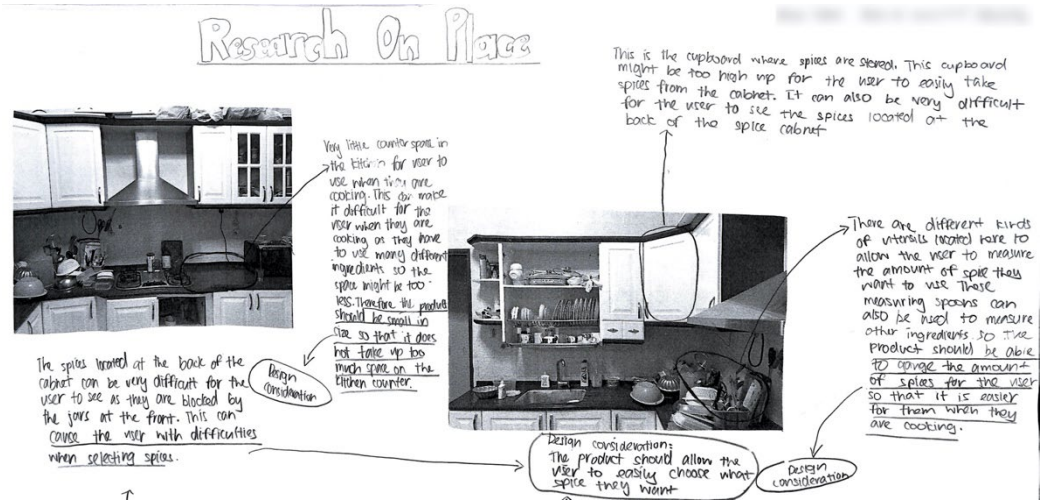

Figure 5 An example of student who did site visits to collect information.

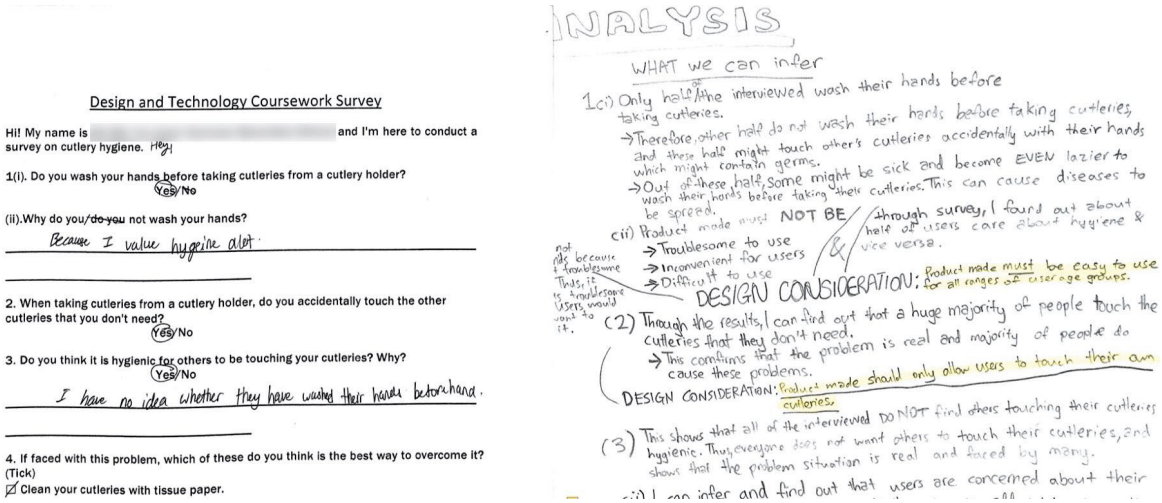

Figure 6 An example of a student who conducted questionnaire survey, followed by interpreting data and listing possible design considerations.

