Design and Technology Education: An International Journal

25.1

Critical Thinking in Problem Exploration in Design and Technology Design Project

Wei Leong Leon LOH, Kyushu University, Japan

Abstract

The current study aimed to identify and clarify students' critical thinking processes in problem exploration. The current study will adopt the definitions of critical thinking conceptualized by Paul and Elder and, at the same time, attempt to apply the concept of elements of reasoning and intellectual standards to achieve the objectives of this study. By using questions to deconstruct the elements of reasoning when exploring problems, the intellectual standards for reasoning in problem exploration can be articulated. Using a qualitative approach to conduct a collective case study, 15 design journals completed by students in the upper secondary Express course in Singa Secondary School are used as objects of study. The primary source of data is collected via the documentations in the design journals. Using intellectual standards for reasoning in problem exploration to interpret the documentations in the design journals, students' quality of reasoning can be observed and consolidated. Based on the findings, the following conclusion can be presented. Firstly, to achieve depth, accuracy and unbiased understanding of the problem, students need to research on information and data from different sources to triangulate the problem. Secondly, it is necessary for students to acquire necessary background knowledge in order to conceptualize problems accurate and clearly. Thirdly, the development of intellectual standards for reasoning relevant to the design process in D&T may be a potentially useful strategy for teachers to explicitly develop critical thinking skills in D&T.

Key words

critical thinking; reasoning; design education; design and technology; problem exploration; problem conceptualization

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). A knowledge-based economy shifted the efficiency driven education into an ability driven education, where ability for life-long learning by its people is key 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). As 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, critical thinking and inventive thinking are included. Since its formalization in 2010, 21CC framework has been infused into the academic curriculum, co-curricular activities, character and citizenship education, as well as Applied Learning Programmes for secondary schools (Tan et al., 2017). However, at the moment, few studies had been done to understand how critical thinking and creativity is being developed systematically through the implementation of pedagogy and practices in D&T at school level (Chia & Tan, 2007; Lim, Lim-Ratnam & Atencio, 2013; Loh, Kwek & Lee, 2015, 2017; Tan, 1996).

As part of a broader study to understand students' critical thinking process in D&T projects, the main focus in this current study is to identify and clarify students' critical thinking processes in the problem exploration. The findings will contribute to the understanding of how critical thinking may be systematically developed through D&T and also contribute to the international pool of knowledge on the practices in D&T education.

Critical Thinking

To be able to identify critical thinking processes, the literature review will first clarify the definitions of critical thinking and the kind of characteristics critical thinkers are expected to show. After that, how critical thinking may be assessed will be reviewed.

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 skillfully conceptualize, apply, analyze, 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 analyzing 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 analyzed 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.

A search for other alternatives to defining critical thinking was conducted but they are merely similar alternatives to those that have been mentioned earlier. One such alternative is offered by Halpern (2014) where critical thinking is used to describe thinking that is purposeful, reasoned and goal directed and is involved in solving problems, making inferences, calculating likelihood and decision-making. Thus, it is the use of rationale thinking to achieve a desired outcome. Others described critical thinking as a process to determine whether claims and arguments used in the process of reasoning are sound by making informed and evaluative judgements (Butterworth & Thwaites, 2013; Hughes, Lavery & Doran, 2010).

How do we know when a person exercised critical thinking?

The earlier section provided a review on the common overlaps in defining critical thinking. To further clarify critical thinking, what type of skills and abilities will a person 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.

To facilitate reasoning, Hughes, Lavery and Doran (2010) suggested that three types of skills are necessary for critical thinking; they are interpretive skills, verification skills and reasoning skills. Language which is used to express thoughts are essential in the process of thinking which is part of reasoning. As such, interpretive skills are necessary to clarify and interpret the meaning in statements and arguments as clearly as possible to remove ambiguities. In order to determine statements that had been clarified in terms of truth and falsity, verification skills are needed. Finally, reasoning skills are needed to assess the arguments in terms of whether the premises are relevant and supportive to the conclusion.

In order to exercise critical thinking, possessing the skills may not necessarily mean that critical thinking has been achieved. For example, the ability to analyze 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 fulfill 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 measures 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, French, Arabic, Japanese) 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).

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.

Research Question

This study sought to answer the following main question.

- Given an ambiguous theme, how do students exercise critical thinking to conceptualize the problems that are related to the theme?

Research Methodology

Research Approach and Method

The current study employed a qualitative research methodology to gain insights on students' application of critical thinking to unpack an ambiguous theme to conceptualize problems that are related to the theme. The method used for the current study was the collective case study as described by Goddard (2010). Collective case study involves more than one case that may or may not locate in one site. The main purpose of collective case study is to explore cross-case comparisons and draw generalizations from the entire population to understand the phenomenon deeply from a variety of perspectives. As the number of cases studied should share some common links or similarities, a common set of research questions should be developed to guide the study of each individual case.
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.

Table 1. Criteria for choosing a 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.

Singa Secondary School (the school name used is a pseudonym), was identified as a potential site for the study. The study was subsequently conducted with permission from school leaders, head of department and D&T teachers. The selection of Singa Secondary School was based on the following reasons in Table 2.

Table 2. Reasons for choosing the current 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

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.

Design journals done by students in Design Project A are regarded by D&T teachers in the school as a detailed record of students' thinking and decision-making processes in the process of design. As much as possible, students are required to record any form of explorations, research, ideation, experimentation and evaluation processes related to problem identification, ideation, idea development and prototyping. Thus, the used of

design journals as objects of study is based on the assumptions that design journals are a detailed collection of students' insights 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 selecting 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.

