Developing Critical Thinking in a STEAM classroom

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Abstract. In an environment disrupted by technology, critical thinking is a crucial 21st Century Skill that allows learners to stay intact when any number of organizations (corporate, political, educational and cultural) try to influence readers to think and act in ways that serve their purposes (Brookfield, 2012). It has also been emphasized in the ATC21S project as one of the desired outcomes under 'Ways of thinking'. In this paper, we aim to share about how Design Based Research and DDMT teaching model can shape a chemistry lesson on water for Grade 5 learners. The lessons will be shaped towards guiding the learners in understanding acidity/alkalinity as required by the national curriculum and also seek to provide an insight into how young learners showcase development of critical thinking in the learning process.

Keywords: Critical Thinking, Steam Education, Tsing Hua Steam School, DDMT Teaching Model

1 Introduction

The emergence of new technology has presented educators with a need to re-evaluate their teaching and assessment practices (Saettler, 1990). There has also been a paradigm change in the expectations of the younger learners. While the learning of content is still considered important to many educators and learners, but there is an increasing call to re-evaluate the way content is being delivered to cater to the diverse learning needs of the new learners. More importantly, established institutions such as OCED and World Economic Forum have emphasized the importance of new skills critical for the young learners to be equipped before they can be work ready.

With this growing emphasis, the emergence of STEAM Education has superseded almost all other forms of education innovations in the last couple of years. It is not uncommon to find technology vendors promoting STEAM Education at major Educational Technology conferences such as ISTE and BETT, even big technology conglomerates such as Microsoft, Google and Apple are jumping onto the bandwagon with new initiatives and applications. Yet, with all these external supports, a pressing question for educators is what is "STEAM Education" and how does it change the way for integration into our teaching.

2 Related Work

2.1 Tsing Hua Steam School

Tsing Hua Steam school is an alliance of K-12 schools in Taiwan with the common vision of "Quality STEAM Education for All Students". It has been advocated and promoted by Prof Tzu-Hua Wang and Prof Chi-Hui Lin since 2018. Educators on board the program aspire to write a STEAM curriculum based on solving daily issues revolving around the learners. Teachers teaching different disciplines are encouraged to partake in this program; but our goal is not about an inter-disciplinary project design, but rather a collaborative process of developing a learning process measuring not just academic content but also competencies (Wang et al., 2019).

There are numerous important elements in this program. The first element is constructivism. We believed that cognition is not located only located within the individual thinker but is a process that is distributed across the knower, environment in which knowing occurs and the activity in which the learner participates (Barab & Squire, 2004). Hence, in the process of designing curriculum, teachers role-played both the roles of a learner and a facilitator as they imagine how their activities would panned out in an actual classroom.

The second important element is empathy. For learners to better appreciate the problem-solving processes, it is important to begin with issues which learners can relate to in their lives. This process will be elaborated in greater details in the following section.

Lastly, there is a need to connect the outcomes of the curriculum to the expectations of the national curriculum. After writing the curriculum and activities intended, teachers must now seek to find an alignment to what the national curriculum is advocating. This way, the STEAM curriculum would not be viewed as another meaningless project. At this point, educators would also be practicing the notion of teachers as the agents of change as suggested by OECD in their white paper for Education 2030.

2.2 DDMT teaching model

The DDMT teaching model was first proposed by Prof Tzu-Hua Wang and Mr Turner Lam in early 2019. It consists of four phases; 'Discover', 'Define', 'Model & Modelling' and 'Transfer' with all four phases revolving around scientific inquiry, design thinking and maker practice. The DDMT teaching model provides a scaffold for teachers to develop their competency-based and interdisciplinary STEM/STEAM teaching activities (Wang et al., 2019) and has been fine-tuned by the academic team of "Tsing Hua Steam School" through the development of STEAM courses.

Discover

This phase requires learners to tap on their daily life experiences and identify problems based on their observation and empathy. This is done through 3 steps: Context awareness, Motivation and Core problem. During Context awareness, we set a boundary for learners to identify problems revolving around their lives. This way, the learners would be more motivated to brainstorm for solutions as they can better resonate with the problems. As the learners provide countless solutions, we want them to focus back on the solution that caters to the Core problem.