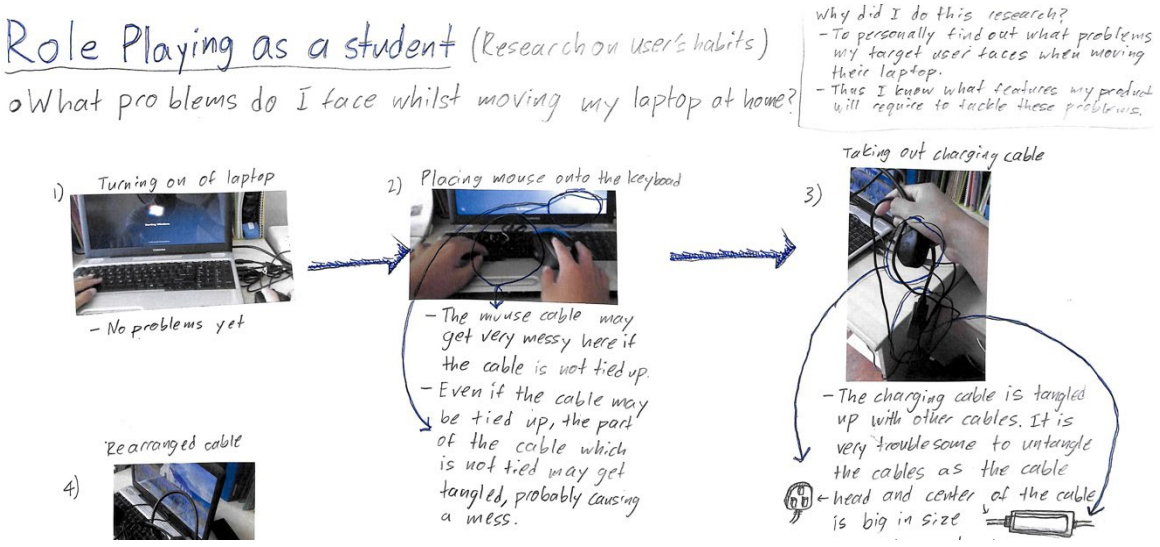

Figure 7 An example of a student playing the role of a target user.

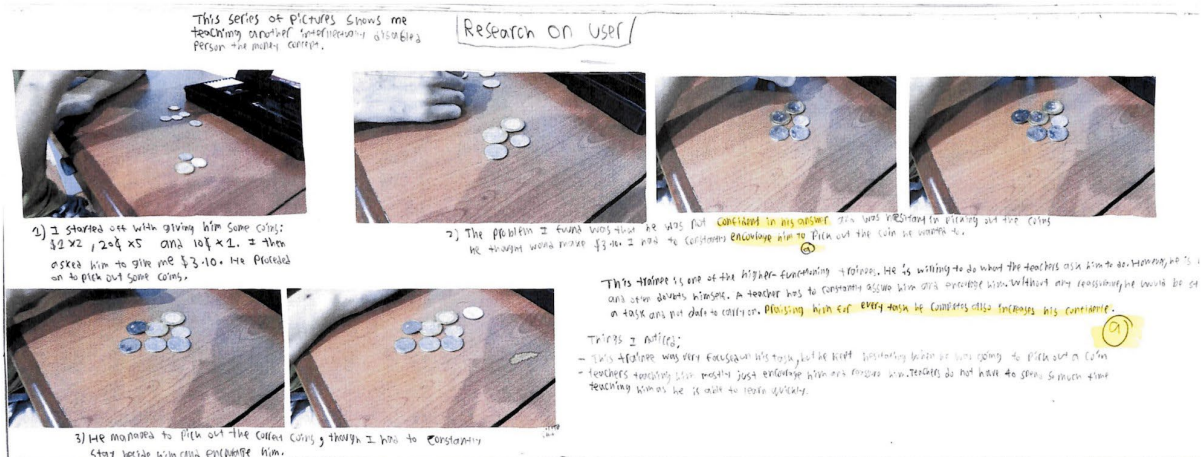

Figure 8 *An example of a student who immersed into experiencing teaching a student with special needs to find out the problems faced by teachers.*