A review of the D&T curriculum of Singa Secondary School was first done. Being selected as a pilot school for 21CC in 2010, 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. The strategy for explicit teaching of critical thinking in problem exploration was explained by Loh, Kwek & Lee (2015, 2017). 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. Number of journal archives 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

According to information related to 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 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.

Research Design

The primary set of data was collected via students' documentations in the design journals. The scope of collection covers students' documentation during the problem exploration process. The start of the problem exploration process began with students receiving an ambiguous theme in the form of a "word" such as, Movement, Storage, etc. Then after this, students would start the exploration by defining the theme and associating the theme to related areas or objects to explore and conceptualise problems. Students' documentation will include written and printed text, sketches and photos.

By consulting the D&T teachers, teachers' expectations of students during problem exploration were first collected by the author (refer to Table 5). 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 to articulate the intellectual standards that are most important for reasoning (Paul & Elder, 2008).

Table 5 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 when exploring problems 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 in problem exploration 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 misinterpretation could be corrected.

As the author is the main interpreter of the data, it is important to reflect on any possible biases that may influence the outcome of the interpretations. The author is an experienced D&T teacher who had also led a D&T department in the past. It is important that during the interpretation of data that the author kept an open mind on the process of problem exploration embarked by the students, instead of looking for a prescribed process that the author may be very familiar with.

Research Implementation

During the implementation of the study, the documentations in each design journal were first studied to understand the problem exploration process embarked by the student in totality. 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 during problem exploration were recorded. After all the 15 design journals, or cases, 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 in problem exploration process

Teachers' expectations of student in problem exploration process
Student to check the dictionary(s) to understand the meaning of the words.
Student uses a mind-map to explore the theme. They can indicate possible problems that they can think of, observe, research from the internet on the mind-map.
Student can go around their neighborhood or different places to observe people, places or products and take photos of the possible problems, inconvenience, etc.
Student can check on the internet on websites like the forum, social media or news to find possible problems.
Student can look at the products or picture of products to analyse for possible problems, area for improvements, opportunity to design.
Student can talk to people to find out problems that they faced.
Student is expected to write his/her problems clearly with detail descriptions and the causes and effects of the problem logically.

Table 6. Deconstructing reasoning and articulating Intellectual Standards for good reasoning

Elements of Reasoning during Problem Exploration	Questions to deconstruct reasoning	Intellectual Standards for good reasoning in Problem Exploration
Purpose	☐ Is student clear about the purpose of problem exploration?	☐ Display ***clarity*** and ***consistency*** in purpose by exploring and identifying design problems that are related to the theme.
Questions	☐ Is student able use relevant questions to understand the given theme? ☐ Is student able to use relevant questions to understand the problems? ☐ Is students able to use sub-questions to help them to understand the theme or to understand the problems?	☐ ***Relevant*** questions are used to unpack the theme. ☐ ***Relevant*** questions are used to clarify the problems. ☐ Sub-questions are used break down the theme or problems to achieve ***clarity*** in understanding.
Point of View	☐ From what point of view did student look at the problems?	☐ Problems identified are seek other point of view to achieve ***fairness*** and ***clarity***.
Assumptions	☐ Are student's assumptions justifiable and reasonable based on evidence or past experience? ☐ Is student clear about the assumptions that he/she is making?	☐ Problem identified are based on student's assumptions which are ***justified*** and ***clear***.
Information	☐ To what extend is student's reasoning supported by relevant, accurate and adequate information? ☐ Did student managed to state the evidence used to define a problem clearly? ☐ How clear, accurate, and relevant are the information to support student's argument?	☐ Source of information in understanding the theme is ***reliable*** and ***accurate***. ☐ Problems identified are supported by ***reliable*** and ***accurate*** evidence.
Concepts and Ideas	☐ Are the key ideas and concepts that guide students' reasoning to be clear, accurate, relevant or deep?	☐ The concepts and keys ideas that guide students in identifying the problems are ***clear***, ***accurate***, ***relevant*** or thought ***deeply***.
Implications and Consequences	☐ What implications and consequences follow student's reasoning about the problems? ☐ Are students able to clearly and precisely articulate the possible implications and consequences of the problems?	☐ Inferences on the design problems based on the evidence showed possible implications and consequences ***clearly***.
Inference	☐ Is student able to make inferences that are justified, reasonable, clear and logical?	☐ Inferences on the design problems are ***based on evidence*** that shows the possible cause to the problems. The causes are explained ***logically***, ***reasonable*** and ***clearly***.

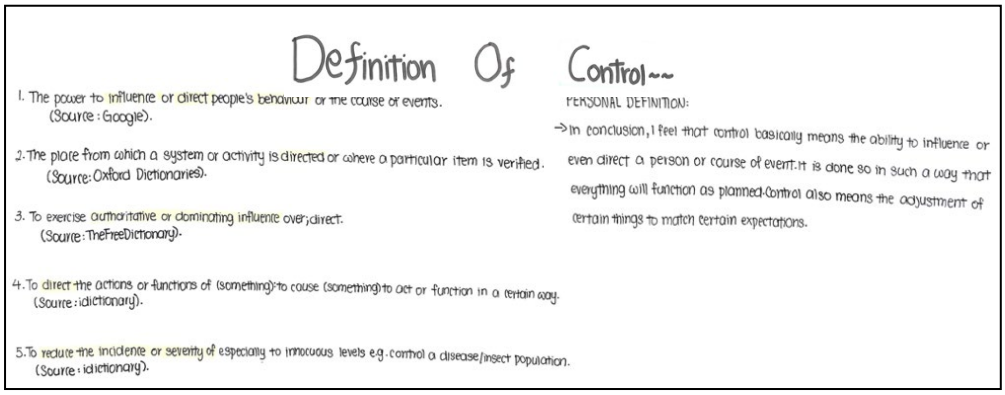
Findings

Observations of Good Reasoning in Problem Exploration

Based on the study of the 15 design journals, the critical thinking processes exercised by the students to conceptualize problems from an ambiguous theme could be broken down into the different elements of reasoning. By applying the intellectual standards for good reasoning in Table 6, the quality of students' critical thinking could be assessed through the documentation in the design journals. In this section, Table 7 consolidates the observations of common and different patterns of good reasoning exercised by students. Each observation is accompanied by an example presented via a figure indicated in the last column of Table 7. As much as possible, examples taken from different design journals are presented.

