Enhancing Students' Design Thinking Skills using STEM PaDL Framework: Exemplary Lesson and Prototype Output

Deva Nanthini Sinniah[1#], Dominador D. Mangao[2], Nelson Cyril[3], Sivaranjini Sinniah[4], Sharfuddin Abdul Shukor[5] & Ng Khar Thoe[6]

[1#, 3, 4, 5 & 6] Training and Research Division, SEAMEO RECSAM, Penang, Malaysia
[2] College of Flexible Learning and ePNU, Philippines Normal University, Manila, Philippines

[#]corresponding author <nanthini@recsam.edu.my>

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Abstract

Purpose and Research Question - STEM education has gained increasing attention over the past few decades to enhance students' understanding of science and mathematical concepts through investigative research with enhanced thinking and problem-solving skills. This study was conducted to explore the STEM Planning and Design Learning (PaDL) Framework developed by the authors for students' learning in primary science topics in a Penang school.

Methodology – The qualitative case study approach was the research design implemented with data collected from students and teachers interviews and observation of teaching-learning activities. The STEM PaDL framework consists of two models, one for Teacher Lesson Planning and one for Student Design Learning. In this article, only the Teachers' Planning model will be elaborated with exemplary lessons and prototypes as learning output illustrated for the teachers. The Teacher Planning model comprises four (4) stages, namely: (1) creating enthusiasm with the class; (2) planning for teaching; (3) designing learning process for students and (4) reflection. Training of Trainers (TOT) workshop was conducted among the Science and Mathematics teachers in a primary school in Penang. Teachers explored and understood the essence of both models by attending TOT workshops. Then a lesson exemplar was developed to illustrate the STEM PaDL Model. The training session was followed by an exploration of students' learning activities with enhanced design thinking skills documented during lesson observation.

Findings – Analysis of findings showed that the students able to built prototypes based on their sketches in response to the problem scenario posted. The analysis of students' exploration also revealed that they were able to execute the Design Learning Process by looking at the behavioural sequencing of the prototype production in the online classroom.

Significance and Contribution in Line with Philosophy of LSM Journal - This article illustrates STEM PaDL Model lesson exemplar piloted in a primary school. In conclusion, the STEM PaDL framework consisting of design learning process is a unique teaching and learning framework as it is comprised of two harmonious and complementary models that facilitated students' learning with enhanced design thinking skills.

Keywords: Design thinking skills; Lesson exemplar; STEM PaDL; Prototype

Introduction

Science, Technology, Engineering and Mathematics (STEM) education is delivered to attain educational goals that prepare students for future life and employment. Integration and implementation of S-T-E-M ideas and procedures are a must for everybody, and young people should have the opportunity to engage in genuine interdisciplinary scenarios (Bybee, 2010). To train future STEM-literate citizens, teachers are essential, and their preparation for STEM instruction is crucial (Rinke et al, 2016). When it comes to STEM education, the theory is not the only component. Theories entail experiential learning, in which students actively engage in classroom activities and construct knowledge. For students to gain from science learning, hands-on experience is a must, unlike other disciplines that may be learned just by reading a textbook. When discussing these topics, caution must be used. Before beginning with the how and what, students must first comprehend the why. This comprehension enhances pupils' appreciation for the material being taught. Equally crucial for the STEM educator is the instruction of application.

According to Nelson and Landel (2007), past research has demonstrated that, in the U.S., there is a need for a reform of the science curricula in schools today, and science learning must become a priority to see an increase in student performance. For these changes to be effective, there must be a focus on science education at the elementary level. Students who begin middle and high school with insufficient knowledge of science are unlikely to reach grade-level performances without intervention. Perhaps the most crucial part of the establishment of an effective science curriculum lies in the effectiveness of the teacher. While many teachers have the necessary supplies to integrate science into their classrooms, some of them lack the professional development and qualifications to teach science effectively. Nelson and Landel, (2007) reported that students, guided by effective teachers for at least 3 years in a row, are considered high achieving regardless of their: (a) family income, (b) race, (c) ethnicity, or (d) parents' income.