Figure 9 *An example of a student's research on existing product.*

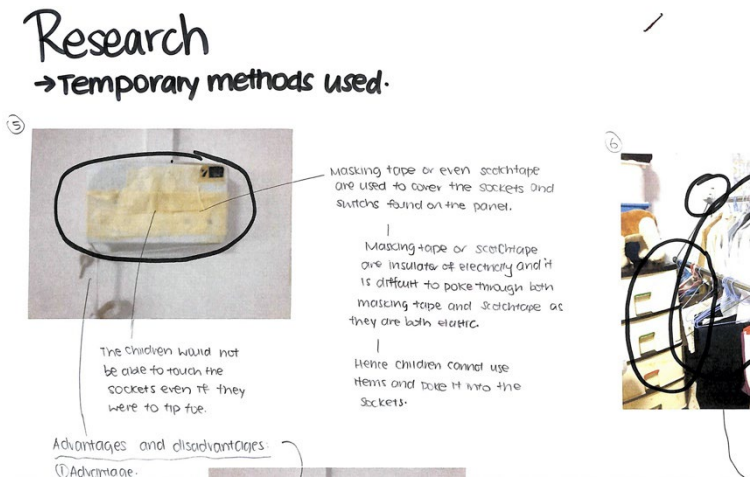

Figure 10 *An example of a student collecting information on relevant "make-shift" solutions*

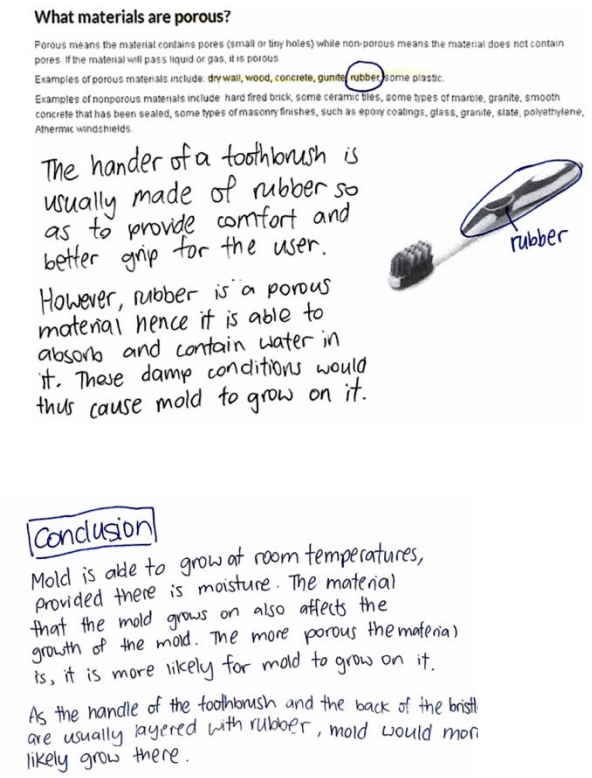

Figure 11 Example of a student who used the concept of the growth of mold with respect to material.

Presenting as Case Example A, it may be useful to present in more detail how Student K conducted different modes of inquiry on related stakeholders and target users. Student K wanted to design a product to encourage intellectual disabled students to learn independently. He conducted a simple questionnaire survey with 13 teachers in a special needs school to find out if students can complete learning tasks on their own and the motivation strategies teachers used in class. He also conducted an interview survey with 9 students with special needs to find out if they were able to complete their learning tasks in daily learning and if not, what were the reasons. Student K then had the opportunity to teach 3 students with special needs using the strategies that he gathered from the questionnaire and interview surveys. Based on the teaching experience, Student K was able to verify the strategies used by teachers and understand the issues presented by the 3 students (refer to Figure 8). Finally, Student K also conducted literature reviews of relevant journal articles on intellectual disabilities to gain more understanding based on expert views. In this example, the combination of different modes of inquiry provided Student K with accuracy and breadth to gain clarity and a fair understanding of his users to derive the possible design considerations.