Table 7. Observations of Good Reasoning in Problem Exploration

Elements of Reasoning during Problem Exploration	Observations of Good Reasoning in Problem Exploration (the number in the bracket represents number of design journals with similar observation)	Refer to the following figures
Purpose	All students started with mind maps to help them to brainstorm areas that are related to the theme and follow by branching out to suggest related problems and/or necessary improvements. The mind maps were articulated clearly to show the relevance and consistency with the theme. (15)	Figure 2
	Some students also used synonyms to guide them in thinking about problems related to the theme further shows consistency when probing the theme. (3)	Figure 4
	During the elaboration of the problem, student used questions such as "link to the theme?" to guide him/her to frame problem related to the theme. This shows student's consistency in keeping focus on the theme. (1)	Figure 5
	Students look for relevant picture of products related to the theme to analyse and look for possible problems/improvement or opportunity for solution that are linked to the theme. (6)	Figure 6
Questions	Some students used sub-questions to help them in elaborating the problems clearly and logically. (3)	Figure 5
	Some students also used 5W1H as questioning technique to guide them in thinking about relevant problems related to the theme. (2)	Figure 3
Assumptions	Assumptions about the problem are generally clear because they are able to explain the cause and effect related to the problems. (15)	Figure 6
Information	Students referred to reliable online dictionary so as to understand the meaning of the theme. (9)	Figure 1
	Students referred to more than one online dictionary to increase accuracy in their understanding of the meaning of the theme. (6)	Figure 1
	Problems identified were supported by photos of the problem situations taken by students or from the internet to justify the authenticity of the problem. (9)	Figure 5
Concepts	In generally, students are able to apply key concepts and ideas such sustainability, hygiene, space constraint, user convenience, safety, health, and etc. to guide them identify problems. (15)	Figure 8
Implications and Consequences	Students made inference based on photos related to the problem to present clearly the possible implication clearly and logically. (9)	Figure 5
	Students explained the cause and effects of the problems logical. (15)	Figure 5
Inferences	To define the theme, students made inferences that follow from definitions and meaning, of the theme, stated in the dictionary to form their own understanding of the given theme that is reasonable and justifiable. (9)	Figure 1
	Students made logical inference based on photos related to the problems to explain or present the possible causes. The causes were explained clearly. Some students supplemented with drawings to illustrate the problem clearly. (9)	Figure 7



Definition Of Control~~

1. The power to influence or direct people's behaviour or the course of events. (Source: Google).

2. The place from which a system or activity is directed or where a particular item is verified. (Source: Oxford Dictionaries).

3. To exercise authoritative or dominating influence over; direct. (Source: TheFreeDictionary).

4. To direct the actions or functions of (something); to cause (something) to act or function in a certain way. (Source: idictionary).

5. To reduce the incidence or severity of especially to innocuous levels e.g. control a disease/insect population. (Source: idictionary).

PERSONAL DEFINITION:

→ In conclusion, I feel that control basically means the ability to influence or even direct a person or course of event. It is done so in such a way that everything will function as planned. Control also means the adjustment of certain things to match certain expectations.