Define

In this phase, the learners must begin to undergo problem definition. The defined problem must be supported by collected or measured data. Technology becomes an enabler in this process as learners search the internet for information or to present their findings. Here, the teacher also plays an important role as he/she facilitates the learning of concept aligned to the solutions proposed by the learners.

Model and Modelling

The third phase is mainly the prototyping stage. In the design of a solution, each group would propose a viable problem-solving model (i.e., a plan containing words, diagrams, legends, equations, etc.) aligned to the concept identified in the Define phase. Apart from a theoretical model, the learners must construct a working prototype to demonstrate the viability of their model. During the prototype construction stage, learners may encounter challenges which they must learn to trouble-shoot. This can also be considered as the debugging stage as the challenges may arise due to technology.

Transfer

Finally, the last phase would require learners to share their proposed model and final product. The value-added ness of this DDMT teaching model is also emphasized at this phase as learners are required to demonstrate their learning through different scenarios. A basic transfer of knowledge can occur between different subjects around a common concept (for example addition in Math and addition in Food Science). A higher order transfer would equip learners to internalize the concepts for use in a different context (for example traffic congestion due to cars and snow skis).

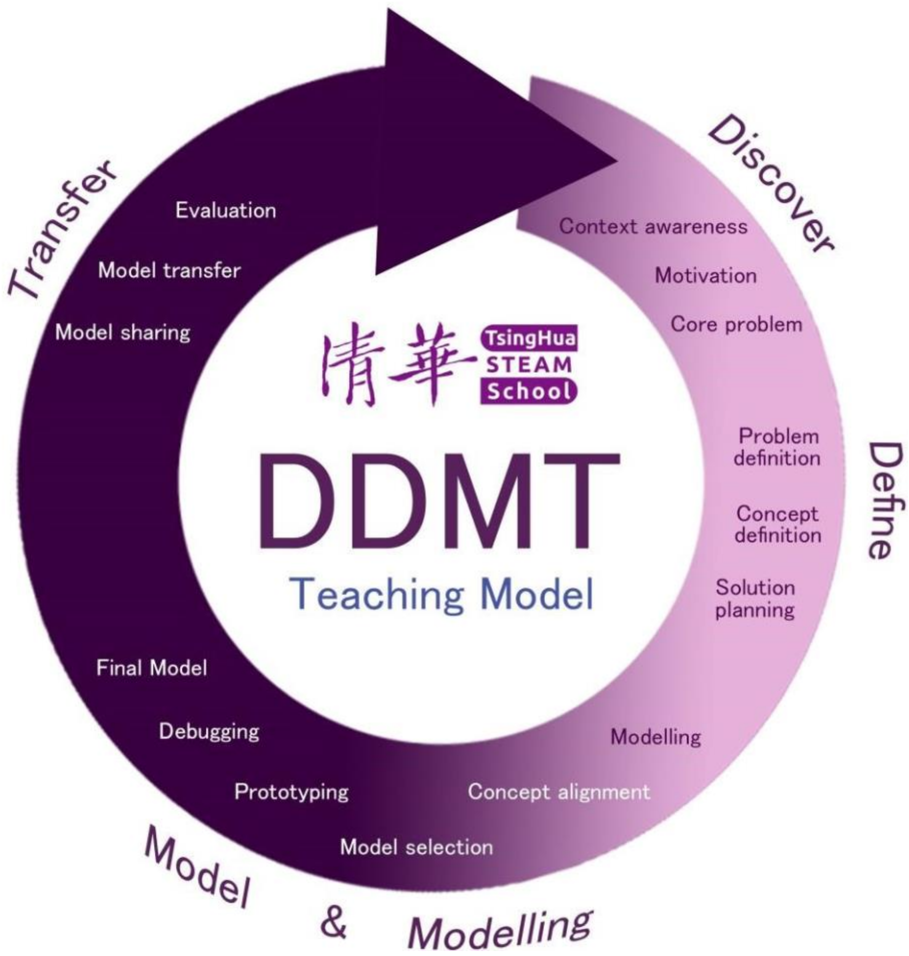

Fig. 1. A graphical representation of the DDMT Teaching Model

2.3 Critical Thinking

Critical thinking has been heavily emphasized as a core 21st Century Skill in recent years and listed as one of five key learning outcomes by Hart Research Associates (2013) and in Assessment and Teaching of 21CC (ATC21S). Furthermore, white papers by Organization for Economic Co-operation and Development (OECD) and World Economic Forum (WEF) has identified critical thinking as pivotal to future employment due to changing nature of jobs caused by advances in technology (Sternberg, 2013). Another important challenge brought about by technological advancements is the presence of fake news and multiple countries have considered implementing rules to cope with fake news. Singapore for example has passed a “Protection from Online Falsehoods and Manipulation bill” to tackle “falsehoods, bots, trolls and fake accounts” (https://www.bbc.com/news/world-asia-48196985). However, it is far more important to equip learners with the ability to reason and think objectively. While there have been increasing efforts to include critical thinking as an education outcome for K-12 learners, it was more common to find research regarding critical thinking for learners at higher education. Hence, it is imperative that more research is done at K-12 level in order to help younger learners develop the ability of critical thinking.

3 Research Methods

3.1 Design Based Research