Using Table 7, 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 10. In general, most design journals did contain a couple of weak reasonings among the good reasonings

observed while clarifying the problem. Thus, the number of design journals associate with weak reasoning are not indicated in Table 10. But instead, the examples of weak reasoning in Table 10 are elaborated in detail to provide a deeper insight into some of the reasoning issues. More importantly, the observations of weak reasoning will serve as important insights to inform teachers that even though students may be able to exercise good reasoning skills in general, there may be instances where their reasoning are not up to the standards. As such, it will be useful for teachers to be aware of such instances and provide interventions to redirect students to achieve quality critical thinking.

Table 10 Observations of weak reasoning during research to clarify the chosen problem.

Elements of Reasoning during Understanding the Chosen Problem	Observations of Weak Reasoning in Understanding the Chosen Problem
Purpose	▪ There were some instances where students reasoned without a clear purpose and forming conclusion based on inaccurate and insufficient data and information. For example, Student O wanted to solve problems related to retrieving disposable utensils from their original packages during parties and BBQ. He conducted an observation survey of users during the BBQ session but noted observations unrelated to retrieving disposable utensils. He seemed to have lost focus on the original purpose of research.
Questions	▪ Some students were not able to craft sub-questions in the questionnaire surveys to gain clearer and more precise understanding of the main questions. For example, Student M hypothesized that the problem of cutleries being touched by different people when trying to retrieve from the cutlery holder in the restaurant is unhygienic and may spread diseases. Using the questionnaire survey, Student M asked very general questions and seems to lack the specifics to find out details like, "how the intended users may come in contact with other cutleries when retrieving cutleries in the cutlery holder?", "under what circumstances where the intended users' cutleries are touched by other?" etc.
Point of View	▪ In some instances, information gathered from questionnaires surveys merely to support students' point of view instead of gaining a broader perspective. ▪ In some instances, questionnaire surveys conducted did not include relevant stakeholders.
Information	▪ There were two students who chose one or all the sites that were not relevant to the problem. Students chose a site that the issues may seem similar, but the context was different. For example, Student A decided to solve a design problem to help people organise electrical cables in a home context. He conducted a field research in school facilities rather than home environment which resulted in inaccurate findings. ▪ When conducting research on a single area, for example understanding the target users, although students may conduct multiple modes of inquiry to understand target users, unsound reasonings with respect to the data may still lead students to a skewed understanding of the design problem and eventually led to conceptualising unsound design considerations. ▪ During research related to products, some students took pictures of products that are available in their homes and conducted the analysis. Some of them did not state the source of information. But nonetheless, the pictures are generally unambiguous that may not affect accurate analysis. ▪ A handful of students sourced and studied information that may have little relevant to their design problem. For example, Student O wanted to tackle the design problem on the difficulties and hygiene issues of taking disposal utensils out of the original packaging during BBQ and parties. However, the information studied was about how kitchen utensils at home are organized and kept clean. The relevance of the information reviewed is questionable as the context is different from the problem.
Assumptions	▪ Some students interpreted information collected from internet based on their assumptions without verifications. For example, Student H collected pictures and made observations of how people collected water in Africa. She did not quote the source of information and was not able to conduct any site observations to make clarifications. Hence, parts of her analysis may be based on assumptions without verifications. ▪ During research related to products, some students analysed the images retrieved from search engines rather than visiting the actual sites where more information may be presented. Hence, the analysis was generally based on their own assumptions that eventually influence their inference. Although there may be some accuracy and logicalness in their analysis, some parts may lack precision or accuracy.
Inferences	▪ At times, some students made unjustified inferences based on visual observations related to the environments with/without target users or stakeholders without further verifications with the users/ stakeholders involved. ▪ There was a single case where student did not clarify the research data and led to his inference of the problem that did not follow the evidence presented. Student L hypothesized that when the straw dispenser lever was pressed, more than one straw was dispensed will be a problem for users. He conducted observation survey and noticed that more than one straw was dispensed only when users pressed the lever several times rather than one time. Furthermore, from his questionnaire survey, 40% of the respondents wanted the dispenser to dispense more than one straw when the lever was pressed. His findings somehow contradicted his hypothesis. But he did not clarify further as his inference about the problem did not follow the evidence presented.

