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1. An Interdisciplinary Design Activity on Chemical Launchers

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Abstract

In a typical university teaching and learning environment, subjects are taught separately with minimal cross participation from other departments or disciplines. In addition, students' learning in non-laboratory-based subjects are usually assessed using timed written examinations. Using such evaluation through written examinations, top grades can be achieved by the students using rote-learning methodologies either through memorising concepts or through increased familiarity as a result of frequent practice. Such learning and evaluation approaches may inhibit in-depth comprehension and versatile application of fundamentals concepts that typically cuts across various complex, real world engineering problems.

In order to foster the ability to synthesise information and apply concepts to real world examples in the students, additional guided and instructive opportunities must be offered to students that allow them to connect the fundamental principles covered in the foundational classes. In this paper, we share the experience and lessons learnt on a hands-on, interdisciplinary activity developed at the Singapore University of Technology and Design (SUTD). Specifically, this study aims to discuss the approach and experiences in the implementation of this activity that connected the principles covered by the four subjects conducted during the same term (i.e., Mathematics, Physics, Chemistry, and Humanities, Arts and Social Sciences).

Broadly, a central activity theme on the efficient delivery of food to a city under siege was used to define and motivate the activity. Students, in teams of 4 or 5, were tasked to use a scaled-down model of a chemical launcher to send a projectile across the room, mimicking food delivery across the castle wall. The activity was evaluated within individual subjects: (1) ethics, strategies and impacts of war in Humanities and Social Science, (2) engineering aspects of a combustion system to launch an object using underlying principles of energy conversion and projectile motion in Chemistry and Physics classes, respectively, and (3) numerical solutions on the distance travelled by the projectile launched by the chemical launcher, taking into account drag forces in the Mathematics class.

At the end of the week-long activity, students strengthened their skills in report writing, data collection and analysis using concepts taught during that term. Specifically, students were guided through an activity where the connections between the different aspects of Science, Engineering, Humanities and Social Science were shown to them. Students were exposed to design and problem solving, where interactions and discussions are important yet challenging in a team setting within a tight project schedule.

Keywords: active learning, collaborative learning, first year undergraduate, interdisciplinary, STEAM

Introduction

For an undergraduate student majoring in engineering in most universities, introductory or first-year Science and Mathematics courses are taught separately to equip students with the foundational concepts required to solve engineering problems at the higher levels. The separate instructions of these foundational subjects can unintentionally result in limited cross-participation from other departments or disciplines. Consequently, there are few opportunities in the first couple of years where students are given the opportunity to connect these concepts learnt across the foundational classes to solve problems that are typically multi-faceted.

Using the approach of solving clearly defined problems, which focused on only one aspect, feedback from students questioning the relevance of concepts taught in these introductory Science and Mathematics courses were frequently received. Bear and Skorton (2019) noted that students did not see the importance in these classes in their field of study and found it hard to draw connections between subjects and relate to real world applications and future jobs. This lack of appreciation in the subject matter was amplified during rigid assessments and written examinations that favour students with better ability to memorise concepts and regurgitate information. As these students progress to their engineering majors, they will need to connect these foundational concepts and apply knowledge from multiple fields other than their own, and be able to evaluate and account for environmental and social factors in their proposed approach, solutions and designs (Bear & Skorton, 2019; Czerniak, 2007; Lattuca, Knight, Ro, & Novoselich, 2017; Van den Beemt et al., 2020). In addition, engineering graduates with communication, teamwork and hands-on design-build skills are highly sought after in the industry upon graduation (Crawley & Waitz; Rugarcia, Felder, Woods, & Stice, 2000). Performance in the form of scoring high grades in non-laboratory based subjects is thus not the only significant aspect in achieving academic and career success as engineering graduates require more than the knowledge of engineering fundamentals when working.

Project work in many engineering undergraduate studies focus on the process of conceiving, designing, implementing and operating (CDIO) (Berggren et al., 2003). In most engineering curriculum, the iterative aspects of problem solving and design tends to be in the form of a paper study or proposal, with limited physical prototyping. Generally, these projects are also constrained within their discipline and implemented within a single semester or year. An example is the final year design or capstone project.

Mirroring the developments in interdisciplinary research, universities are accelerating the adjustment and development of their programs by focusing on a more inter- or multi-disciplinary curriculum to better equip students to address complex engineering problems. Collectively, English (2016), Huutoniemi, Klein, Bruun, and Hukkinen (2010) and Klein (2010) defined interdisciplinary engineering education as the interaction and integration between different disciplines and fields to deepen knowledge and skill. Akkerman and Bakker (2011) stated that interdisciplinary learning encourages critical thinking and provides different perspectives to students.

Interdisciplinary learning could be conducted through collaborative projects, which require students to integrate and apply knowledge from more than one discipline, and if applicable, a contrasting discipline such as social science. Lam, Walker, and Hills (2014) reported that interdisciplinary problems tend to be driven by complexity, originating from real world or in urgent need of a solution.

At the Singapore University of Technology and Design (SUTD), which focuses on engineering and architecture disciplines, the undergraduate curriculum was created with a strong emphasis on interdisciplinary and hands-on learning. To foster a more active learning approach to improve learning outcomes, hands-on and design activities are incorporated as part of the education framework in addition to typical formal assessments such as written examinations. Hands-on activities are interweaved into the course content to help students better understand concepts; while design activities are included either within subjects or across multiple subjects to reinforce students' learning. In particular, design activities, which cut across multiple subjects during the term (also known as 2D activities), may be open-ended or student-driven. These 2D activities, either one week long or across the entire term, are team-based tasks that encourages students to connect and apply core concepts in two or more courses within the same term to address or solve a problem with a focused theme.

In this paper, we will discuss the creation, design, implementation and reflection of a Year 1 Term 1 2D activity on chemical launchers. Students are enrolled in four subjects in Term 1, as shown in Table 1 with the subject description. This one-week long, guided activity was presented in four parts, focusing on Chemistry, Physics, Mathematics and Humanities, Arts and Social Sciences (HASS), where the theme revolved around efficient delivery of food to a city under siege.

Table 1: Description of Year 1 Term 1 subjects

Subject	Subject Description
Advanced Math 1	This subject provides students with the foundation in single variable calculus, which covers the techniques and applications of differentiation and integration.
Physics 1	This is a first year mechanics course, focusing on one- and two-dimensional motion, forces, Newton's laws of motion,

	conservation of momentum, rotational motion kinematics and dynamics.
Chemistry	This is an introductory chemistry course, emphasising on basic principles of atomic and molecular electronic structures, chemical bonding, thermodynamics, acid-base and redox equilibria, chemical kinetics and catalysis.
World Text and Interpretations	Through classic texts, this introductory Humanities, Arts and Social Sciences subject equips students with critical reading, thinking and writing skills.

Implementation

Chemical Launcher and Combustion Reaction

The chemical launcher (Figure 1) was made in-house by instructors from the Chemistry teaching team and staff from the Fabrication Laboratory. The base of the chemical launcher was made from a piece of wood with the lid of a plastic canister glued to its surface. In the wooden base, the metal ends of a spark igniter and copper wire, which served as a ground, were passed through bored holes in the wood and lid of a plastic canister. The metal ends of spark igniter and copper wire were placed approximately 1.5 mm apart. A tyre pressure gauge was also attached to this wooden base through bored holes in the wood and lid of a plastic canister.

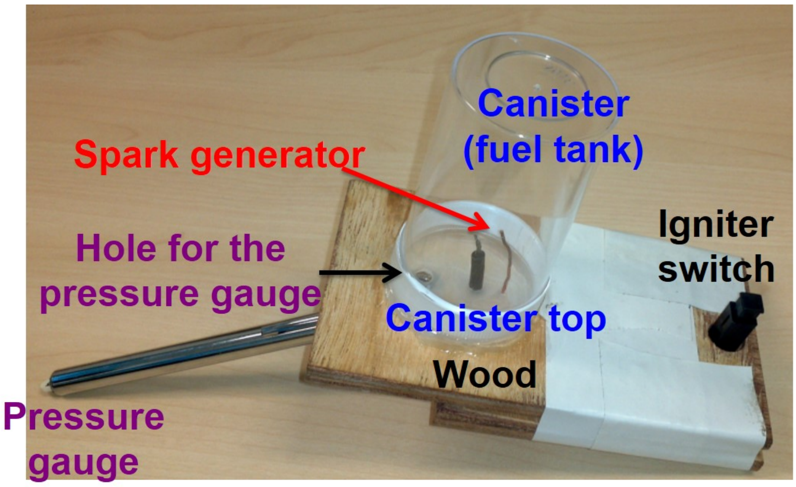

Figure 1: Chemical launcher set-up

The canister functioned as a 'fuel tank', holding the liquid and gaseous form of the fuel, and fitted securely to the lid on the surface of the wooden base. For this activity, ethanol was used as the fuel. The body of a Pringles acted as a barrel for this chemical launcher, as shown in Figure 2. The launch angle of the chemical launcher was adjusted using an F-clamp that was connected to a piece of wood hammered into the soil for stability (Figure 3 and 4).

Figure 2: Barrel of the chemical launcher

Figure 3: F-clamp to adjust angle of the chemical launcher

Figure 4: Chemical launcher set-up during field-testing

The spark igniter consisted of a piezoelectric element attached to a spring-loaded steel hammer, which was also the igniter switch. This igniter switch was placed at the other end of the wooden base, away from the canister. The metal ends of the spark igniter produced electricity in the form of a spark when pressure was applied to the igniter switch. This spark ignited the fuel air-mixture in the canister instantaneously, initiating the combustion process between the ethanol, a highly volatile and flammable gaseous fuel, and oxygen in air. This led to an instantaneous production of combustion gases and ejection of the canister from the wooden base and out of the barrel due to a sudden and large increase in gas pressure built up inside the canister, a closed chamber. The pressure built up inside the canister was measured using the tyre pressure gauge.

Outline of the Design Activity

During the week of the 2D activity, classes were suspended for one week such that no new examinable content was taught. Instead, scheduled class times were used as discussion and analysis sessions on 2D-related content. In HASS class, students discussed the ethics, strategies and impacts while the science and engineering aspects of a combustion system, as observed in a chemical launcher, were studied in Chemistry, Math and Physics classes as summarised in Figure 5.