According to Collins, Joseph and Bielaczyc (2004), Design Based Research is “designing experiments that brings together two critical pieces in order to guide us to better educational refinement: a design focus and assessment of critical design elements”. The assessment analysis comprises both qualitative and quantitative aspects (Choi, Lee, Lee, 2016).

There are a few differing factors between Design Based Research from conventional design and traditional research. Firstly, when designers receive formative feedback, their intuition often leads to changes that may neither be grounded in theory nor be limited to enable comparative research across time. A big challenge we faced in education is the complexity of conditions for success required in effective interventions (Dede, 2005). Secondly, Design Based Research emphasizes on adapting a design to its local context, a vital attribute for scaling up a successful innovation in one venue as compared to other venues with dissimilar characteristics

(Dede, 2004)

Design Base Research provides a cycle that promotes the reflective and long-term foundation upon which research can be undertaken (Amiel, Reeves, 2008). This process provides a richer understanding into how K-12 learners can develop critical thinking abilities.

3.2 Participants and Settings

The proposed study was carried out at The Affiliated Experimental Elementary school of National Tsing Hua University in East Division, Hsinchu City, Taiwan. This locale was chosen because of the following. Firstly, the school has been appointed as the experimental curriculum school of the national 12-year basic education policy. Hence, the school serves as a good test ground for new STEAM initiatives from the university. The research studied 28 Grade 5 learners over a 4.5 h (1.5 hour per session) to verify their ability in critical thinking through DDMT teaching approach in STEAM Education.

4 Results

4.1 Lesson 1: Discover

In lesson 1, learners are given 2 activities to show how much they understood about water. The intention of this lesson was to look for any prior assumptions the students have regarding the availability of water dispensers around them. Activity One was asking learners to identify the different sources of water around them. The learners are asked to list as many sources of water they can identify in their everyday lives in groups. Activity Two required learners to work individually to identify which source of water identified earlier was drinkable. The learners were also required to list down the reasons accounting for sources of water that is not consumable on post-it slips. Each student will then paste their slips to the teacher for collation. The teacher will then regroup the answers and lead students towards the concept of acidity and alkalinity. Although learners may give many differing answers, this is the portion where the teacher will facilitate the learning towards acidity and alkalinity as this is the curriculum standards required of Grade 5 learners. Feedback to alternative answers can be provided to the learners at a later stage.