5. Findings: *Critical Thinking in Stating Design Specifications*

After clarifying the problem through research, students created a list of Design Specifications mainly based on the design considerations identified during research. Design Specifications is list of requirements that the design solutions should fulfil and will be used to evaluate the final design prototype. Based on Table 8, the quality of students' reasoning can be observed (refer to Table 11). At this stage, students generally displayed good reasoning skills. The degree of accuracy of each design specification is highly dependent on the quality of research. Thus, any weak reasonings in conceptualising the design specifications would be related to the previous section of this paper.

Table 11 Observations of good reasoning when determining the list of design specifications.

Elements of Reasoning during Design Specifications	**Observations of Good Reasoning in Design Specifications** [1,2] [1]The number in the bracket [ ] represents number of design journals with similar observation [2] When necessary to present the observation clearer, a picture of the journal may also be provided as a figure
Purpose	▪ Only one student noted the objectives of crafting a list of design specifications ***clearly*** and ***logically***. [1] (Refer Figure 12) ▪ All students generally determined the list of design specifications based on ***relevance*** and ***significance*** to solving the problem. The relevance and significance on the selection of the design specifications were ***clearly*** and ***logically*** explained. [15] (Refer to Figure 13)
Point of View	▪ About half of the students articulated the design specifications ***clearly*** based on ***relevant*** and ***fairly gathered*** points of view from target users or related stakeholders during research. [8] (Refer to Figure 12)
Concepts and Ideas	▪ Slightly less than half of the students used ***relevant*** concepts and ideas to articulate the adopted design specifications ***clearly***. In addition, ***depth*** of thinking on the concepts and ideas were also displayed. [6] (Refer to Figure 13)
Implications and Consequences	▪ All students articulated the need for the adopted design specifications ***clearly*** based on the ***significant*** potential implications and consequences surfaced during their research. [15] (Refer to Figure 13)
Inference and Interpretations	▪ All students were able to articulate the design specifications ***clearly*** and ***logically*** with justifications based on their research. (15) (Refer to Figure 13) ▪ Only one student ***justified*** the selection of design specifications based on ***accurate*** data by tabulating the frequency of occurrence of each design considerations that were surfaced at the end of each research area.

Figure 12 Example of a student who provided clear objectives of crafting design specifications.

Design Specifications (FINAL)

Design specification	Reason	Design specification	Reason.
The product should prevent the clogging of water.	After use, the toothbrush bristles would still remain wet, however users would usually immediately store their toothbrush back into the toothbrush holder before allowing it to dry. If the product clogs water, water from the bristles would not be drained out thus may provide a good environment for bacteria and mold to grow.	The product should not occupy more space than an existing typical toothbrush holder	Since there is not really much space on the sink countertop in the bathroom, the product should not occupy too large of a space so that the users have more ease when using the sink and also have ample space to put other items on the countertop.
The product should allow the toothbrush to dry up easily.	Without ventilation, the moisture from the toothbrush would not dry up and the water in the bristles may end up contributing to the clogging of water. The moisture would provide a good environment and thus causing the growth of mold and bacteria.	The product should be simple and convienient for users to use.	As brushing teeth is the first thing people normally do when they wake up, the would feel very groggy and lethargic thus they would not have an alert state of mind to do things. Therefore, the product should not be too complicated to operate and use so that users can use it with ease.
The product should not	Toothbrush holders are often neglected in the	The product should have good stability.	For toothbrush holders that is made to be attatched to the wall : It is to ensure that the toothbrush holder is able to

Figure 13 Example of a student who crafted the list of design specifications with good reasonings.

6. Discussion

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 understanding the problem and determining design specifications.