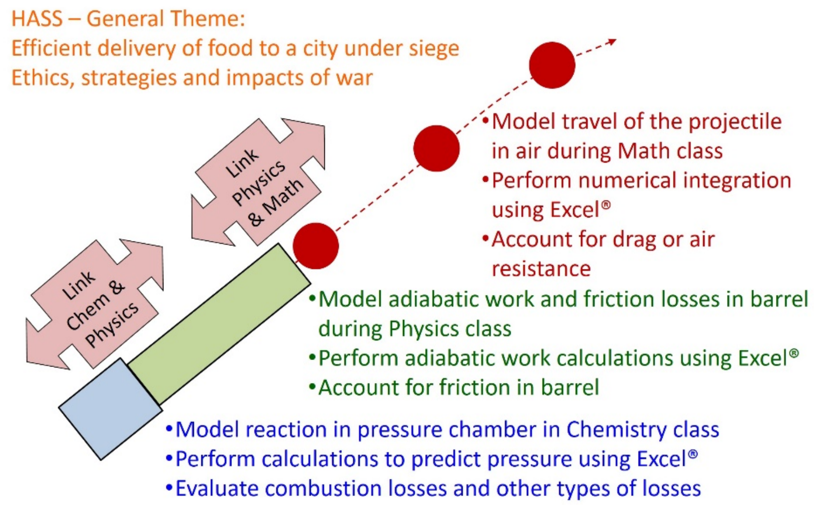

Figure 5: Summary of concepts examined and evaluated in each subject

Students were randomly divided into groups of 4 or 5. Each group was first tasked with performing a parametric design based on the chemical launcher to launch an uncooked potato (payload), at various launch angles, across the room using ethanol. Through this parametric design, students identified the independent, dependent and constant variables, determined the parameters needed to optimise the desired performance and understand the cause and effect relationships in the design of a chemical launcher. Examples of design and performance parameters are shown in Figure 6. Following this activity, students were informed to optimise the concentration of fuel required with the distance that the payload will be delivered to for an assigned launch angle.

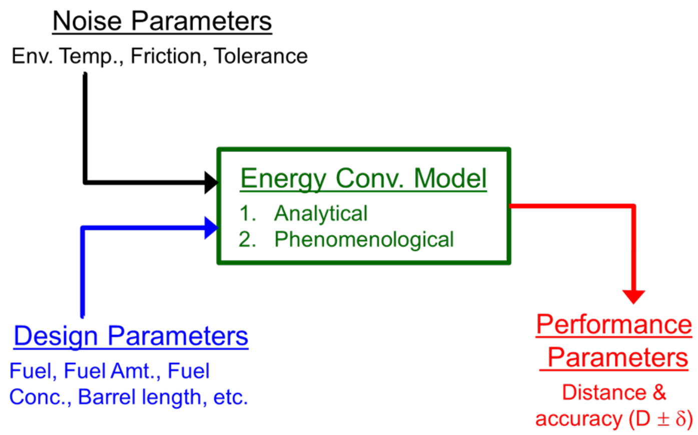

Figure 6: Schematic flow of parametric design of a chemical launcher

Using this as a starting point, each group was given 90 minutes to optimise their chemical launcher/payload system through trial and error during field-testing. Students collected and recorded data on distance travelled and built-up pressure for each launch angle. The data collected was then used to optimise calculations performed on a Microsoft Excel spreadsheet created by students with guidance from instructors. The spreadsheet was set up based on the relationship established between Chemistry, Mathematics and Physics classes. This was represented with a model that highlighted the underlying principles of energy conversion and projectile motion with numerical solutions on the distance travelled by the projectile after launch. With the spreadsheet and the data collected, the energy losses and the fuel concentration needed to achieve a target distance travelled could be predicted.

Though this guided 2D experience, the students' learning outcomes were: (1) to develop skills in report writing, data collection and analysis, (2) to gain an understanding and appreciation on the application and inter-disciplinary nature of Science, Engineering, Humanities and Social Science, and (3) to be exposed to design and problem solving in a team setting. Students submitted a group technical report for each subject at the end of the week, showing calculations, predictions, justification and evaluation of results, and commented on any discrepancies between theoretical and actual results.

Modelling the Chemical Launcher and its Travel

Modelling of the launch of the projectile using a chemical launcher was conducted in three main stages (Figure 7) during Chemistry class: (1) vaporisation of the fuel, (2) large increase in gas pressure upon combustion and (3) expansion of gases leading to work and kinetic energy. In Physics class, energy conversion and projectile motion were studied while numerical solutions on the motion and distance travelled by the projectile launched by the chemical launcher was modelled and developed during Mathematics class.

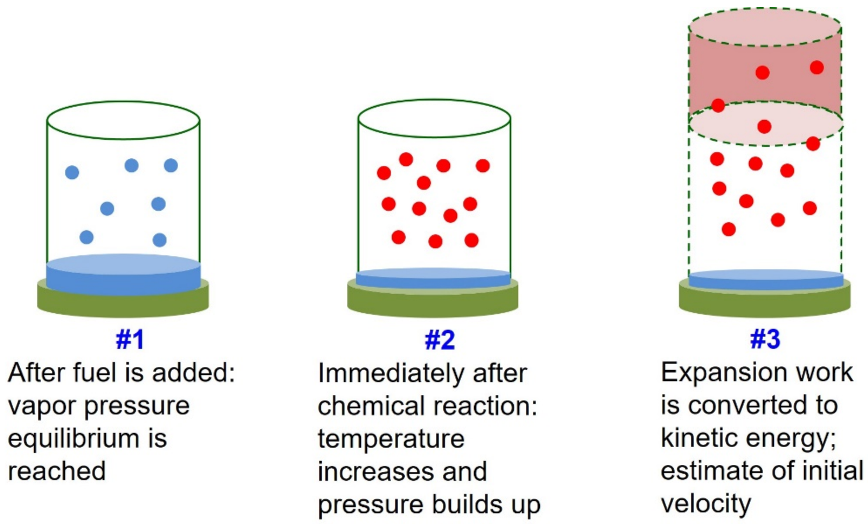

Figure 7: Different stages of chemical processes in a chemical launcher

In Stage 1, over-the-counter liquid cord spirit for disinfection containing 70% ethanol was added to the canister as fuel. Since ethanol has low vapour pressure, it is highly volatile and some of this liquid will vaporise to form an equilibrium mixture of vapour and liquid ethanol. The partial pressure of ethanol P_i (Pa) is calculated using Raoult's law:

$$P_i = x_i P \qquad \text{Equation 1}$$

where x_i is the mole fraction of ethanol (-) and P is vapour pressure of pure ethanol (Pa).

The number of moles of ethanol in the vapour phase n_i (mols), and thus the amount of fuel in the vapour phase, can then be calculated using the ideal gas law:

$$P_i V = n_i RT \qquad \text{Equation 2}$$

where V is the volume of the canister (m^3), R is the gas constant (J/mol.K) and T is the temperature (K).

As described in Reaction 1, the combustion products of this exothermic reaction are carbon dioxide and water.

$$C_2H_6O_{(g)} + 3O_{2(g)} \xrightarrow{\text{ignition}} 2CO_{2(g)} + 3H_2O_{(g)} \qquad \text{Reaction 1}$$

The change in enthalpy of the reaction ΔH_{rxn} (J/mol) can be calculated from the difference in the heats of formation of the reactants and products, which can be easily found in textbooks:

$$\Delta H_{rxn} = n \sum \Delta H_{products} - m \sum \Delta H_{reactants} \qquad \text{Equation 3}$$

where n and m represent the number of moles of products and reactants respectively (mol).

During ignition, only fuel in the vapour phase will react with oxygen; the remaining fuel in the liquid phase will burn if the flame front is unable to dissipate quickly. Assuming complete combustion with ethanol as the limiting reactant and oxygen in excess, the theoretical maximum amount of chemical potential energy, which is , that is available to be converted to heat released by the exothermic reaction is determined:

$$Q_{rxn} = n_i \times \Delta H_{rxn} = mC_p\left(T_f - T_i\right) \qquad \text{Equation 4}$$

where Q_{rxn} is the energy released in the exothermic reaction (J), m is the mass of unreacted components of air (mainly nitrogen N_2 and excess oxygen O_2) and products (kg), C_p is the weighted-average specific heat capacity (J/mol.K), T_f is the highest temperature achieved in the canister (K) and T_i is the initial temperature of the gases, which is ambient temperature (K). The amount of combustion products carbon dioxide and water vapour and amount of unreacted or excess oxygen are determined from Reaction 1. The combustion reaction stops once the reactants are completely exhausted.

Using Equation 4, the highest temperature achieved in the canister is approximated, assuming that there is no energy losses. This temperature is also known as adiabatic flame temperature. Based on the experiments and analysis conducted by the SUTD Chemistry teaching team, it appeared that a 50% energy losses is a conservative number that will allow the students to calculate a reasonable adiabatic flame temperature using Equation 4. Some examples of energy losses in such a system are incomplete reaction, poor combustion efficiency, poor sealing between the canister and wooden base, and heating of the canister.

It can be seen from Reaction 1 that there is a net production of the number of moles of gaseous products compared to that of gaseous reactants (i.e., an increase in the number of moles of gases in the canister as reaction proceeds). Applying the ideal gas law model shown in Equation 2, in a closed system such as the canister in this activity, the increase in gaseous molecules increases the gas pressure inside the canister. This build up in gas pressure ultimately leads to the ejection of the canister from the wooden base. With the estimated adiabatic flame temperature and total number of moles of gaseous components in the canister, this final pressure before the canister leaves the wooden base can be estimated using ideal gas law (Equation 2).

As the reaction happened quickly, the chemical launcher was assumed to have undergone adiabatic expansion. This pressure-volume relationship and the amount of expansion work W (J) in an adiabatic process are thus represented as:

$$PV^{\gamma} = \text{constant} \qquad \text{Equation 5}$$

$$W = \int_{V_{\text{intiial}}}^{V_{\text{final}}} P - P_{\text{atm}}\, dV = \int_{V_{\text{intiial}}}^{V_{\text{final}}} \frac{\text{constant}}{V^{\gamma}} - P_{\text{atm}}\, dV \qquad \text{Equation 6}$$

where is 1.4 for air, V_{final} is the volume of the barrel (m^3), $V_{initial}$ is the volume of the canister (m^3) and P_{atm} is atmospheric pressure (Pa).