Background and Overview

The necessity for a design thinking approach has never been more pressing. According to the National Research Council (2000), it takes years or decades to develop the competencies that societies demand, meaning we need to start generating scientists and engineers in elementary and middle school. Blending engineering-based problem solving into students' mathematics, science, and technology learning is gaining traction in many countries, with STEM in K-12 becoming a more important component of contemporary 21st-century education (Berland, 2013)

As a result, children may learn how to be mentors, create user-centred learning experiences, and share their experiences as growing STEM professionals with middle school students using design thinking as a framework (Carroll, 2015). With its emphasis on empowerment and agency, design thinking is a strong tool for meeting the requirements of 21st-century learners by offering a human-centred framework for issue characterisation and solution. Students must be able to empathise with others, see issues, and come up with innovative solutions. In other words, students must be equipped with good design thinking skills.

Review of Related Literature and Problem Statement

Teaching and learning frameworks are evidence-based models for course design that assist instructors in aligning learning objectives with classroom activities, creating engaging and accessible learning environments, and incorporating evaluation into the learning process. The National Research Council (2000) highlighted psychological, cognitive, social, and educational research findings that are used to develop effective teaching and learning frameworks. Students learn best when their prior knowledge and "preconceptions" are recognised and engaged in the classroom when they have to practice and time to build "conceptual frameworks" upon fundamental skills through active, experiential, and contextually diversified learning, and finally when students have practise and opportunity to take responsibility for learning through comprehension reflection.

Previously, there were many frameworks just as Teaching with Model, TPACK, Science and Engineering Practices, Polya's 4 Step, NGSS and many more. Each framework with its features was separated by learning models. Thus, this study employs a framework complementing the pedagogy aspect and the learning perspectives. The framework is known as STEM Planning and Design Learning (PaDL).

Problem Statement and Rationale of Study

There have been various attempts to define STEM education by scholars and legislators aiming to change public education, making a clear definition of integrated STEM education difficult (Wong et al., 2016). However, the link across STEM disciplines, as well as the emphasis on real-world settings in bringing about such integration, emerged as a unifying aim for STEM integration throughout the many definitions we studied in the literature. Thus, the paper will be focusing on the impact of students' design thinking skills in school try-out activities (appendix A) by using the STEM PaDL framework. Moreover, the paper will emphasize the level of effectiveness of the Teacher Planning model in PaDL framework in preparing the lesson plan.

Research Objectives

1. To determine the impact of design thinking skill in Teacher Planning model from PaDL framework, and
2. To identify the effectiveness of Teacher Planning model from PaDL framework in preparing lesson plan

Methodology

The STEM PaDL Framework was developed during the *Teaching to Transform* week-long regional workshop organised and conducted by SEAMEO RECSAM with collaborators in November 2018. Participants were curriculum specialists from the Ministries of Education of SEAMEO STEM experts, advocates and academics from higher education institutions, school teachers teaching science, mathematics, technology, and specialists from RECSAM and SEAMEO sister-centres. Each participant was involved step-by-step and benefited from the process of creating the PaDL Framework. Participants in the workshop were organised into ten small groups. Each group was given a variety of Western educational models to analyse the

essential elements of the models. Five groups analysed the teacher planning-models while the remaining five groups worked on student design learning models.

Each group focused their evaluation on the details of each model, looking at each component in-depth and discussing its merits. After thoroughly examining and critiquing each model, the groups analysed the bigger picture by comparing the models' merits through a consensogram feedback method. From these within and between model criticisms, the two combined groups developed their draft Teacher Planning Model or Student Design Learning Model. The participants took back their draft models to reflect and refine in their home countries and schools with their colleagues. Constant and open lines of communication were established between the participants, project collaborators, STEM experts and project coordinator from RECSAM to further refine the two draft models. Gradually, two new models emerged, one for the teachers' planning and the other one for the students' design learning. Therefore, Training of Trainers was necessary to try and evaluate the STEM Planning and Design Learning (PaDL) Framework.