Firstly, the observations of good reasonings in this study will provide D&T teachers with useful insights of what the students are capable of achieving when applying quality critical thinking in clarifying the problem to determine appropriate design specifications. Conversely, observations on common weak reasoning exercised by students may provide D&T teachers with more awareness and develop strategies that may be used to guide students to have a deeper understanding of the problem. More importantly, weak reasonings in an element of reasoning often have chain effects on other elements of reasoning. As such, the current study proposed that teachers may use the intellectual standards drafted in Table 7 and 8 as general guidelines when coaching students to clarify design problems and determining design specifications. Furthermore, the author believes that the questions to deconstruct reasoning and intellectual standards in Table 7 and 8 can still be further developed, contextualised and articulated to suit the required student outcomes of other design projects.

Secondly, research is an important process to enable students to triangulate the causes and effects of the problem. In addition, research will generate important background knowledge relevant to the design problem that is important for students to understand the problem holistically so that appropriate design specifications may be crafted. As supported by Bailin (1999), background knowledge will form important intellectual resource that can be accessed by students to achieve good reasoning skills in the critical thinking process. But based on the weak reasonings observed in findings, it can be suggested that different research areas should be done in order to achieve the holistic understanding of the problem. For example, some students in this study conducted visual observations on the environment related to

the problem but without including target users or stakeholders into the research to further justify the causes and effects of the problem perceived. Other examples include some students who collected information from the internet rather than conducting site visits when situation allowed.

Design problem generally revolves around environment, users and products and it occurs when there is a need. The need generally occurs when the users are interacting with the environment and/or the product to do something. In a way, conducting research in areas related to environment, users and products will form a good basis of background knowledge that may lead to the holistic understanding of the design problems. At a minimal level, students should conduct research related to environment, users and products, refer to Figure 14. Depending on the nature and context of the design problem, research on *environment-users* interaction, *product-users* interaction, *environment-product* interaction, and/or *environment-users-product* interaction may be required.

Thirdly, when conducting research, the following points should be noted. When conducting research related to the environment, it is important for students to conduct field visits as much as possible to understand the actual environment where the problem occurs. Thus, it is important for students to engage problems that are accessible. As much as possible, students should find opportunities to interview users and related stakeholders to understand the problem with clarity, accuracy and depth; as it may not be possible by just doing questionnaire survey or visual observations. In forming questions for questionnaire survey for users and related stakeholders, it seems that some students faced difficulties in breaking down their main questions into sub-questions to obtain a clearer and more precise understanding of the users and the problem. To enhance students' abilities of drafting good questions and sub-questions for questionnaire survey, it may be useful for students to first conduct a couple of user interviews to have a good background knowledge of the design problem before seeking to obtain more quantitative inputs. With this background knowledge, students will have a clearer purpose on what they hope to know through the questionnaire survey and are clear and precise about the questions they are going to ask.

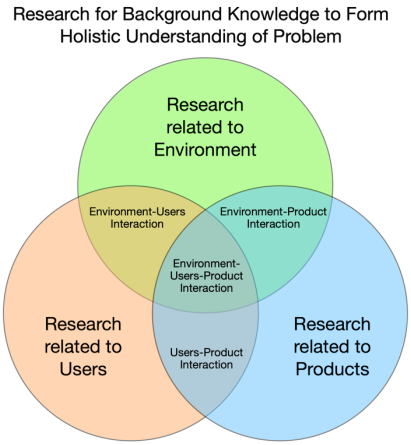

Figure 14 Areas of research to gain a holistic understanding of the problem.

7. Limitations

As limitation to this study, observations in the findings can only be based on what are documented in the design journals. However, what goes into the discussions between student-teacher and student-target users-stakeholder, that may influence students' analysis and conclusion of their research may not be fully clarified. This can be quite apparent where only one observation can be surfaced on how student decided on the design specifications by using statistical method. But how other students decided on their list of design specifications in the first place was not known.