From here, assuming 100% conversion in thermal to mechanical energy, students calculated the kinetic energy available (J) and hence the initial launch velocity v (m/s) for projectile motion using:

$$W = \frac{1}{2} m_{payload} v^2 \qquad \text{Equation 7}$$

where $m_{payload}$ is the mass of the payload (kg). Internal combustion engines that use ethanol as a fuel are reported to have a conversion efficiency of 40% or energy losses of 60% (ETSAP, 2010). In this activity, thermal to mechanical losses, such as friction and air drag, was observed through experiments conducted by the instructors to be 67%, which was reasonable compared to internal combustion engines. Thus, students calculated the initial launch velocity in Equation 7 with 67% energy losses.

Together with the assigned launch angle (°), the distance travelled by the payload x (m) can then be estimated:

$$x = \frac{v^2}{g} \sin 2\theta \qquad \text{Equation 8}$$

where g is acceleration due to gravity (= 9.81 m/s^2).

In Physics and Math classes, students performed detailed modelling of the speed and path of the projectile in air and numerical integration to determine the energy losses through friction and air drag. This served as a crosscheck to the estimated energy losses assumed during Chemistry class (Equations 4 to 8). In addition, students validate their findings in Physics and Math classes with the data collected during field-testing.

Student Feedback and Reflection

We received mixed feedback from the students about the 2D activity. While some enjoyed the process of building their own mathematical models for data analysis and prediction, many commented that it was tiring and frustrating to understand the concepts and at the same time connect the concepts between subjects within one week. There are a few possible reasons for the exhaustion and frustration. One of the reasons may be the heavy requirements in a short duration to submit one report per subject in addition to carrying out experiments for data collection, designing their payload and creating their model.

In addition, the pressure and distance predicted from the theoretical model did not match the data collected from field-testing as a result of a multitude of unpredictable real world factors (e.g., wind direction, temperature, operation variabilities). The poor theoretical predictability derailed the importance and significance in using theoretical calculations prior to prototyping or constructing of any design. The disconnection between theory and real world utility might have dispirited student's motivation. To address this disconnection, with some examples described in detail below, future design challenges would have to be crafted such that there is minimal influence from external conditions leading to improved predictability. This would require the design of more robust prototypes that are engineered to be more tolerant with less assembly involved (e.g., design of combustion chamber and barrel).

The difference in the theoretical results and data collected might be due to idealisation of the system and estimation of energy losses in the theoretical model. The amount of fuel in the vapour phase may have been poorly estimated as ambient conditions such as temperature and humidity variations prior to the launch was not taken into account. Lastly, we observed that the tyre pressure gauge was unreliable in the measurement of built-up pressure in the canister before launch. This might be due to poor sealing of the canister to the lid of the wooden bases, leading to leakage, or the imprecision in response time in this rapid combustion reaction. Although a more robust set up was constructed in the following year with better sealing of the canister to the base of the chemical launcher, the measurements from the tyre pressure gauge was still inconsistent and inaccurate after repeated runs. A pressure gauge with faster response time is thus needed for this activity.

Alternatively, a combustion reaction that is more reproducible and repeatable could be formulated. Instead of depending on the vaporisation of the liquid fuel to generate a sufficiently combustible vapour phase, combustion reactions based on either gas phase reactions (e.g., propane/butane gas) or solid fuel reactions would improve the predictability and repeatability of the reactions. Likewise, the design of improved combustion chamber with minimal assembly and parts would also improve the reproducibility of pressure generated. There could have been opportunities for the 2D activity to have greater relevance to real world problem by including additional design tasks to the students so as to motivate them to create better engineering solutions. An example is to connect to the challenges encountered in developing energy efficient fuel systems that can drive or move vehicles.

There were also comments from students that this particular 2D activity covering four subjects was contrived and did not connect well to real world scenarios. As reported by Van den Beemt et al. (2020), students are more motivated in completing an assignment if they are able to see direct application of the topic to practical needs. As complex engineering problems are usually open-ended and ill defined, and solving them is an iterative process, more time and guidance (e.g., with structured questions or sections) allocated to the 2D activity would be recommended, starting with more-structured problems in Term 1 and progressing to projects that are more open-ended over the years.

In addition, students commented that the expectation of the assignment, in terms of measurable outcomes, was unclear. This feedback seemed to be common in interdisciplinary assignments, as observed by Van den Beemt et al. (2020). To address this, it would be necessary for the team of instructors from every subject to communicate a consistent overall objective and share how each part of the solution fits to address that specific problem. Furthermore, for most interdisciplinary engineering problems, there will be multiple good solutions. This is vastly differently from solving typical textbook questions which general have one ideal solution for each question. In this instance, a well-defined problem statement with sufficient clarity from the respective subjects would need to be balanced by the opportunity of allowing multiple good solutions. It would have to be communicated clearly to students that multiple good solutions are possible, and a mindset shift will be required. Instructors leading the projects must be ready and comfortable to explore multiple good solutions as well.

We also noted that, as with any assignments, a constant renewal of 2D activities was necessary for novelty to keep students interested and to minimise copying between various years. Creating and development of 2D activities could also possibly involve upper year students, who had first-hand experience and were genuinely interested in contributing to SUTD’s curriculum. This could bring about new ideas and discussion points, and might avoid the mismatch in expectations between the students and instructors on the learning outcomes of the activity. As seen in the creation of one particular 2D activity on a sugar rocket by

Sophomore and Junior students with advice from faculty members of the MIT-SUTD Collaboration Office (Council, 2021), these students demonstrated that they knew the elements required in executing a good 2D activity, such that it was a fun activity and yet met the educational experience expected.

Although there were comments that this particular 2D activity covering four subjects was contrived, many students appreciated and commended the effort of the teaching team and enjoyed the out-of-classroom and fun learning experience. In a study conducted by Gero (2017) where senior year students taught their peers interdisciplinary lessons, all students commented that they invested a lot of time and resources, and felt insecure to teach a discipline that they were not trained to teach in. As noted by Gardner, Jansujwicz, Hutchins, Cline, and Levesque (2014), instructors with interdisciplinary experiences were more enthusiastic in developing such activities and programmes. The collaborative effort from SUTD instructors of different subjects bringing their expertise to create this activity and their belief that this activity would be valuable to students played a big role in making this successful.

Conclusion

Though this guided 2D experience, albeit ‘forced’ because of incorporating the topics covered in four subjects of the term, students drew connections between Science, Engineering, Humanities and Social Science to design and model a chemical launcher-payload system in a team setting within a tight project schedule.

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Author's Biographies

Li Ling Apple Koh is a Senior Lecturer at Singapore University of Technology and Design (SUTD). She obtained her Bachelor of Engineering in Chemical and Biomolecular Engineering from The University of Melbourne. She continued to pursue a PhD with the Department of Chemical and Biomolecular Engineering and School of Chemistry at The University of Melbourne, in partnership with Dairy Innovation Australia. Since joining SUTD, Apple has been actively developing and executing interdisciplinary activities to demonstrate the interconnectivity between various subjects and to promote students' appreciation in the applications of science and engineering concepts.

Mei Xuan Tan is a Senior Lecturer at Singapore University of Technology and Design (SUTD). She obtained her Bachelor of Science in Chemistry with a minor in Mathematics from the National University of Singapore (NUS). She went on to pursue her doctorate with the NUS Graduate School for Integrative Sciences and Engineering (NGS). During her PhD, she spent 4 years at the A*STAR Institute of Bioengineering and Nanotechnology (IBN). At SUTD, she has revised the Chemistry curriculum, developed 1D and 2D projects, and took on pedagogy research to investigate the effectiveness of active learning and digital tools in education at SUTD. She believes that education should be more than just acquiring technical knowledge and skills. She hopes that education can continue to shift towards a holistic approach that serves to bring out the potential in each individual.

Gim-Yang Maggie Pee is a Senior Lecturer at Singapore University of Technology and Design. Maggie has 4 years of teaching experience as an Assistant Professor, Adjunct Professor and teaching associate in the United States before joining SUTD. Since joining SUTD, she teaches chemistry, integrated biology and chemistry, and thermodynamics. She is interested in exploring the various ways to improve students' learning outcomes and has done pedagogy research to investigate the effectiveness of active learning and digital tools in education.

Mei Chee Tan is currently an Associate Professor at the Singapore University of Technology and Design (SUTD). She graduated with her bachelor degree in Chemical Engineering, and earned her master and doctorate degrees with the Singapore-MIT Alliance at the National University of Singapore. Later, she continued to expand her research and teaching experience as a postdoctoral researcher at Rutgers, The State University of New Jersey. Her research activities at SUTD expands on the study and engineering of tailored interfaces based on an interdisciplinary approach for the development of innovative engineering applications that are founded on sound scientific principles.

2. Science and Language Connects the World - When STEM meets STSE with CLIL Beyond a Classroom Context in Hong Kong

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Abstract

Science literacy plays a crucial part in science education nowadays. However, it is confined toa need for assessments – few students are aware of the importance of science in the world. Worst still, even if students are literate in science, they do not know how to present themselves effectively through English. Consequently, a teaching and learning programme is tailored-made for students to increase their awareness of science to other disciplines through the science, technology, engineering and mathematics (STEM) approach (Bybee, 2010, 2013). Together with their awareness of the current environmental issues through science, technology, social, and environment (STSE) approach (Bencze et al., 2020) with language support through content and language integrated learning (CLIL) (Lin, 2016).

This action research adopted a design-based intervention design with a group of Secondary two (Grade 8) Science students (n = 5) with mixed ability in an EMI school in Hong Kong. Students in the intervention received additional language support of CLIL by a teacher-researcher for the background science knowledge. The teacher initiated students' thinking on sustainable development and endangered species by the STSE approach. After that, students were asked to design a device to help save the population of the endangered species by using the STEM approach. Through the research period, language support used in the intervention group will be gradually removed by careful scaffolding in order to increase learners' responsibility (Elliot, Frey and Fisher, 2019) to observe the learning progress of students. Teacher's observations and students' work were also used to understand the teacher and students' attitudes towards teaching and learning in various approaches during the study. Results, pedagogical and theoretical implications for STEM, STSE and CLIL are discussed.

Keywords: student science research, STSE, STEM

Introduction

Besides teaching students how to know science, it is more important to cultivate them to think science (Zoller and Nahum, 2012). Moreover, science is not a standalone subject; it has strong connections with mathematics and engineering subjects. Therefore, science, technology, engineering, and mathematics (STEM) education have become a popular topic for researchers and teachers to investigate how students learn science in a multidisciplinary approach (Bybee, 2010, 2013). However, recent studies (Rahman, 2021; Yuen *et al.*, 2021) are more inclined to robotics and programming. Few studies are replying to the social calls of environmental protection. Researchers have established science, technology, social and environmental education for a long time (Brown, 2012; Bybee, 2010, 2013; Stohlmann and Moore, 2012; Kelley and Knowles, 2016). Numerous successful studies show that environmental education is essential in science learning and teaching (Littledyke, 2008). Therefore, a learning and teaching programme with STEM and STSE elements was developed.