Figure 1. Student B defined the theme based on different sources

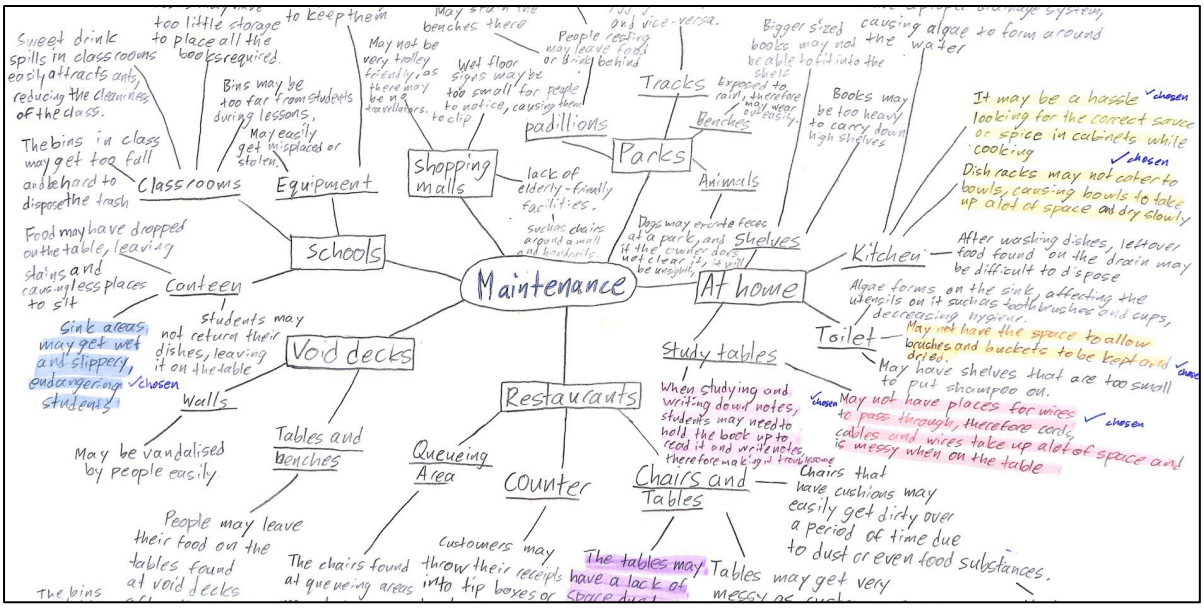


Figure 2. Student I brainstormed areas related to the theme

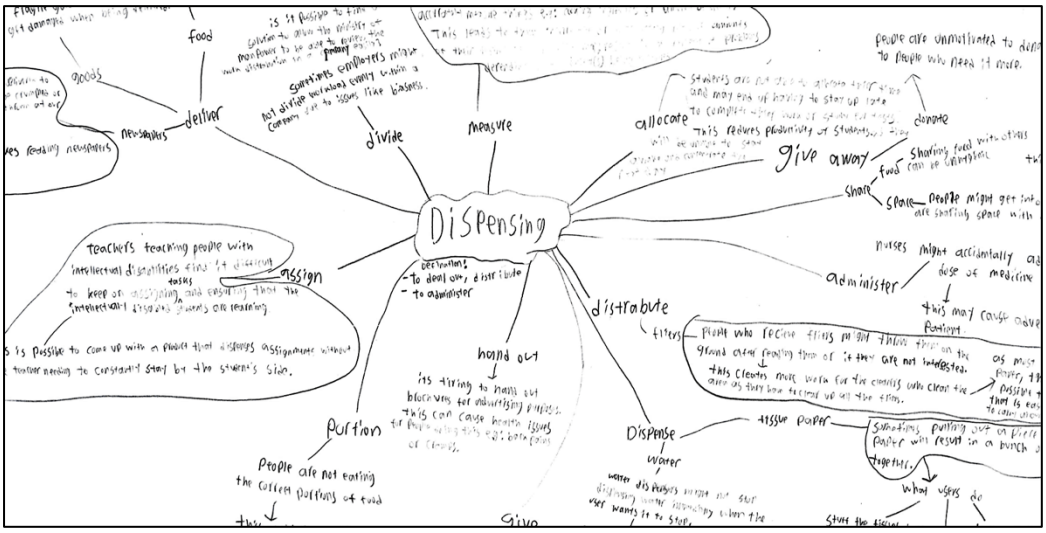


Figure 3. Student J used 5W1H during to define the theme

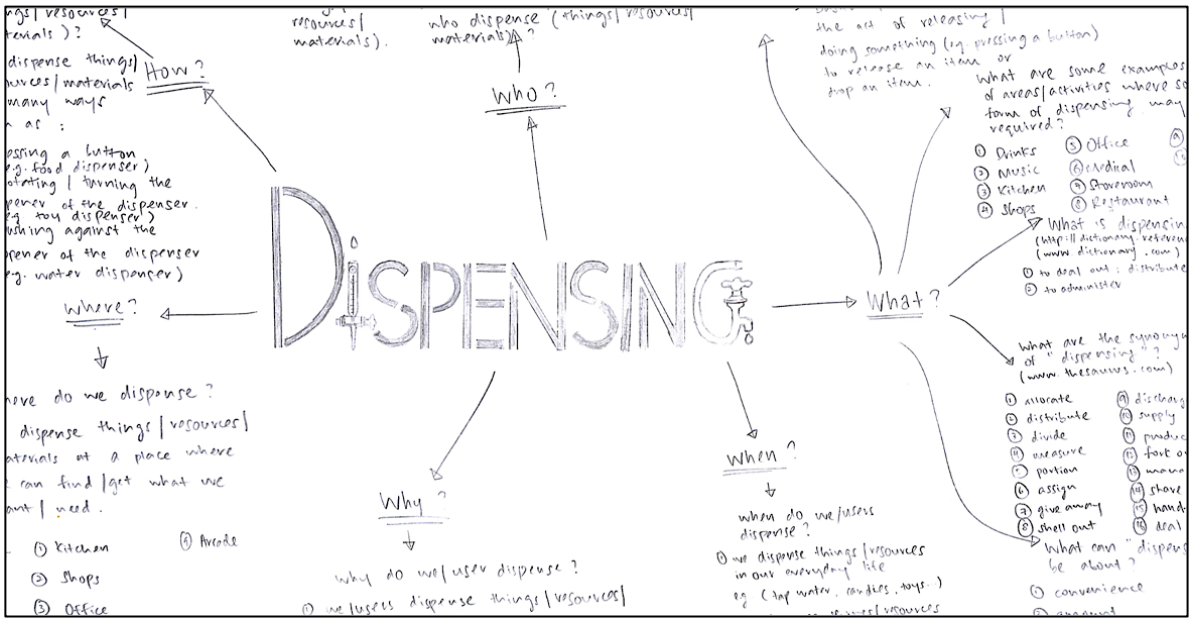


Figure 4. Student K used synonyms to brainstorm areas related to theme

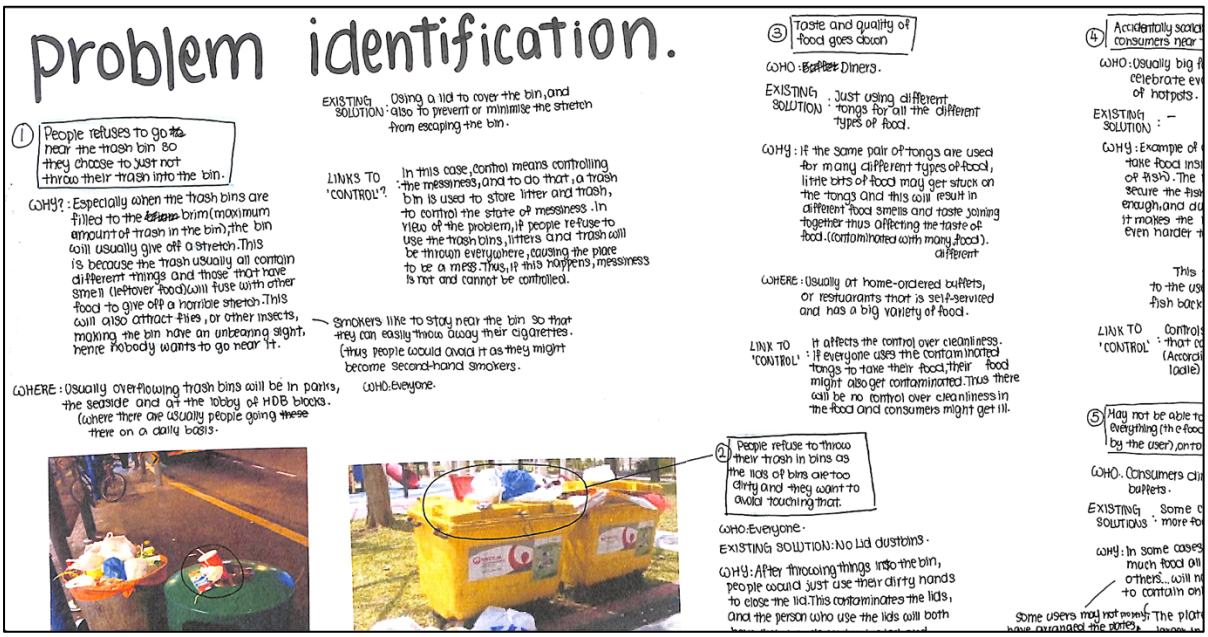


Figure 5. Exploration of possible problems by Student B

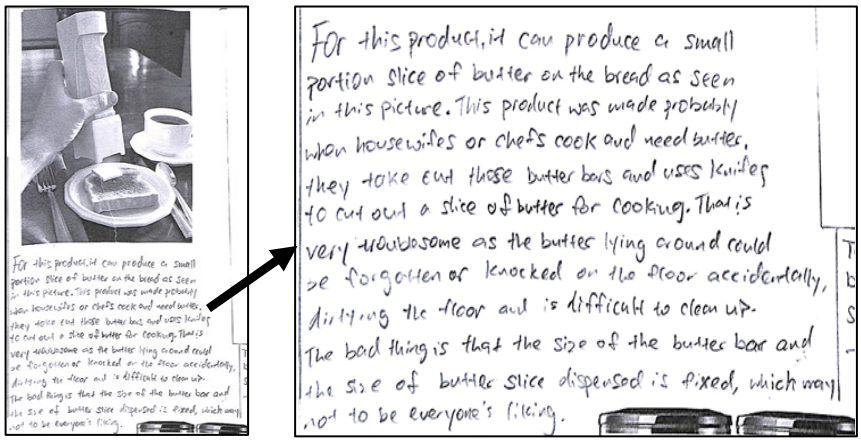


Figure 6. Student O analyzed products to look for potential problems

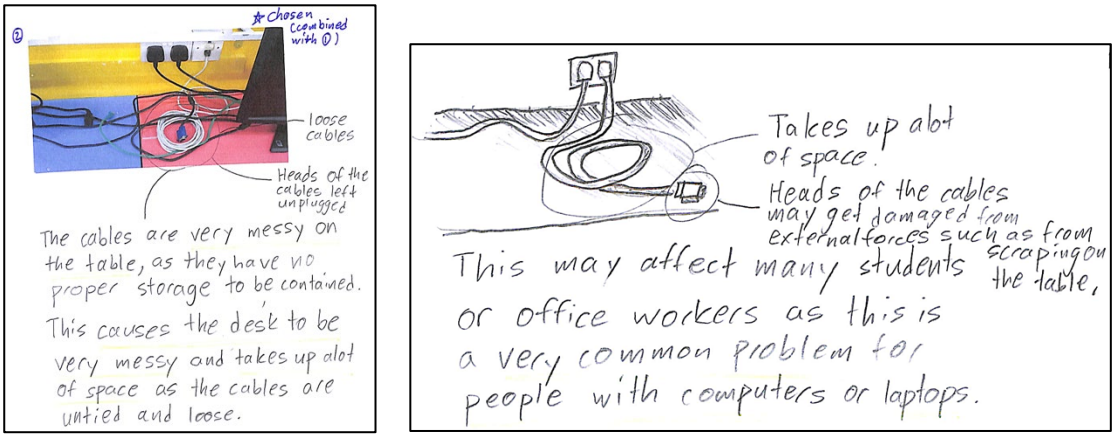
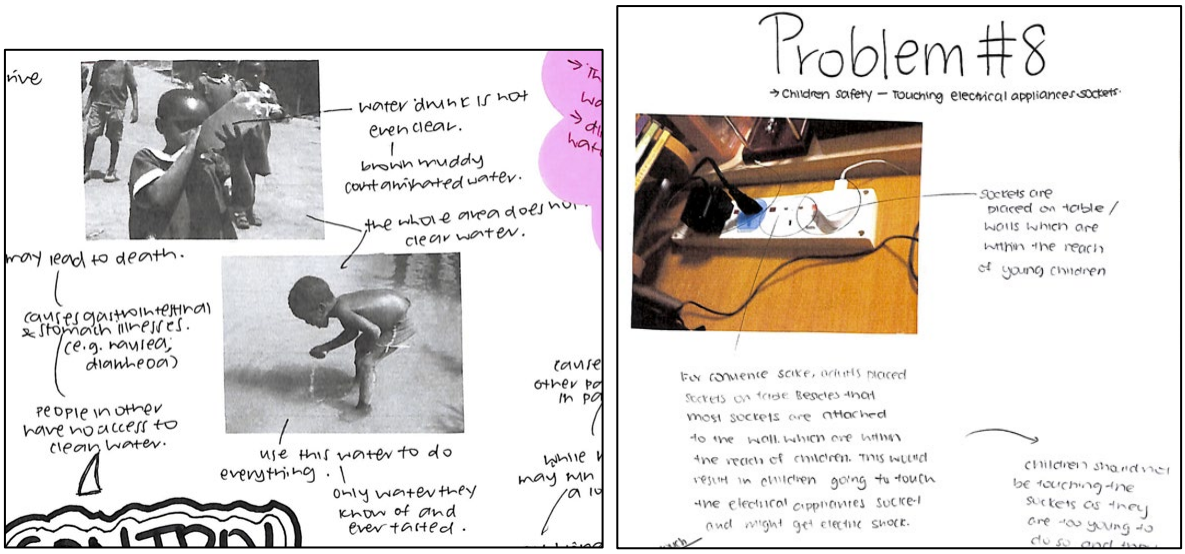
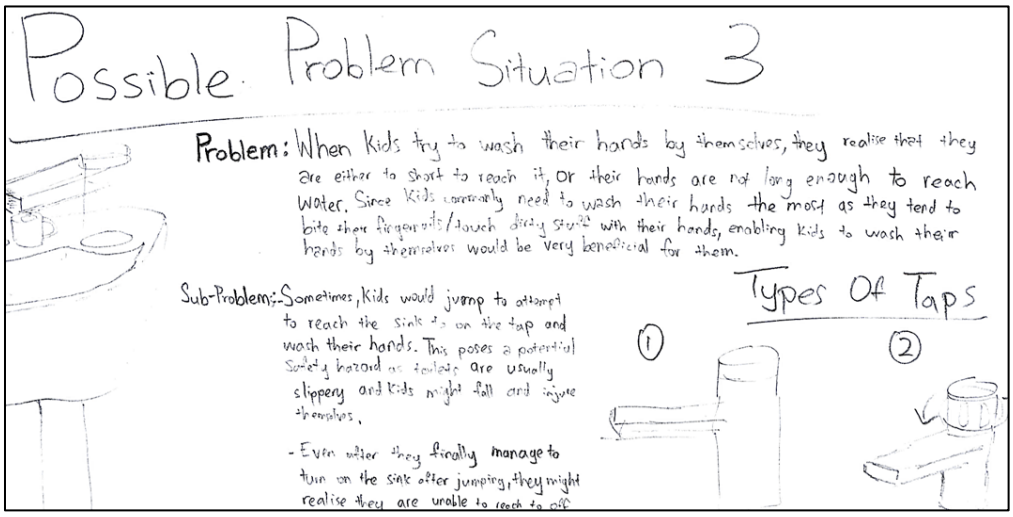


Figure 7. Student I explained a potential problem using photo and sketch



(a) (b)



(c)

Figure 8. Students applying concepts and ideas such as, (a) environment sustainability and health, (b) electrical safety and (c) user convenience

Observations of Weak Reasoning in Problem Exploration