In addition, some of the students' assumptions that were not justified in the documentations could not be verified if they were being informed by teachers or other sources that are not visible in the documentations.

8. Conclusion

The current study aimed to identify and clarify students' critical thinking processes to understand the design problem towards determining appropriate design specifications, using Singapore D&T as a context. Breaking down students' critical 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 intellectual standards contextualised for understand the problem and determining design specifications may provide D&T teachers with useful guidelines for supervising students during the design projects. Secondly, for students to achieve good reasoning standards, background knowledge generated by research in a minimal of three areas such as environment, users and products, with respect to the design problem, is necessary. Finally, to enhance research authenticity and accuracy for the benefit of learning, it is important for students to engage in a problem where field visits and interview with target users and/or stakeholders can be conducted.

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.

9. References

Bailin, S., Case, R., Coombs, J.R., & Daniels, L.B. (1999). Conceptualizing critical thinking. *Journal of curriculum studies*, 31(3), pp. 285-302.

Butler, H. A. (2017). Assessing critical thinking in our students. In R. Wegerif, L. Li & J. C. Kaufman (Eds.), *The Routledge International Handbook of Research on Teaching Thinking* (pp. 305-314). London and New York: Routledge.

Chia, S.C., & Tan, S.C. (2007). Use of SketchBook Pro with Tablet PC (Tab-SketchTM) as a Design Thinking Tool in the Teaching and Learning of Design and Technology. *Education & International Research Conference. The Design and Technology Association*, pp. 11-20.

Davis, W.M. (2006). An 'infusion' approach to critical thinking: Moore on the critical thinking debate. *Higher Education Research & Development*, 25(2), pp. 179-193.

Elder, L. & Paul, R. (2013a). Critical thinking: Intellectual standards essential to reasoning well within every domain of thought. *Journal of Developmental Education*, 36(3), pp. 34-35.

Elder, L. & Paul, R. (2013b). Critical thinking: Intellectual standards essential to reasoning well within every domain of thought, Part 3. *Journal of Developmental Education*, 37(2), pp. 32-33.

Ennis, R. (1991). Critical thinking: a streamlined conception. *Teaching Philosophy*, 14(1) pp.5-24.

Ennis, R. (1993). Critical thinking assessment. *Theory into practice*, 32(3), pp. 179-186.

Ennis, R. (2015). Critical thinking: A streamlined conception. In Davies M. & Barnett R. (eds), *The Palgrave handbook of critical thinking in higher education*. New York: Palgrave.

Ennis, R. (2018). Critical thinking across the curriculum: A vision. *Topoi*, 37(1), pp.165-184

Fischer, S.C, & Spiker, V.A (2000). *A framework for critical thinking research and training*. (Report prepared for the US Army Research Institute)

Fisher, A., & Scriven, M. (1997). *Critical thinking: its definition and assessment*. Point Reyes: Edgepress.

Facione, P. (1990). Critical thinking: a statement of expert consensus for purposes of educational assessment and instruction. *Executive summary: "The Delphi Report"*, pp. 3-4. California Academic Press.

Goddard, J. T. (2010). Collective case study. In A. J. Mills, G. Durepos & E. Wiebe (Eds.), *Encyclopedia of Case Study Research* (pp.163-165). California: Sage Publications, Inc.

Goh, C. B., & Gopinathan, S. (2008). Education in Singapore: Development since 1965. In B. Fredrik Sen & J. P. Tan (Eds.), *An African Exploration of the East Asian Education* (pp. 80–108). Washington, DC: The World Bank.

Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking* (5th ed.). New York and London: Psychology Press.

Jones, E. A., Dougherty, B. C., Fantaske, O. & Hoffman, S. (1995). *Identifying college graduates' essential skills in reading and problem-solving: Perspectives of faculty, employers and policymakers*. University Park: U.S. Department of Education/OERI.