Other than thinking science, science communication has played an indispensable role in science learning and teaching. However, science educators and researchers had little focus on this issue for EFL learners except vocabulary building (Coxhead, 2018). Therefore, strong language support, such as that under CLIL approaches, is essential for Hong Kong students who are ESL/EFL learners while receiving sophisticated chemical knowledge using English as a medium of instruction (EMI). As a result, students can read and extract essential information from the text in reading materials and produce their work verbally and in written work using subject-specific vocabulary, general academic vocabulary and appropriate signalling words at a text level. It is hoped that this study can shed light on CLIL approaches in a science context in STEM and the STSE approach to give more insights to science scholars and teachers that language learning is crucial in science learning.

The research questions in this study include:

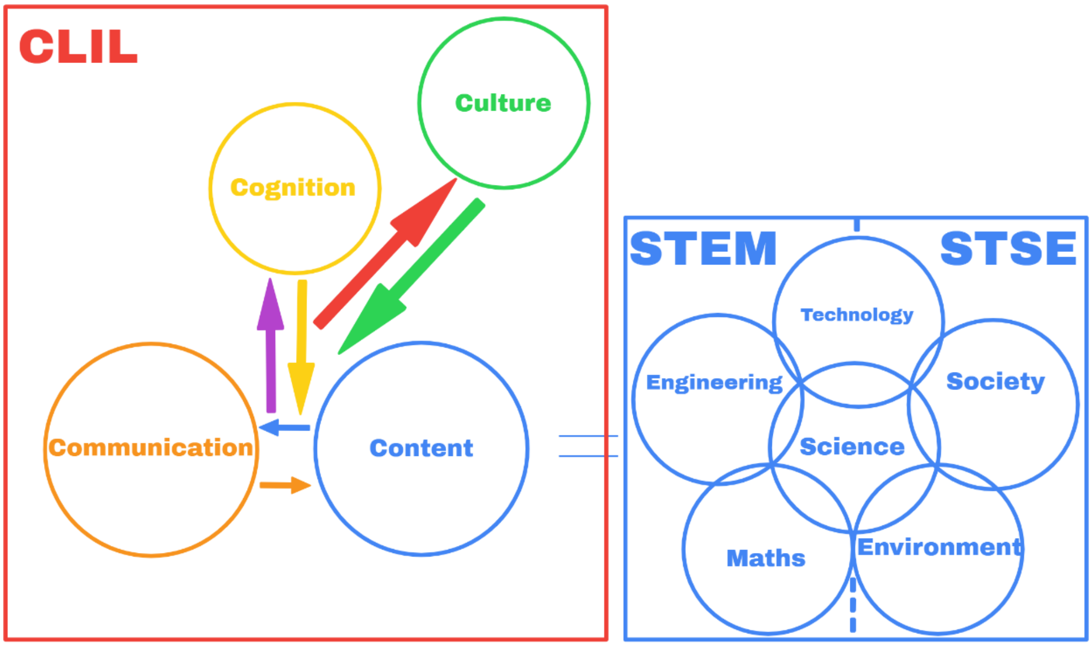
- the extent of the feasibility of integrating STSE, STEM and CLIL in an environmental education programme.
- the extent of teaching and learning effectiveness of the programme in scientific, technological, engineering, mathematical, social, environmental, linguistic and cultural components.

Theoretical Framework

This theoretical framework is based on the 4C model of CLIL suggested by Professor Coyle (2010) with content, communication, cognition and culture. Throughout this study, students' receptive and productive skills in English were examined. In this study, the content includes science background (S), technological (T), social (S) and environmental (E) impact to the endangered species by the STSE approach. After discussing the undesirable impact to that endangered species, students applied science concepts they learnt (S), technology and computer literacy acquired (T), engineering principles (E) and concepts for mathematical manipulation (M) to build a prototype for improving the environment. Therefore, this study provides multi-dimensional learning opportunities for students. With plenty of scientific knowledge delivered, effective communication between teachers and students is crucial. As a result, careful planning for communication in lessons is necessary to foster effective teacher-student knowledge exchange. While students acquire sufficient basic science concepts with accurate language, they can analyse, evaluate and create science knowledge, which is the cognition process of the CLIL model. Ultimately, it is hoped to build students as responsible global citizens, which is the culture of the model.

Figure 1

Incorporation of the STEM, STSE and CLIL model in this study



Literature Review

The importance of STSE education

Environmental education is essential in value building, including being responsible, committed and care for nature (Bencze et al., 2020). However, if value-building is the principal teaching and learning objective, the background knowledge may not be sufficient. Therefore, environmental education should be promoted as value education embedded with essential knowledge. This teaching and learning programme involves students choosing an endangered species that they wanted to protect and conserve. Next, they learned about the endangered species' features (science) and how technological advancement threatened the species (technology). After that, they acquired knowledge about the societal (society) and ecological (environment) impact of the endangered species' decreasing population. Students showed their learning achievements of endangered species through written and oral presentations, which can evaluate the programme's teaching and learning effectiveness.

The importance of STEM education

STEM refers to science, technology, engineering and mathematics education (Bybee, 2013). Many educators misinterpreted it as science, technology, engineering and mathematics in a teaching and learning programme. However, the key to successful STEM education should be *integrating* scientific, technological, engineering, and mathematical elements in the programme. In this study, the extent of integration of the four elements in the programme was investigated.

Recent studies (Rahman, 2021; Yuen *et al.*, 2021) are more inclined to computer-based STEM programmes such as robotics and programming. It may help improve human living standards by increasing convenience to people. However, when it comes to environmental education, especially conservation biology, a technologically inclined STEM programme might not help. Therefore, in this study, more science concepts were embedded to form a concrete knowledge base to solve environmental problems.

This teaching and learning programme involves learning a scientific approach to build a shelter to conserve an endangered species (science). Before students had found appropriate materials for the shelter, they searched for necessary information for shelter building (technology). After that, they make a shelter prototype (engineering) with careful calculations (mathematics). All four elements of STEM education were present, the effectiveness of the programme was investigated.

Improving students' English proficiency in science through the CLIL approach

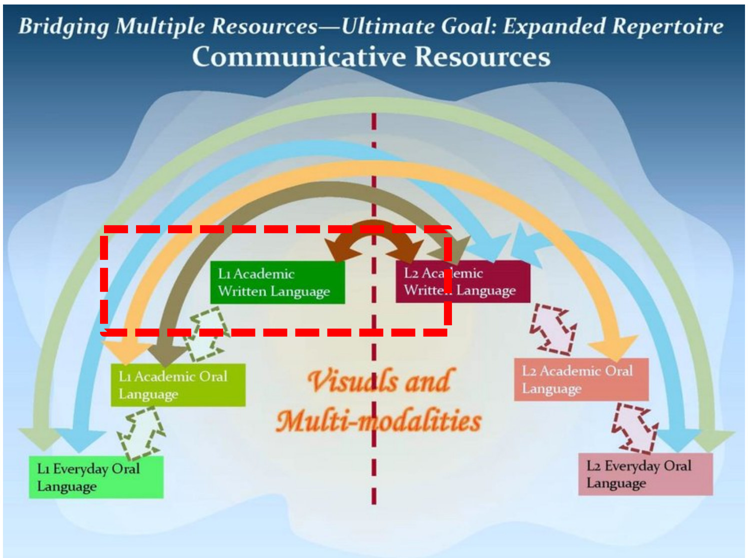
Content and Language Integrated Learning was defined as' a dual-focused educational approach in which an additional language is used to learn and teach of both content and language' (Coyle, Hood and Marsh, 2010). When participants were Grade 8 students with mixed English ability of ESL and EFL learners, English support through CLIL was necessary. When they learnt the environmental impacts of endangered species through the STSE approach and built a prototype to help conserve endangered species through the STEM approach, the CLIL approach is essential to bridge the participants into the target language.

Code-switching between Chinese and English

At the beginning of the programme, some EFL learners searched Chinese (L1) information for the endangered species. Instead of asking the students to find the information again in English (L2), it was a golden opportunity to introduce subject-specific English words to increase their vocabulary. After that, they tended to search information bilingually to have various angles for their endangered species research. This scaffold was removed in the latter part of the programme as the EFL students were more accustomed to learning science in English as the only medium of instruction.

Figure 2

The ‘Rainbow Diagram’ (Lin, 2016) illustrating code-switching as the transition between L1 and L2 academic languages



Promoting literate talk

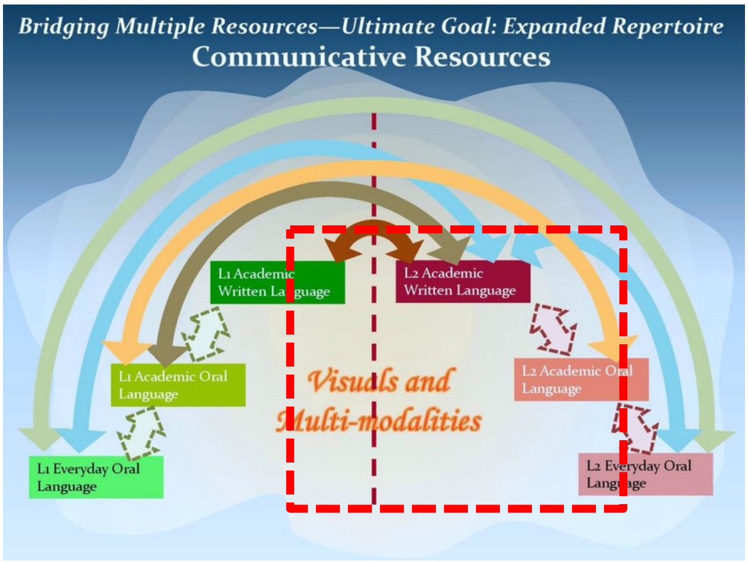
Some subject-specific vocabulary can be explained from students' schemata as they had learned English words in English lessons used for daily scenarios. For instance, when a teacher-researcher explained the meaning of 'biodiversity':

'When we look at the word "biodiversity", we can chop it down into two parts – "bio" and "diversity". Do you still remember the word 'biology'? It is the study of … Yes! Plants and animals. Diversity means "how many", the number of, the amount of. Therefore, biodiversity means the number of plants and animals in the world.'