Training of Trainers (TOT)

Two Training of Trainers (TOT) workshops were held, the first workshop including eight RECSAM Science Specialists, took place on April 6 and 8, 2021, while the second session, featured two mathematics and design subject teachers from one of the schools in Penang, Malaysia and a RECSAM Science Specialist, took place on April 20-21, 2021.

The Teacher Planning Model was first investigated by the participants. The core of the Teacher Planning Model was determined, followed by a discussion of curriculum alignment between the PaDL Framework, Common Core Regional Learning Standards in Science and Mathematics, and the vision of the Ministry of Education, Malaysia, which emphasises cross-curricular components. Following that, the participants looked at the PaDL Framework's second component, the Student Design Learning Model. The participants revisited the model's main themes and their connection to the Teacher's Planning Model.

School teachers who took part in the STEM PaDL Framework TOT at SEAMEO RECSAM helped with the trialing process. These teachers then led an in-house workshop for their colleagues in the school. A total of four teachers who teach science, mathematics and design subjects are involved in the training. The PaDL Framework try-out with students was the subject of this research. At the end of the try-out, we collected data on the teacher's perception towards the effect of the PaDL framework in their lesson. There is a teacher who stated that "*It's good for both teacher and students in creating a new environment of lesson which integrates more than a subject", and one more teacher said that "very good framework, it works as guidance to prepare the lesson".* Finally, all of the educators who participated in the school trial provided very favorable feedback on the framework.

School Trial Run Activities

A group of science and mathematics teachers were identified into the Lesson Demonstration Team, and 37 students from Grade 4 class (Key Stage 2) became the trial class. The Demonstration Team developed a lesson exemplar entitled "Used Face Masks: A Waste Management Crises" (Appendix A). This topic was selected to illustrate the real-life social and

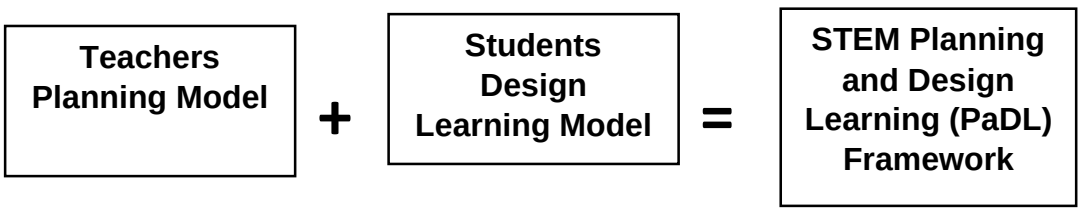
health issue of abandoned face masks during the COVID-19 outbreak, which students in Penang Island and Malaysia had to deal with. A Google Meet platform was used to conduct the online trial run activities session with the students by the science, mathematics and design teachers for two days. In each session, the lesson sequence used was developed by the Demonstration Team (Appendix B).

Findings and Discussions

STEM Planning and Design Learning (PaDL) Framework

This development process of the STEM Planning and Design Learning (PaDL) Framework is described in Figure 1 below. This PaDL framework illustrates the complementary roles of teacher planning and designing learning processes for students which are presented in two models. The PaDL Framework shows the relationship at each stage of the STEM planning for teachers and student design learning process for students with designing of instruction and student learning as well as how each stage influences subsequent decisions and activities. The PaDL Framework is designed to be used by both the teacher and the student even though without Student Design Learning. This is what sets the PaDL Framework apart and unique from other design thinking paradigms or frameworks which simply assist teachers in planning or students in designing, but the PaDL framework accomplishes both. One of the teacher's feedback was that "the students enjoy the design learning process, and look forward to having more activities based on that. Another teacher mentions that "Teachers Design Planning Model able to guide us to design a lesson plan for project-based learning".

Figure 1 The development process of the STEM Planning and Design Learning (PaDL)



Teachers Design Planning Model

In the Design Planning model, teachers work through the 4 stages:

Stage 1 - Creating enthusiasm subject to the ethical use of knowledge and social awareness:

The teachers need to start with great enthusiasm as they are going on a learning journey. Teachers must examine how to tell students about the moral considerations they will make as they gather and use evidence. While working in small groups and sharing learning ideas, teachers must stress to their students in considering and responding to ethical and social awareness.