4.2 Lesson 2: Design

In lesson 2, learners were provided with 4 liquids (2 acids and 2 alkalis) and blue and red litmus papers. Their tasks were to use the litmus paper to check for the acidity and alkalinity of each liquid. All the learners were able to perform the task successfully. They were also able to identify that an acid turns blue litmus paper red while an alkali turns red litmus paper blue. After completing the tasks, all learners were able to identify from the experiments that identifying acids and alkalis with litmus paper is not enough. They wanted to have a more precise method of distinguishing between strong and weak acids/alkalis. Out of the 26 learners, 24 of them were able to suggest the use of a universal indicator as a preferred solution, despite the concept of universal indicator not being in the syllabus. To further stretch the learners, a question was posed to the learners. If milk has a pH color corresponding to orange, what can I do to change the final color to green? Again, the learners were able to display the concept of neutralization by pouring alkali to ‘dilute’ the acid. The final question was something which was made up on the spot because of the unanimous answer of ‘universal indicator’. I wanted to test the learners’ understanding of universal indicator.

4.3 Lesson 3: Model & Modelling

Based on the tasks in lesson 2, I got learners to write-down the steps undertook in arriving at the pH of the liquid. The learners were able to identify the processes involved:

1. Use a clean dropper to prepare a sample of the liquid to be tested into a testtube
2. Pour a few drops of universal indicator into the sample
3. Shake the test-tube
4. Repeat steps 1 – 3 for another 2 times
5. Find the average reading

The aim of lesson 3 was to get learners to get learners to design an automated pH monitoring device using the Micro:Bit. Apart from helping learners realize how technology can improve efficiency based on their thought processes, I also wanted to build upon the notion of STEAM Education mentioned earlier.

At the end of the lesson, learners were given a worksheet to obtain their feedback on the 3 lessons. The worksheet comprised of the following questions:

1. How do you feel about the 3 STEAM lessons which has just taken place?
2. Which aspect of the lessons did you enjoy? Which areas did you least enjoy?
3. Detergent can turn red litmus paper blue. Is detergent acidic or alkali?
4. When using a universal indicator, the obtained result is 2.5. Would you consider this value acidic or alkali?
5. What do you think are the advantages and disadvantages of litmus paper?
6. What do you think are the advantages and disadvantages of using a pH scale?
7. Do you think learning the Micro:Bit was useful? In which areas was it useful?
8. Which other aspects would you like to learn more about the Micro:Bit?
9. The average pH level of human blood lies between 7.35 ~ 7.45. It is considered slightly alkaline, thus drinking slightly acidic liquids aids in promoting wellness. It is common to find many mineral water suppliers promoting their water as slightly acidic. If you are tasked with the responsibility to measure pH, which method (litmus paper, universal indicator or Micro:Bit) would you choose?

5 Further considerations

Although the research was able to bring out evidences of critical thinking in Grade 5 learners, improvements could be applied to further improvements to the study. Firstly, we over-estimated the amount of time needed for the learners to learn the Micro:Bit. While many of the learners could appreciate the efficiency of algorithm, they needed more time to apply technology for the 'Transfer' phase. Owing to the lack of time and computers, many learners were stuck at the 'Model & Modelling' phase. Secondly, the lesson was intended to be conducted in Mandarin. However, due to a clash in schedules, the lesson was conducted in Mandarin by a non-native Mandarin speaker. Generally, learners were able to understand the basic Mandarin used in delivering instructions. Some confusion arose when terminologies were delivered in English instead although the final survey showed that learners could deliver the outcomes highlighted at the start of the study, more could be done to make the data more reliable.

6 Conclusion

From the study, it can be observed that learners thoroughly enjoyed the STEAM lessons comprising hands-on activities, technology-integration to construct knowledge. Although there were many impromptu changes brought about through Design Based research, the use of the DDMT teaching model has provided researchers with an ability to help learners delve deeper into learning of content which is beyond national curriculum requirements. This approach has also provided researchers with an ability to better bring out the critical thinking abilities of the learners in a formative way; using activities and questions to propel learners to explore the limitations of litmus paper and suggest alternatives to improve its reliability. More importantly, this short study has demonstrated that it is viable to identify and cultivate critical thinking in Grade 5 learners.

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