The teacher-researcher started introducing the term biodiversity by chunking the words into two parts, "bio" and "diversity". For the first part, the teacher-researcher recalled the word they learned in science lessons (biology). Then, the teacher-researcher used words they have learnt in English lessons (plants and animals). Similar practice went on for the second part. The teacher-researcher used words they have learnt in English lessons' how many', then he paraphrased as 'the number of' and 'the amount of'. Overall, he used a wide range of daily oral language and oral academic language vocabulary to target written academic language.

Figure 3

The 'Rainbow Diagram' (Lin, 2016) illustrating literate talk as transition of L2 language registers



Using multimodalities

Multimodalities refer to audio-visuals, images, diagrams, concept maps, graphic organizers, demonstrations, role-play, actions and gestures (Lin, 2016). When students do not understand words from other words, multimodalities can help students to understand the concepts other than words. For instance, when students learnt the biodiversity of organisms, videos were used to introduce some complex and abstract concepts. With explanation using daily oral English and elaboration using plenty of photos, students could understand the term 'biodiversity' easily. When students learn the life cycle of an endangered species, diagrams familiar to students were shown to students with further explanations. These multimodals serve as the bridge between students' prior knowledge in daily experience and the knowledge to be learnt in English.

Figure 4

The ‘Rainbow Diagram’ (Lin, 2016) illustrating using multimodalities (red arrow)

Research gap to be filled

There are few studies concerning environmental education from the STEM approach. Moreover, there are few studies concerning hand-on activities from the STSE approach. When there are more hands-on activities for environmental education, there can be more practical solutions for environmental problems from individuals. With sufficient language support, the current study evaluates students' learning effectiveness in acquiring science knowledge in a classroom using English with language support through CLIL in a STEM and STSE classroom.

Methodology

Research design

Compared with other research designs, action research is a plausible method in this context to promote a naturalistic enquiry to knowledge co-construction between teachers and students (Burns, 2009). This study was practical action research involving problem-solving of an environmental issue – conserving an endangered species. Therefore, practical action research was carried out to discover the meaning of participants' behaviour in the research with the outcomes depends on the participants. A brief scheme of work is shown below.

Figure 5

Scheme of work in this study

Stage of study	Content	The teaching and learning approach used	Assessment	Duration
1	Sustainable development	CLIL	Poster design	30 minutes
2	Endangered species	STSE, CLIL	Poster design and oral presentation	3 hours
3	How can we help to conserve endangered species	STEM, CLIL	Eco-house design and oral presentation	4 hours

Before participants learnt how to conserve living organisms, they needed to know the importance of protecting them. Otherwise, this study would undesirably become a knowledge-draining activity after they were convinced that environmental protection is of paramount concern. They needed to find an endangered animal or a plant for investigation. In this study, students chose to study bees for further investigations. They studied the features and the life cycle of bees, which is the science part of the STSE approach. Next, they researched how the decline in the bee population affects society and the environment. After participants knew the negative impact of the population decline of bees, they were required to build an eco-house to support the bee population. At that time, the STSE approach was completed, and the STEM approach was conducted. Participants needed to conduct internet research on how to attract bees to settle down its eco-house. Next, they need to find suitable materials for building an eco-house. After that, they calculated the numerical parameters for a suitable living environment for bees. Finally, they built the house, cutting down the materials they found with their results after calculations.

Research setting and Participants

Participants (n=5) were drawn from Grade 8 (13 years old) students studying Science with mixed ability in a secondary school in Hong Kong. Other than students, one science teacher was also involved as a teacher-researcher to co-construct knowledge with students through STSE, STEM, CLIL learning, and teaching strategies.

Methods of data collection and analysis

Observations

Observations were employed to increase the amount of research data quantitatively by recording events and programme context in detail, ultimately providing a more holistic picture for the study.

Regarding the type of observations, the programme was planned, and the observation focus was known before the study. Moreover, the researcher aimed to test the hypothesis: 'STSE, STEM and CLIL approaches are helpful to non-native English students to learn environmental education effectively'. Furthermore, the observer was also a teacher-researcher in the lesson, taking an active role in observation. The observations recorded in this study were structured, with full participation. Throughout the 8-week study, lessons were audiotaped, transcribed and analysed to answer one research question – to evaluate the teaching and learning effectiveness of the programme in scientific, technological, engineering, mathematical, social, environmental, linguistic, cognitive and cultural components.

Students' works

Students' works were collected to enrich research data qualitatively, ultimately providing a more comprehensive picture for the study. Throughout the study of eight weeks, students worked on two posters – one emphasising the importance of sustainable development and another one focusing on the rationale of conserving bees by the STSE approach. After that, students created an eco-house to conserve bees by the STEM approach. Throughout the programme, language input and output of students' works were supported by the CLIL approach. Students' works were analysed to answer one research question: what students have achieved in scientific, technological, engineering, mathematical, social, environmental, linguistic, cognitive, and cultural components.

Research Questions

1. the extent of the feasibility of integrating STSE, STEM and CLIL in an environmental education programme
2. the extent of teaching and learning effectiveness of the programme in scientific, technological, engineering, mathematical, social, environmental, linguistic and cultural components.

Ethical Considerations

Informed consent was received from the students, parents, and principal to guarantee students' privacy and their rights in the study period. A power relationship existed between the researcher and the participants, as the researcher was the participants' teacher. Therefore, the research process was democratised, and the power relationship was minimised as they were free to participate in the research aspects of the study and had the right to opt out at any time. These measures were implemented to allow a smooth investigation and make participants feel at ease and comfortable.

Results

Students were required to produce two posters, one for stressing the importance of sustainable development and another for reporting what they have done in this learning project. After that, students needed to present what they have done based on their second poster in an oral presentation. The followings report the effectiveness of every component in the STSE, STEM and CLIL approaches.

After students had known the importance of sustainable development, they were asked to one endangered species to study, and they agreed to investigate bees. Next, students were required to report information on the structure of a bee in its life cycle and how the adaptive features help bees to survive. Students initially reported much information about the structures of a bee without synthesising the valuable information in the poster. Therefore, the teacher-researcher intervened by teaching students how to find out crucial information from the data source. After that, students managed to synthesise information and reported that the hard shells of eggs, hard pupa, wings, and stings helped protect themselves. Other than that, they reported that the community living of bees also helped to protect bees from each other. However, due to excessive human activities and technological advancement, bees were on the verge of extinction, leading to irreversible social and ecological impacts.

Figure 6

Participants' Poster design to summarize their ideas on the bees' extinction

After they had known that the bees would become extinct, they searched for ways to help bees. They discovered that there were some solitary bees which do not have a nest. Therefore, they started to build a nest as the eco-house for the solitary bees. That was the 'bee hotel'. When students built the bee hotel for solitary bees, it was essential to know about the dimensions of the house. Therefore, they searched bees' sizes from the internet and managed to design and create a bee hotel that suits their needs.

Figure 7

The bee hotel as a prototype of bees' shelter

From the observations of the project team, some solitary bees stayed for some time for a short rest, but they did not regard it as a living place. Students noticed that they just considered the length and width of the hotel, but they neglected its depth. Because of the insufficient depth of the bee hotel, solitary bees did not stay long. Therefore, they are currently investigating to build a modified version based on the prototype to make the hotel more suitable for bees to live in.

Language played an essential role throughout the whole project. The teacher-researcher bridged students' schemata of their mother language to target academic vocabulary. Next, the teacher-researcher constructed knowledge jointly with students by exchanging students' daily English language to target academic vocabulary. After that, the teacher-researcher co-constructed knowledge with students from multimodalities to target academic vocabulary. While the teacher-researcher gradually removed language scaffolds, students were asked to write more and more, from point-form posters to paragraph-length presentation scripts. The teacher-researcher did the final stage of the study to give oral and written feedback only, without much language support. This gradual release of learners' responsibility, suggested by Elliot, Frey and Fisher (2019), ran smoothly throughout the programme. Overall, students were engaged in every teaching and learning activity. The teacher-researchers observed that they were particularly interested in making the bee hotel, especially drilling the holes with the calculated diameter. Moreover, they were highly concerned about the number of bee visitors coming to the bee hotel; especially one student was asking the teacher-researcher how we can seduce more bees to come', hoping that they could stay longer to save them from extinction. These shows not only the high engagement of participants but also their increasing environmental awareness.

Discussions

Compatibility of STEM, STSE and CLIL

This study showed that the STEM, STSE and CLIL approach not only existed but also integrated fully in this programme. From the teacher's observations and students' works, Participants learnt the features of bees and how their adaptive features help them survive. Also, how the advancement of technology adversely affects society and the environment was thoroughly discussed. Moreover, there is a smooth transition from STSE to STEM when the teacher-researcher asked participants to work on a prototype to conserve bees. They improved their information literacy in an internet search for scientific facts for providing a comfortable living place for bees. Furthermore, they designed and created a bee hotel prototype as an eco-house for bees with careful mathematical manipulations. Besides, this study showed that students could produce relevant subject-specific vocabulary, general academic vocabulary in the poster presentation and signalling words to link their ideas in oral presentation text. Other than that, participants showed high cognitive ability in analysing, creating and evaluating the bee hotel by applying the scientific, technological, engineering and mathematical concepts they learnt. Most importantly, students were more and more environmentally aware of conserving bees from their responses in the programmes. These responses from the participants show that teacher-researcher successfully co-constructed knowledge based on various teaching and learning objectives, and students appreciated the value of the programme about species conservation. While students were strong at acquiring what they should learn, they were generally weak in how they should. In other words, they lacked the skills to accomplish teaching and learning tasks. For example, they had limited knowledge to extract information from data, and they tended to work independently instead of working most of the time collaboratively. Such practices hindered the teaching and learning effectiveness of the programme and their further studies. Consequently, in the next run, more skill-based activities should be introduced before concept teaching and learning.

Limitations

The sampling size (n=5) of the participants was not significant, which may affect the generalizability of the results. Moreover, the programme was run only once, which may affect the trustworthiness of the results. Nevertheless, the teacher's observation and students' work were highly triangulated, showing that the results were trustworthy and highly credible.