Among the good reasoning observed, there were also instances where examples of weak reasoning surfaced. The observations for weak reasoning are presented in Table 8. Examples of weak reasoning observed did not form the majority of the cases, there were just a couple weak reasonings among some of the good reasonings within a single design journal or a single case. Thus, the number of design journals associated to such weak reasoning are not indicated. Instead, the examples of weak reasoning will be further elaborated in this section 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 off the standard. As such, teachers should be aware of

instances where students may not be exercising good reasoning and provide interventions to redirect students to achieve quality critical thinking.

Table 8. Observations of Weak Reasoning in Problem Exploration

Elements of Reasoning during Problem Exploration	Observations of Weak Reasoning in Problem Exploration
Assumptions	Although problems identified were elaborated with cause and effects that seem logical from students' perspectives. However, some may students lack certain background knowledge to comprehend the problems or lack of consideration of certain factors of the problems. Thus, the evidence presented were not sufficient to justify the conclusions made towards the problem. Some of the assumptions made on some of the problems were not supported by any evidence.
Information	Some problems identified did not any evidence to justify. Most problems were only supported by evidences from the photos taken. No other evidences were used to justify the problem.
Implications and Consequences	A couple of problems were elaborated clearly with cause and effect, but the depth of understand problems stated were superficial or the probability of the problem to occur may be uncommon.
Inferences	Problems inferred from the photos related to the problems did not follow the evidence resulting in drawing irrelevant conclusion.