Stage 2 - Planning for teaching and Stage 3 - Design learning process for students:

In this step, teachers incorporate posing a real-world problem or issue and prepare a scenario challenge. Next, the teacher must connect the scenario challenge to the curriculum, and plan the sequence of learning activities, resources and assessments. Teachers must incorporate the STEM Design Learning Model into their teaching and learning planning. The single arrow represents the cyclic process between teachers' planning process and students' design learning process. By trying the steps in the model, teachers will experience the students' learning and have a stronger empathy and comprehension of the learning experiences.

Stage 4 – Reflection

Teachers' attitudes and awareness will shift as they reflect on their preparation and teaching. These attitudes and awareness enhance their professional development as instructors, as well as the learning assistance they give to students. Teachers begin to take control and unlock the option of transforming their ordinary classroom lives into better ones.

The reversible arrows in Appendix C denote the relationship between the components requiring several cycles. In STEM planning, teachers will need to go back to the previous step or even back to the first step, to go forward based on teachers' way of thinking and working with their students.

Teachers' Planning Model from the PaDL framework is very unique by itself as teachers are able to reverse back to the starting point of the lesson by analyzing the reflection received. According to one of the student's interviews, she mentioned that "*wish to have more STEM activities by using this methodof teaching method by the teachers*". In stage three, the design learning process for students was mentioned. In line with this students who participated in the school try-out able to sketch design for a solution (Appendix D). This is the ability to conceptualise a solution, visualize what the solution might look like. All the students who participated in the school try-out activities said that *they like all the activities conducted and they like to solve more problems in this new learning activity*. While doing the activities, one of the most valuable things that students carry is the social awareness which was highlighted in the Teachers Planning Model.

Conclusion

Teachers Planning Model able to assist the teachers in developing a distinctive and successful lesson plan which embedded the design thinking skills. Besides that, the Teachers Planning Model is iterative and requires multiple cycles. In lesson planning, teachers need to go back to the previous step or even back to the first step, in order to go forward. This process is only a suggestion and in the end teachers have to adapt to their style, work and conditions of the classroom.

Limitations

We were only able to have the school tryout at one of the schools in Penang because of the epidemic. We have high hopes of expanding the school tryout by adopting the STEM PaDL framework to a large number of additional schools across the SEAMEO countries.

Implications and Recommendation

Based on the results of this study, recommendations are then made that instructors in SEAMEO Member Countries utilise the STEM PaDL framework while creating unique lessons for their pupils. In addition, it would be ideal if instructors could document their implementation experiences and emphasise methods that were beneficial or yielded positive outcomes in terms of student learning.

In conclusion, we hope that the unique STEM PaDL framework will become beneficial to curriculum planners, STEM advocates, and teacher educators. We expect STEM PaDL will inspire teachers and students to be inquisitive, critical, creative, and innovative when addressing real-world problems and issues through problem-solving and inquiry in a STEM learning environment.

Significance and Contribution in line with the philosophy of the LSM journal

This article contributes to the bulk of knowledge in science pedagogy. This study will suit any educators looking into a framework that may assist them in creating unique lesson plans that incorporate multiple essential skills for a more positive, motivated, and exciting student learning.

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Appendices

(STEM PaDL Lesson Exemplar and Framework)

Appendix A: COVID-19 Face Mask Problem Scenario

Used Face Masks: A Waste Management Crisis

With the current pandemic swirling around us, most Malaysians now wear a face mask when they go out. In fact, it has become a must-have item. What is worrisome is that millions of these used face masks are being discarded indiscriminately. I have seen face masks strewn on pavements, in drains and on escalators. Even our beaches are not spared.

Besides being an eyesore, used face masks pose a public health risk. They may carry the Covid-19 virus, and so they should not be randomly discarded as normal waste. Think about it, should a contaminated face mask be discarded inside a confined space such as an elevator? No! The mask is a threat to people using the elevator.