Conclusions and Implications

In this study, the STSE, STEM and CLIL approaches were successfully implemented in an environmental education programme, leading to high teaching and learning effectiveness in scientific, technological, engineering, mathematical, social, environmental, linguistic, cognitive and cultural components was high. Moreover, students achieved all teaching and learning objectives in cognitive and affective domains. However, more emphasis and support about learning skills should be introduced to students to further increase the teaching and learning effectiveness of the programme and participants. In the next run, it is hoped that the sampling size can be more significant to increase the reproducibility and trustworthiness of the programme.

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3. Use of Online Formative Assessment Tools to Facilitate Self-directed and Collaborative Learning of Students

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Abstract

This paper aims to provide an account of how Secondary Three students utilize online formative assessment tools (goformative, peardeck and parlayideas) to enhance their learning of Biology. During the home-based learning, the teachers would not be able to meet the students face-to-face to ask questions directly. It is difficult to have spontaneous discussions with the students. The online formative assessment tool such as goformative (goformative.com), allows students to participate online in the answering of questions simultaneously. The students can get immediate feedback from the teachers and clarify their doubts with the teacher. In the traditional classroom, the teacher only calls on some students to answer questions. With the help of goformative, it would ensure equal participation of every student and provides an alternative platform for the participation of students who are less likely to speak up in class and be more active during online platforms. Pear Deck (peardeck.com), is an interactive presentation and lesson delivery tool which can enhance the learning of students. Teachers can create different question types, including drawing, dragging, text, number, and multiple choice. After that, teachers can view students' responses to these questions immediately and share the results anonymously on-screen for all students to see. Parlayideas (parlayideas.com) helps to facilitate discussion of learning content among the students. Students can comment on one another’s comments and learn collaboratively with one another. It is greatly suitable for remote learning and allows teachers to provide a supportive environment for students who may be reluctant to speak up in class, or communicate better in writing than speaking out loud. Lastly, collaborative learning continues to take place even outside curriculum hours, at an online platform. By conducting surveys and analysing the survey results from the students, it is hoped that students will find learning of Biology effective through the use of online formative assessment tools.

Background of study

The integration of technology in the classrooms is beneficial for effective teaching, especially in the 21st century. As there is a need to shift to home-based learning due to unforeseen circumstances and to ensure that students still continue to learn effectively online, online learning can be further enhanced via the use of suitable technology.

Popham (2011, p. 270) defined formative assessment as ‘a planned process in which assessment-elicited evidence of students’ status is used by teacher to adjust their ongoing instructional procedure or by students to adjust their current learning tactics”. Formative assessment provides students with just in time feedback that improve their performance.

There are a number of technologies that allow the teachers to use formative assessment during the instructional process. These technologies include goformative, Pear Deck and Parlayideas. The advantage of using these technologies is that the teachers are able to collect real-time formative assessment data that allows teachers to provide feedback for the students. Beatty and Gerace (2009) reported that “Teachers have limited time to assess students’ performances and provide feedback, but new advances in technology can help solve this problem” (p. 142).

In normal curriculum lessons, teachers have been devising different ways of using online formative assessment tools to enhance the students’ learning of content. The students are able to learn anywhere and anytime in addition to the normal curriculum time. It is hoped that the different modes of formative assessment tools used are able to facilitate the self-directed and collaborative learning of the students.

Statement of the Problem

Remote learning has garnered a significant amount of attention in the last several months due to the global COVID-19 pandemic. Educators needed to find a way to continue to teach but from a distance as home-based learning is implemented. There are some available tools to support student learning, engagement and achievement. (Denise & Tina, 2021)

During the home-based learning, the teachers would not be able to meet the students face-to-face to ask questions directly. It is difficult to have spontaneous discussions with the students. To address this problem, online formative assessment tools are used to allow students to participate online in the answering of questions simultaneously. The students can get immediate feedback from the teachers and clarify their doubts with the teacher.

In the traditional classroom, the teacher only calls on some students to answer questions. Hence, not all students would have the chance to speak up and answer the questions. Most of the time, the same student would always be the one answering all the questions. To address this problem, online formative assessment tools are used to ensure equal participation of every student and provides an alternative platform for the participation of students who are less likely to speak up in class and be more active during online platforms.

Parlayideas (parlayideas.com) helps to facilitate discussion of learning content among the students. Students can comment on one another's comments and learn collaboratively with one another. It is greatly suitable for remote learning and allows teachers to provide a supportive environment for students who may be reluctant to speak up in class, or communicate better in writing than out loud. Lastly, collaborative learning continues to take place even outside curriculum hours, at an online platform.

Purpose of the Study

This study is targeted at investigating the effectiveness of online formative assessment tools on the learning of Biology in Secondary Three students. It posits that through the use of various online formative assessment tools, it engages students in the learning of content and concepts. And with the use of these formative assessment tools, it leads to better understanding of the learning content for the students.

Research Question

The following research question will guide this study.

- How effective are online formative assessment tools in enhancing the learning of Biology in Secondary Three students?

Brief Literature Review

Formative assessment is the major area of interest within classrooms that "provides teachers and students with continuous, real time information that informs and supports instruction" (Ramsey & Duffy, 2016). Ramsey and Duffy (2016) identified two major advantages: a) supporting individualized learning, and b) opening up time in lecture courses for interactive sessions.

Black and William define formative assessment practice that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited (2009, p. 9).

Different research studies have highlighted the fundamental strategies of effective formative assessment practices such as:

(1) Learning intentions and criteria for success should be clarified and shared with students and be focused on students' process of learning and progress toward goals.
(2) Use a range of divergent assessment techniques, together with realistic, challenging problems and tasks that elicit evidence of student learning and understanding (Swan, 2005).
(3) Timely feedback, focused on the task at hand instead of marks, should be provided in order to monitor learners' progressive development, helping them become more aware of where they are going, where their learning currently is and what they can do to move forward (Looney, 2010).
(4) Teachers should engineer effective classroom discussions, fostering a classroom culture that encourages active involvement of students in the learning process (Looney, 2010).
(5) Self-assessment and peer-assessment should be encouraged to activate students as both instructional resources for one another and owners of their own learning (Swan, 2005)

Formative assessment has several aspects that become the main principles. According to Suratno (2007) and Assessment Reform Group (2002), the aspects are as follows: a) Formative assessment is part of an effective learning; b) Formative assessment focuses on how students learn and it is the basis of the learning process as well as the key of teacher professionalism; c) Better to consider the aspects of sensitivity and constructive feedback; d) Formative assessment emphasizes on improving students learning motivation and emphasizes the development of self-assessment; e) Formative assessment is aimed at achieving overall educational attainment.

Feedback is one of a form of assessment for learning. The students can use it to know how far their level of understanding and it also can guide students to achieve teaching and learning objectives. Feedback will encourage the students to improve the learning motivation and corrects errors that have been made or decreases negative things that become weaknesses in their learning. For the teacher, feedback can provide information of the strong and weak of the process the students have done, or which part of the process that can be improved to obtain better results (Zainul, 2008).

As timely feedback is given to the students, they are able to track their own learning progress. Hence, with the help of online formative assessment tools such as goformative and Pear Deck, they are able to facilitate self-directed learning of the students. According to Knowles (1975), SDL (self-directed learning) assumes that (a) the human being grows in capacity and need to be self-directing as an essential component of maturing and that this capacity should be nurtured to develop as rapidly as possible. (b) learning experiences should be organized as task accomplishment or problem solving learning projects and learners are motivated by internal incentives, such as the need for self-esteem, the desire to achieve, the urge to grow, the satisfaction of accomplishment, the need to know something specific and curiosity.

While Knowles' (1975) assumptions of SDL explore the definition of SDL and related conceptions (informal learning, self-management learning, self-monitoring and motivation), the research presented here focuses on self-directed learning (SDL), in which learners have the fundamental responsibility for their own educational experiences.

Parlayideas is a discussion forum platform which helps to facilitate discussion of learning content among the students. According to Kearsley (2000), the most significant applications of computer-mediated communication in online learning environments are discussion forums. Discussion forums provide a way for students to extend the classroom discussions. It provides better cognitive and exploratory learning, increased student-to-student discussion and cooperation, superior learner empowerment and upgraded critical thinking skills.

Method

In this study, one Secondary Three class is used. The students are using online formative assessment tools such as goformative and Pear Deck to answer questions posed by the teacher. They are also given the opportunity to use Parlayideas as a platform to discuss learning content with one another. Students can comment on one another's comments and learn collaboratively with one another. After the lessons, surveys will be conducted to find out the learning progress of the students.

Materials

Pear Deck, an interactive ICT tool is incorporated into the lessons. Questions such as "Explain why the upper epidermis has fewer stomata compared to lower epidermis." and "Did you find this lesson interesting and challenging?" are asked during the lesson. It is able to flip the traditional lecture by actively engaging students in real-time and incorporate formative assessment into google slides.

There are different types of questions such as multiple choice questions and free response questions that can be incorporated. At the end of the lesson, the teacher is able to view the student responses and provide feedback to the students instantly.

Another ICT tool, goformative is used to pose questions to the students. An experimental set-up was shown to the students and they were asked about the rationale of the different procedures used in the experiment. Different types of questions such as multiple choice questions and free response questions can also be incorporated. The students can also show their responses by drawing certain diagrams, for example, drawings in chemical bonding. Other possible ways of using goformative are doing a quick online poll to gauge how the students did or starting a discussion to encourage more confident students to push their understanding further. The students can be engaged in a reflection activity to help students articulate their own learning goals and to help motivate them to find the answers.

Parlayideas is used as a platform for discussion forum to facilitate collaborative learning of the students. An inquiry-based scenario is presented to the students and students are given the opportunity to conduct a discussion about the given topic. After that, the students would look at their peers' answers and respond by either agreeing or disagreeing with the answers. There are instructions and guiding questions for the students to build on, question and challenge their classmates' submissions after joining the discussion.

Survey Analysis

A survey was conducted on the Secondary Three students. These are the survey questions: (a) Does online formative assessment motivate you to learn Biology? (b) What was it like for you? (c) I have gained a deeper understanding of the topic on plant nutrition – agree or disagree?

Figure 1

Survey results for question 1: Does online formative assessment motivate you to learn Biology?