Although in most cases, students provided evidence to support their inferences or assumptions of the problem, sometimes they might also be making inferences or assumptions without any evidence to support them. In this case, it might be associated to students' weak reasoning or students might have consulted relevant stakeholders to hear their point of view in order to understand the problems before documentation. As there was no documentation that indicated reasoning through a point of view or any other forms, interpretations could not be made accurately. In most cases, students' main source of information came from photos taken either by themselves or from the internet. As such, other forms of evidence, data, information should also be brought to the surface in order to achieve accurate claims or assumptions about the problems. This could be explained by how Student O explored possible issues with the butter dispenser in Figure 6. Student O made some logical assumptions on issues related to the disadvantages of dispensing a fixed quantity of butter slices and possibility of accidentally knocking the dispenser onto the floor. But Student O assumed that this dispenser was designed for dispensing butter for cooking instead of using as a bread spread. Thus, a dispenser for cooking and for bread would probably be designed differently. If Student O had collected other sources of information about the dispenser, perhaps his/her inferences about the possible problems may have been more accurate.

In another case, Student M mentioned that the stacking of bowls and cups on the table in a buffet restaurant will be an issue when kids run into the table and hence cause the bowls

and cups to fall (refer to Figure 9). Student M later reflected that the problem might not be realistic as the probability of that happening was low. In a way, Student M's understanding of the problem was not deep enough although clear implications and consequences were provided.

Lastly, there was a case where a student's inference did not follow the evidence provided. Student E mentioned the issue of "killer litter" in public flats (refer to Figure 10). "Killer littering" in Singapore refers to throwing litter out of the flats that may endanger lives. But the photo evidence provided by Student E was putting objects dangerously at the ledge rather than objects being thrown down the flats.