Unfortunately, not many consider the face mask a hazardous waste and hence pay little attention after its use. We have convinced most Malaysian to wear face masks when they are in public places. Let's go one step further by instilling in them the importance of disposing of used face masks in a responsible manner.

Adapted from: https://www.nst.com.my/opinion/letters/2020/05/594780/public-health-risk-discarded-face-masks

City Council

Waste Management Crisis

We need you help

Contaminated face masks are littering our streets. We need you to **design and then create,** a model of a tool to collect contaminated masks for disposal.

Everyone needs to be more responsible with the disposal on their masks.

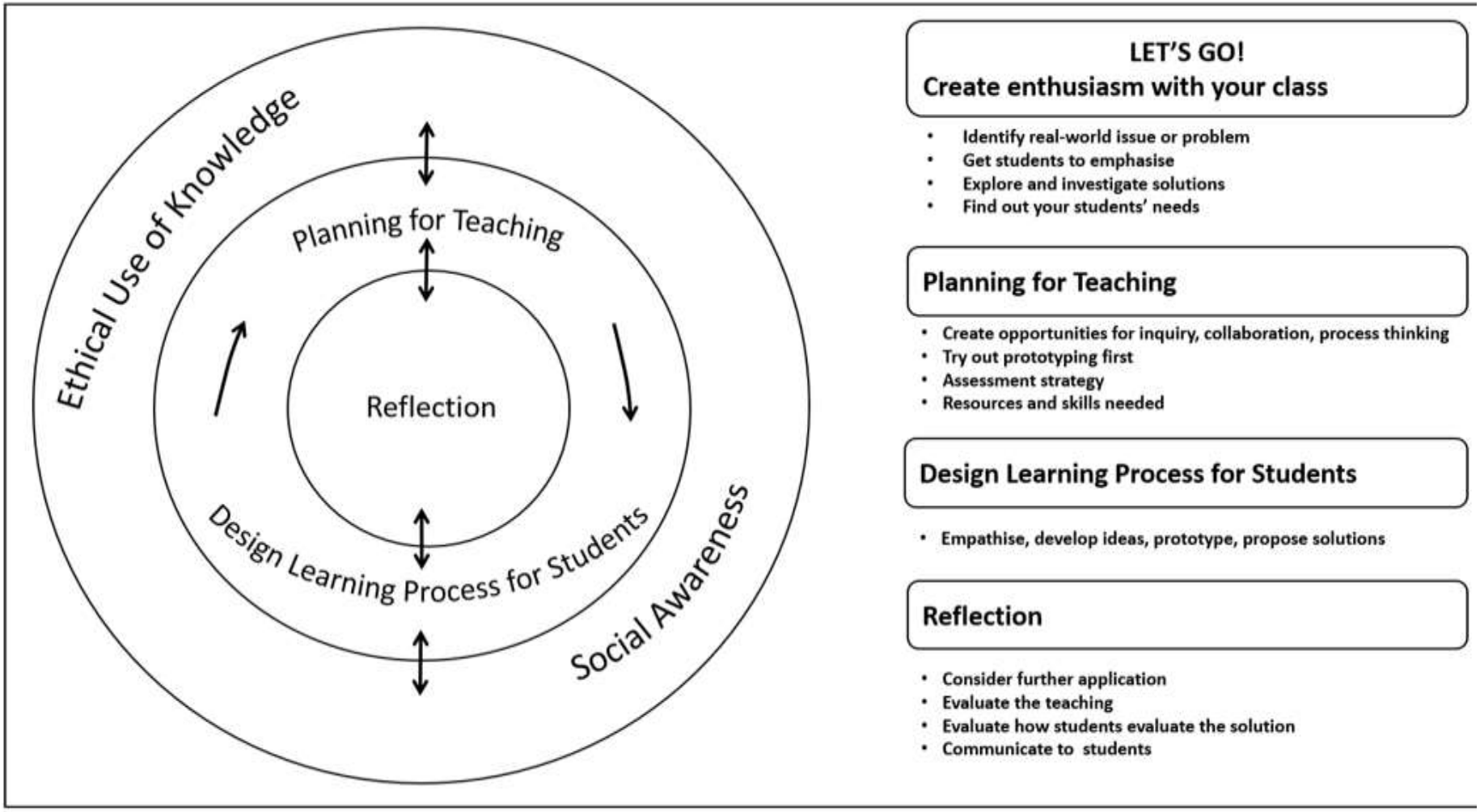
Appendix B: Lesson Sequence

Step	Teaching and Learning Activities	Learning Strategies, Teaching Considerations	Resources
1	The teacher will show a video clip on the COVID-19 pandemic. Brief discussion - the teacher asks: How do you feel about the problem? What should we do to protect ourselves and other people against the CoVID-19 pandemic? (The main idea here is to provide the context of the lesson and let students "empathise" with the severe cases of patients afflicted with COVID-19 and draw out the use of face masks).	Video analysis on the COVID-19 pandemic https://www.unicef.org/malaysia/stories/fight-coronavirus Example questions: ● What issue is the world facing now? ● What are we doing to prevent these diseases? ● Why should we wear masks? ● How to wear the mask correctly?	https://www.wmc-card.com/uk/the-importance-of-wearing-masks/ https://theconversation.com/single-use-masks-could-be-a-coronavirus-hazard-if-we-dont-dispose-of-them-properly-143007 https://www.nst.com.my/opinion/letters/2020/05/594780/public-health-risk-discarded-face-masks
2	The teacher will give the Problem Scenario (news clippings) to the students. To make the problem more dramatic and appealing to the students, the teacher will show the video. The teacher asks: What is the problem about? How do you feel? What	Analysis of the problem scenario via the newspaper clippings Video analysis on the problem caused by improper disposal of masks. https://youtu.be/60vDnOeAcoA	https://www.independent.co.uk/life-style/face-masks-coverings-dispose-throw-away-safe-environment-litter-single-use-a9612946.html https://www.greenpeace.org/international/story/44629/where-did-5500-tonnes-of-