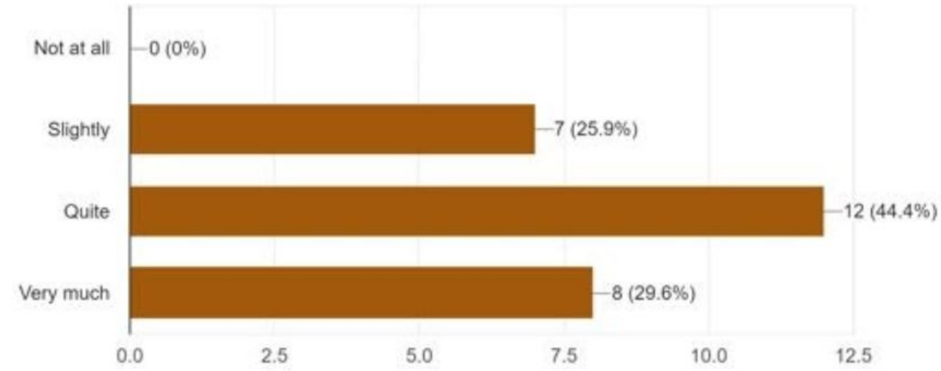


Figure 2

Survey results for question 2: What was it like for you?

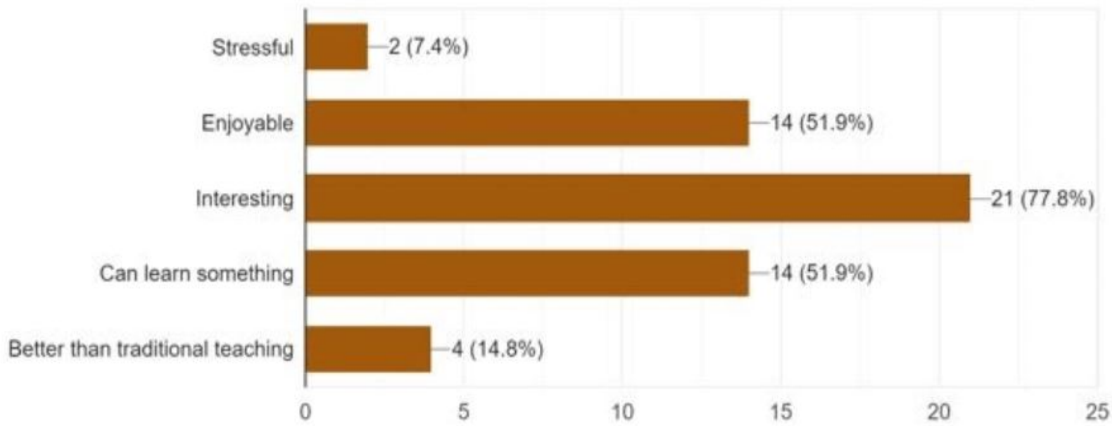


Figure 3

Survey results for question 3: I have gained a deeper understanding of the topic on plant nutrition – agree or disagree?

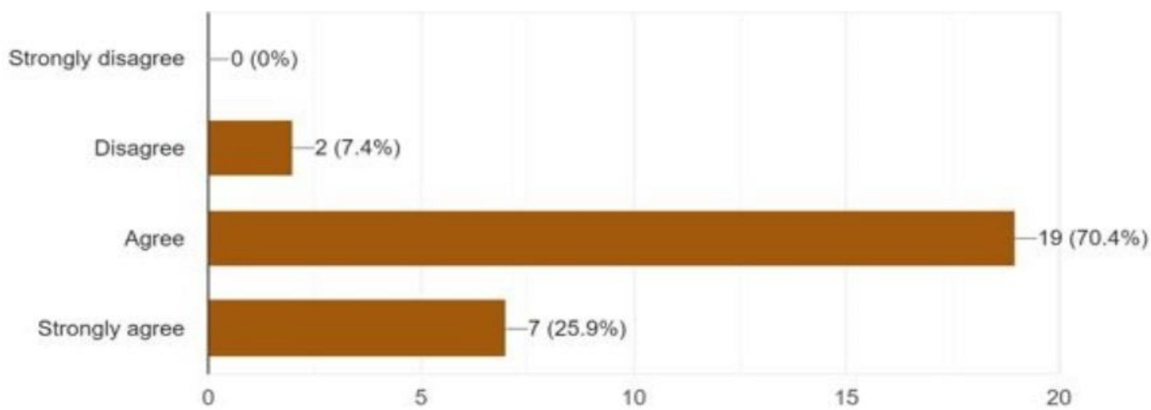
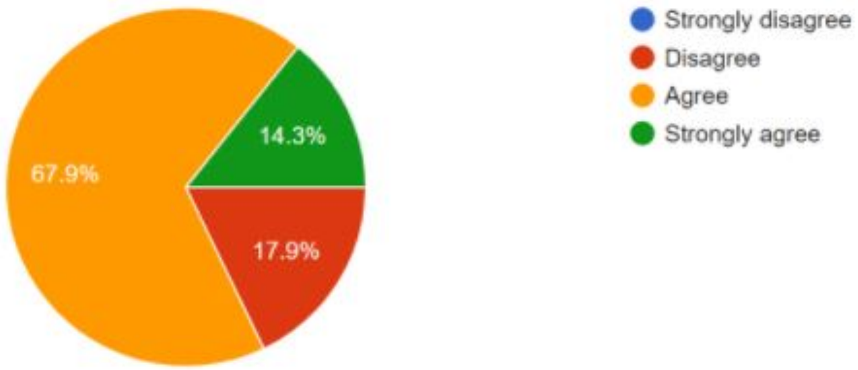


Figure 4

Survey results for question 4: I learned more because I understood the content better through online formative assessment.



Discussion

Based on the survey results, 54% of the students feel that online formative assessment tools motivate them to learn Biology. 82.2% of the students felt that they learned more because they understood the content better through online formative assessment.

Tools such as Pear Deck and goformative were crucial to engaging students in a remote learning environment. It was critical to be able to assess student understanding of the concepts and the texts in the moment. (Denise & Tina, 2021).

Goformative is a site that can be used in a class or school. This site was designed to give many assignments for students. Then, the teacher can give feedback and score to students in a short time. Goformative has several advantages, such as having many features, the assessment can be done periodically without requiring long time, paper-less, and can support communication between teacher and student everywhere and everytime. (Himmatul, 2018)

A pilot study from Avans University in the Netherlands, found that giving students an opportunity to take the lead in making decisions and choices helped to raise grades, increase attendance and enhance overall engagement. When students are given the opportunity to take an active part in class they learn to take initiative, making them more involved in their own learning. Discussions are especially interactive and are a space where students teach one another through collective knowledge that is shared.

Class discussions are useful activities that can make learning interesting and engaging. It is important to get all students involved in a class discussion so that everyone can engage with the material and their peers, share different perspectives, build on each other's ideas and have a deep and meaningful discussion that illuminates the subject.

Questions are the heart of discussion. Great questions will challenge the students and spark collaborative thought-provoking class conversations that lead students to communicate with their peers. Great questions can involve 21st century skills such as communication, critical thinking, collaboration, creativity and problem solving.

Conclusion

Based on the survey of the study, it provides an account of how Secondary Three students utilize online formative assessment tools in their learning of Biology and how they learn individually from goformative and Pear Deck and collaboratively from Parlayideas discussion forum. These online formative assessment tools have helped to enhance the learning of Biology for the Secondary Three students.

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4. Exploring Variation Theory in the Teaching of Physics as Professional Development in Pedagogy

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Abstract

This article reports on the process of incorporating Variation Theory in a learning study cycle for the teaching of physics to aid professional development of teachers in the department. The article will highlight some of the challenges faced by teachers during the lesson. The class consists of forty Secondary Two (Grade 8) students. Observers' feedback were collected from the lesson and an improved lesson was crafted to be carried out in future to address the challenges faced by the teachers. Observers and teachers' feedback gathered through the learning study indicated that the Variation Theory provided a better pedagogical approach towards crafting and delivering the relevant lessons. It allowed teachers to target specific misconceptions held by students and address them appropriately.

Introduction

Professional Learning Communities (PLC) has shown to be effective in raising the effectiveness of the teachers through structured collaboration (Parry 2007). During a PLC meeting, it was proposed to use Variation Theory and the learning study cycle in the teaching of thermal physics. Through literature reviews, Variation Theory was agreed to be highly suitable for identifying misconceptions and coming up with appropriate strategies to address these misconceptions amongst students.

Learning study is a collaborative teacher development tool that focus on the structure of students' learning outcomes. It consists of three elements; collaboration between teachers to plan, teach and review lessons; plan and review lessons on learning outcomes guided by Variation Theory; and using the review process to progress towards deeper understanding of teaching and learning. (Peter & Richard, 2008). Variation Theory is thus used as a framework to guide, analyze and evaluate the teaching pedagogy during a learning study (Po Yuk Ko 2014).

Variation Theory states that for learning to occur, variation must be experienced by learners. When there is variation, there will be discernment. When there is discernment, there will be learning (Kullberg, Runesson Kempe and Marton, 2017). According to Variation Theory, there is a limited number of aspects of a phenomenon that any learner can focus on at any point of time. Learners' understanding of the phenomenon will depend on the aspect that each individual focused on and thus different individuals will form different understanding of the phenomena (Orgill 2012). In order for learners to come to a shared understanding of a concept, they must first be guided towards focusing on certain critical aspects of that concept being taught (Bussey, Orgill and Crippen, 2013).

Thermodynamics is one topic that students face difficulty understanding due to their strongly held prior misconceptions (Erickson, 1980). In our experience, our students often have difficulty differentiating the scientific meaning of heat and temperature and thus formed misconceptions about the transfer of thermal energy at the later stage of the topic. The team decided to explore Variation Theory for this topic as a possible teaching pedagogy to draw out any prior misconceptions that the students may have and address them accordingly whilst teaching.