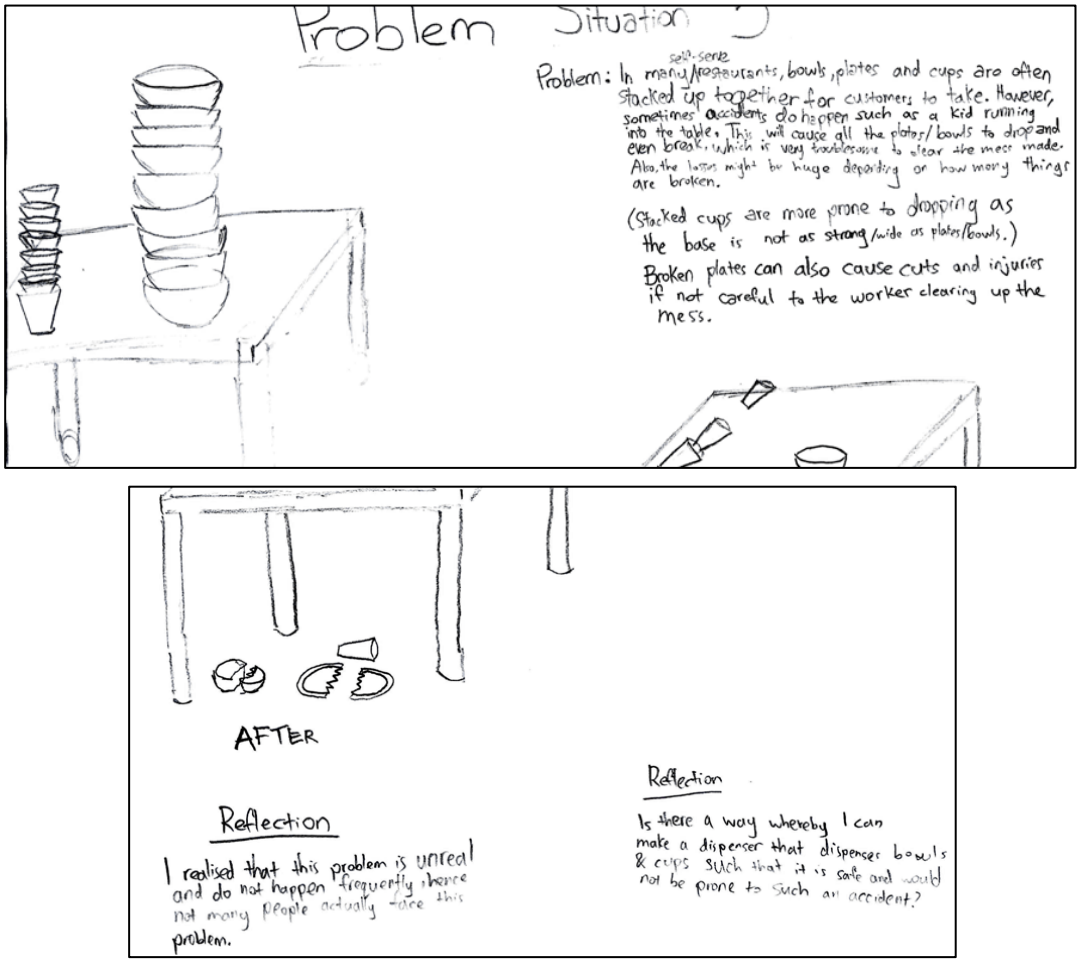


Figure 9. Inference of the possible problem that is superficial

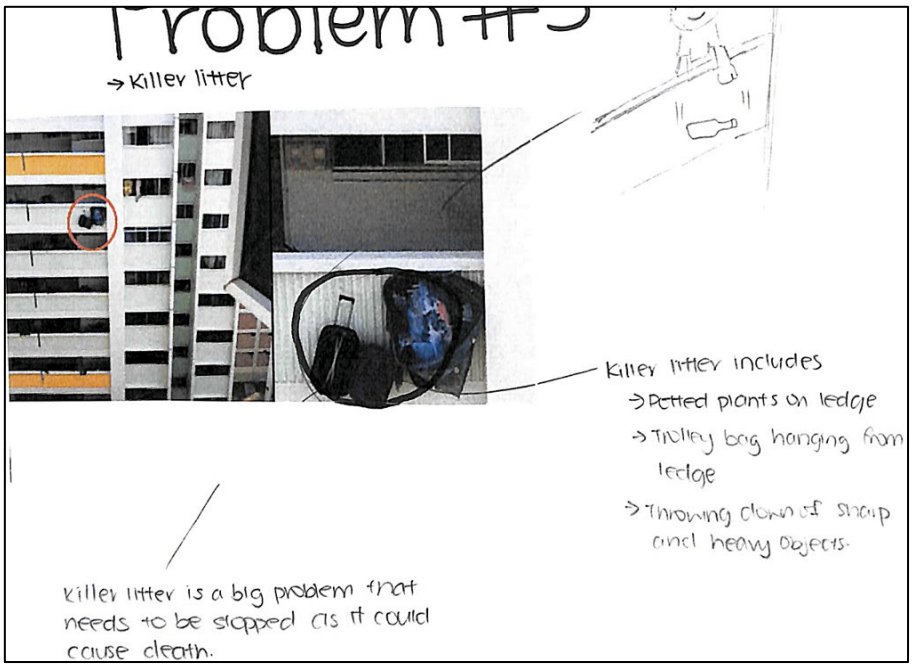


Figure 10. Inference made based on irrelevant evidence

Discussion

Using the critical thinking model by Paul and Elder (2002, 2008, 2019), this study showed a possibility of disserting the critical thinking processes embarked on by students in problem exploration. When given an ambiguous theme to identify and conceptualize possible problems, the findings have shown that students are capable of exercising good reasoning skills that are purposeful and focus on the given theme. Using a variety of approaches such as questioning techniques and information collection and analysis, students are able to clarify and justify their assumptions and inferences of the problems. More importantly students are able indicate the possible implications and consequences of the problems clearly.

But at the same time, the examples of weak reasoning surfaced during the study may have certain implications for D&T learning with respect to problem exploration. Firstly, although students may be able to provide justifications to conceptualize the problems, the accuracy and depth of understanding about the problem may not be sufficient as evidence is mainly from one source. This will impact on their solutions in the latter part of the design process if the understanding of the problem is superficial. Thus, using information and data from different sources to triangulate the problem is important to achieve depth, accuracy and unbiased understanding of the problem.

Secondly, some of the misconceptions about the problems are due to lacking prior knowledge related to the environment, stakeholders or related products. Thus, background knowledge is important for students to achieve an accurate conceptualization of the problem. This is supported by Bailin (1999) who considered that background knowledge is

one of the key intellectual resource to achieve quality critical thinking. In a way, when supervising students in design projects, teachers may direct students to pick up necessary background knowledge during their research on the problems.

Thirdly, to enhance the quality of reasoning skills in students, it is necessary that students are constantly aware of their thinking and constantly assessing the strengths and weaknesses in their thinking. Thus, it will be necessary to work out and articulate the intellectual standards for reasoning, with respect to the elements of reasoning, for all parts of the design process. By increasing students' awareness of the intellectual standards for reasoning for all elements of reasoning and applying them during the design process, the quality of critical thinking of students may be improved. Although this approach may be a potentially useful strategy for teachers to explicitly develop critical thinking through D&T, further research is required to look into developing the intellectual standards for reasoning for all parts of the design process.

Limitations

As limitation to this study, current findings are mainly based on the documentation from the design journals. However, what goes into the discussions between student-teacher and student-stakeholder, that may influence students' understanding of the problems are not able to be clarified. This can be apparent as no observations could be found in the findings related to reasoning through other points of view. As the nature of seeking other points of view suggests, students might have sought other point of view during the conceptualization of the problems but did not document the information in the design journals. It was also clarified with the teachers during interpretation of documentations that students were not told to explicitly record what they have heard from others or the details related to any discussions with the teachers.

Conclusion

The current study aimed to identify and clarify students' critical thinking processes in problem exploration. This study adopted the definition that critical thinking revolves around reasoning. By using questions to deconstruct the elements of reasoning when exploring problems, the intellectual standards for reasoning in problem exploration could be articulated. Using a qualitative approach to conduct a collective case study, 15 design journals done by students in the upper secondary Express course in Singa Secondary School are used as objects of study. The primary source of data is collected via the documentation in the design journals. Using the intellectual standards for reasoning in problem exploration to interpret the documentation in the design journals, students' quality of reasoning could be observed and consolidated. Based on the findings, the following conclusions can be presented. Firstly, to achieve depth, accuracy and unbiased understanding of the problem, students need to research information and data from different sources to triangulate the problem. Secondly, it is necessary for students acquire necessary background knowledge in order to conceptualize problems accurately and clearly. Thirdly, the development of intellectual standards for reasoning relevant to the design process in D&T may be a potentially useful strategy for teachers to explicitly develop critical thinking skills in D&T.

Acknowledgements

The author would like to thank all the school leaders and teachers who have contributed to providing information for this study. In addition, the author would like to thank all the teachers who are involved in the interviews. This work was supported by JSPS KAKENHI Grant Number JP18K13168.

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.

Butterworth, J., & Thwaites, G. (2013). *Thinking skills: Critical thinking and problem solving*. Cambridge: Cambridge University Press.

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.

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)

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.

Hughes, W., Lavery, J., & Doran, K. (2010). *Critical Thinking: An introduction to the basic skills (6th ed.)*. Canada: Broadview 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.

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, B.N., & Parker, R. (2015). *Critical thinking (11th ed. International Edition)*. New York: McGraw-Hill Education.

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.

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.

Watson, G., & Glaser, E.M. (2008). *Watson-Glaser critical thinking appraisal® short form manual*. Upper Saddle River, NJ: Pearson Education.