	information do you know? What other information do you want to know? How should you help in solving the problem of contaminated face masks? In pairs, students research the importance of masks in preventing the spread of bacteria or viruses, the types of masks, materials used in making masks, cost of masks.	Search the internet for information about the face mask. Assessment (formative): Rate students' sharing of answers to the given questions. Examples of other protective materials (gloves and hand sanitisers) Assessment (formative): Evaluate students' understanding of the contaminated mask from the answer given.	discarded-face-masks-end-up/ https://youtu.be/T4KjcDgqpSc https://timesofindia.indiatimes.com/videos/motion-graphics/how-to-wear-use-take-off-and-dispose-a-face-mask/videoshow/74982175.cms
3	Before the start of the sketch design and building of the tool to collect contaminated masks, students must understand the importance and the danger of improper mask disposal. Planning and generating ideas - design the tool to collect contaminated masks. Creating a design sketch/drawing of the mask collector tool.	Compare readily available materials at home Establish mask measurements to determine minimum size using geometry. Ask students: how do we make the mask collector more affordable? Propose the use of a spreadsheet to record the steps undertaken to develop the tool. Example questions.	

	Understanding which material is suitable to be used to make the tool. Considerations: strength, lightweight, easy to carry around or even better collapsible and can be transported to other places easily.	• How long can we wear the same mask? • What do we do with the mask once we have used it? • Is the mask safe to be tossed in the rubbish?	
4	Developing the mask collector tool. Students will work individually to select the best sketch to develop the tool. Create a prototype tool using suitable material according to the design sketch. Students present and explain their prototypes to other students.	Assessment (summative): assess the tool to collect the contaminated mask Presentation skill: the students will be evaluated by their preparedness and their knowledge of the prototype tool. The tool does not need to work, but students need to describe what the idea is to imagine it working	
5	The teacher leads students to reflect on the whole learning experience of students.		

Appendix C: Teachers' Planning Model



Appendix D: Example of sketches drawn for the face-mask activity which highlight the design thinking skill

(Adapted from SEAMEO STEM Planning and Design Learning (PaDL): Towards 21st Century Skills and Design Thinking, 2022)