Jones, E. A., Hoffman, S., Moore, L. M., Ratcliff, G., Tibbetts, S., & Click, B. A. (1995). *National assessment of college student learning: Identifying college graduates' essential skills in writing, speech and listening, and critical thinking*. Washington, DC: U.S. Government Printing Office.

Koh, A. (2013). A vision of schooling for the twenty-first century: Thinking Schools and Learning Nation. In Z. Deng, S. Gopinathan, & C. K-E. Lee (Eds.), *Globalisation and the Singapore curriculum: From policy to classroom* (pp. 49–63). Singapore: Springer Science+Business Media.

Kuhn, D. (2015). Thinking together and alone. *Educational Researcher*, 44(1), pp. 46–53.

Lim, S.H, Lim-Ratnam, C., & Atencio M. (2013). Understanding the Process Behind Student Designing: Cases from Singapore. *Design and Technology Education: An International Journal*, 18(1), pp. 20-29.

Loh, W.L.L., Kwek, H.M.G. & Lee, W.L. (2015). Design Thinking in Pre-Tertiary Design Education: An Example Based on Design and Technology Study in Singapore Secondary School. *Proceedings of IASDR 2015 Interplay*, pp. 1322-1349.

Loh, W.L.L., Kwek, H.M.G. & Lee, W.L. (2017). Re-clarifying design problems through questions for secondary school children: An Example Based on Design Problem Identification in Singapore Pre-Tertiary Design Education. *Proceedings of IASDR 2017 Re:Research*. https://doi.org/doi:10.7945/C2K67C

Moore, T. (2004). The critical thinking debate: How general are general thinking skills?. *Higher Education Research & Development*, 23(1), pp. 3-18.

Paul, R., & Elder, L. (2002). *Critical thinking: Tools for taking change of your professional and personal*. New Jersey: Pearson Education.

Paul, R., & Elder, L. (2008). *Intellectual standards: The words that name them and the criteria that define them*. CA: Foundation for Critical Thinking.

Paul, R. & Elder, L. (2013). Critical thinking: Intellectual standards essential to reasoning well within every domain of human thought, Part two. *Journal of Developmental Education*, 37(1), pp. 32-36.

Paul, R., & Elder, L. (2014). Critical thinking: Intellectual standards essential to reasoning well within every domain of human thoughts, Part 4. *Journal of Developmental Education*, 30(3). pp.34-35.

Paul, R. & Elder, L. (2019). *The miniature guide to critical thinking concepts and tools* (8th ed.). Lanham, Boulder, New York and London: Rownman & Littlefield.

Poon, C.L., Lam K.W., Chan M., Chng, M., Kwek, D., & Tan, S. (2017). Preparing Students for the Twenty-First Century: A Snapshot of Singapore's Approach. In: S. Choo, D. Sawch, A. Villanueva, R. Vinz (eds) *Educating for the 21st Century* (pp.225-241). Singapore: Springer.

Scriven, M. & Paul, R. (1987). *Critical thinking as defined by the national council for excellence in critical thinking*. Retreived February 10, 2020, from http://www.criticalthinking.org/pages/defining-critical-thinking/766

Siegel, H. (1988). *Educating reason*. New York: Routledge.

Tan, J. (2013). Aims of schooling for the twenty-first century: The desired outcomes of education. In Z. Deng, S. Gopinathan, & C. K-E. Lee (Eds.), *Globalisation and the Singapore curriculum: From policy to classroom* (pp. 15–47). Singapore: Springer Science+Business Media.

Tan J.P.L, Koh, E., Chan, M., Pamela, C.O., & Hung, D. (2017). *Advancing 21st Century Competencies in Singapore*. Asia Society. Retrieved from https://asiasociety.org/sites/default/files/2017-10/advancing-21st-century-competencies-in-singapore.pdf

Tan, S.C. (1996). *A Case Study on the Teaching of Design and Technology in Secondary School*. National Institute of Education, Nanyang Technological University.

About the Author:

Wei Leong, Leon LOH Leon is interested to explore and study the development of critical thinking and creativity for secondary and high school students through design and technology subject.