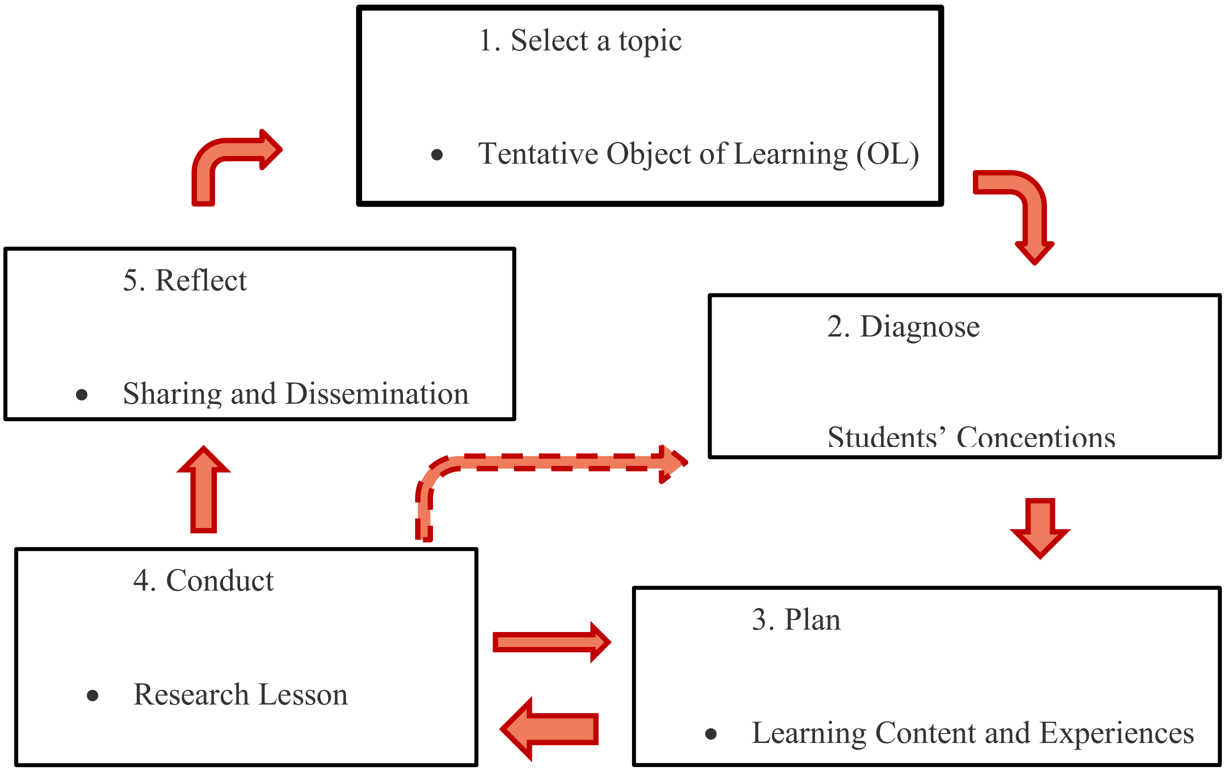
When planning a lesson using Variation Theory, we need to first identify the object of learning. In this case we selected the concept that 'thermal energy transfers from a region of higher temperature to a region of lower temperature'. Following that, we will need to consider the possible critical aspects that the topic involves and select one of the critical aspects to be varied. The team administered a probe quiz to identify the possible misconceptions held by the students. The results showed that many of the students have the misconception that pure ice will always be at 0 ºC and pure ice cannot be cooled further below 0 ºC. Hence, some students concluded that no thermal energy transfer will take place with a colder surrounding when ice is at 0 ºC. With this finding, the team decided to vary the temperatures of different materials in a class demonstration that is to be shown. This is to allow students to focus on one critical aspect to be varied i.e. thermal energy transfers from a region of higher temperature to a region of lower temperature.

Methodology

The team followed the learning study cycle shown in Figure 1 as a guide for the project.

Figure 1

Learning study cycle



The first step of the learning study (LS) process is to select the object of learning (OL) and the critical aspects (CAs) to be varied, in accordance to Variation Theory. Based on literature reviews and teachers' personal experiences, it is noted that most students have numerous misconceptions for the topic of Transfer of Thermal Energy. The team thus decided to base this learning study on the Transfer of Thermal Energy. The OL is chosen to be "Thermal energy flow from a region of higher temperature to a region of lower temperature until the two regions have the same temperature". The CAs that will be focused on through class demonstrations are:

- Temperature is a measure of degree of hotness.
    1. Any object can be a source of heat if it is of a higher temperature than the other object.

2. Two objects in contact will finally reach thermal equilibrium.

Based on the CAs, a diagnostic probe quiz (**Appendix A**) was crafted to identify and confirm the possible misconceptions that the team had listed earlier before the probe quiz. After analyzing the probe quiz, it was observed most students were able to describe the changes to the temperature of a hotter object and colder object when in contact correctly. However, they were unable to explain the scientific concepts behind this. Some of students had a fixated idea that the temperature of ice is always at 0 ^{o}C and it does not get any lower even if the surrounding temperature is below 0 ^{o}C. They are not able to identify that ice can actually be a source of heat to another object of lower temperature. Most of the students also do not realise that the temperatures of the objects will eventually reach the same temperature when they are in contact with each other (Thermal equilibrium). These findings indicate that the team's identified OL and CAs are suitable for these group of students.

Planning and conducting of the research lesson one (RL1)

The Pattern of Variation Table was constructed (**Appendix B**) to guide the design of the learning activities for Research Lesson 1 (RL1). A pattern of variation table serves as a strong guide towards crafting the lesson plan as it clearly lists out the different variants. This allows the teacher to plan appropriate class demonstrations to be shown to the students for them to focus on and discern the desired CAs. For example, to illustrate the CA that "Temperature is a measure of the degree of hotness in a region", different objects made with different materials, states of matter, mass, size, colour, texture and surface area were prepared. These different properties are collectively known as the variants. During the teacher's class demonstration, the temperature of the objects will be kept constant at room temperature. When shown to the class, the students will be able to discern that while the types of object are different (variation), the temperatures of these objects remain the same and teacher will lead them to the conclusion; different objects have the same temperature because they have the same degree of hotness as the objects have the same temperature with the surroundings.

RL1 was executed to a Secondary Two (Grade 8), class of 40 students according to the lesson plan (**Appendix C**). Before the lesson, a pre-lesson probe quiz (**Appendix D**) was administered to glean knowledge of the students' prior knowledge of the topic. There were four teacher observers for the lesson using a designed observation form (**Appendix E**).

Observations and review on RL1

Learning study and Variation Theory provided clear, systematic and logical steps in designing a lesson which focused in overcoming students' misconceptions. The diagnostic probe quiz ensured that the misconceptions were correctly identified during the planning of the RL1. Using the pattern of variation tool, it enabled us to design suitable learning activities to lead students towards discerning the targeted CAs. While the lesson was largely successful in achieving the desired learning outcomes, there were some significant limitations and various room for improvement observed during the study. The team used authentic context in the form of teacher's live demonstrations with suitable variations to help the students discern the CAs. However, the live demonstrations was not as engaging as expected due to changes in temperatures occurring too slowly in the ambient surrounding temperature. This caused the students to lose interest and focus in the demonstrations. In RL1, the team used both Nearpod (online learning platform) to elicit responses from the students and a digital temperature sensor in the classroom to illustrate real-time temperature changes. When the teacher started toggling between the display for Nearpod and digital temperature sensor, the process resulted in lag and down time due to network issues and hardware lag time. These issues affected the smooth running of the lesson which contributed to the students being further disengaged. Upon review, the team felt that a recorded video of the live demo could be used to speed up the demonstration and allow students to focus only on the key parts. An alternative online learning platform, the Student Learning Space (SLS), could be used to capture students' inputs and to engage them in Thinking Routines such as STW (See-Think-Wonder), POE (Predict-Observe-Explain), IRF (Initiation-Response-Feedback) for generation of discussion among students. Another advantage of the SLS platform is that it allows videos of the demonstrations to be embedded in the platform. This minimises the time needed for students to toggle between multiple platforms during lesson. With the SLS platform, the lesson could also be further enhanced into self-directed and collaborative learning.

Planning of research lesson 2 (RL2), a refinement of RL1

Taking into account the limitations observed, a plan for RL2 was drafted. The main changes of the lesson activities were changed from teacher's live demonstrations in RL1 to pre-recorded video in RL2. The students will logon their SLS to access the lesson package. From there, the lesson is largely self-directed. The teacher is thus freed up to facilitate students' queries and misconceptions. A copy of the pattern of variation for RL2 is in **Appendix F** and the lesson plan is attached in **Appendix G**. Unfortunately, due to the COVID-19 situation where school closure occurred, RL2 could not be carried out for the same cohort of students in the same year. The team then decided to use the opportunity to scale up the professional development for teachers who were not within the PLC team in 2020. RL2 was planned to be carried out with the next cohort of students involving science teachers who will teach this topic in 2021.

Conclusion

Learning study with the use of Variation Theory is useful in the pedagogical design of lesson learning to the professional development of teachers. It was also shown that the use of the diagnostic probe does help teachers to confirm the object of learning, critical aspects and the misconceptions for the students. As the students have to be shown many variations for them to discern the critical aspects, significant time was invested in setting up and carrying out live demonstrations which is a constrain in a typical one-hour lesson time. As such, the use of technology tools such as pre-recorded videos are used to speed up the intended demonstrations and shorten the time needed to show the variations to the students. The time saved could be used by the teachers to engage students in thinking routines, conduct assessment of learning or further classroom discussions. By harnessing technology and learning platforms, teachers can better engage the students while ensuring the same intended effect of applying Variation Theory in the teaching of physics.

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Appendix

Appendix A

Diagnostic probe quiz

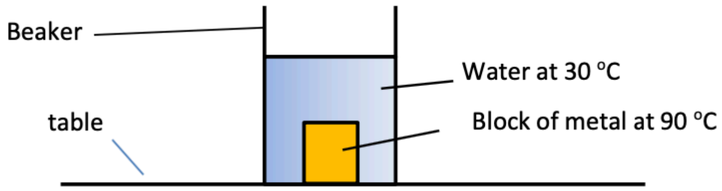
LEARNING STUDY
YUAN CHING SECONDARY SCHOOL
TOPIC: TRANSFER OF THERMAL ENERGY

Name:………………………..…………..…… (   ) Class:….. Date:…………………

Duration: 15 to 20 minutes

Answer the following questions. You may use diagrams to help explain your answers.

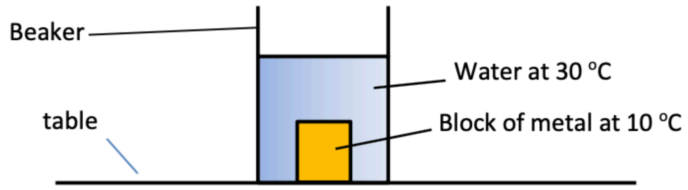
1. A beaker of water has been placed on a table for 2 hours. The temperature of the water in the beaker is 30 °C. A block of metal with temperature about 90 °C is immersed in the beaker of water as shown in the diagram below.



Describe what will happen to the temperature of the metal block and water (i) after 2 minutes and (ii) after 2 hours. Explain your reasoning.

(i) <u>After 2 minutes</u>
(ii) <u>After 2 hours</u>
<u>My reasoning</u>

2. A beaker of water has been placed on a table for 2 hours. The temperature of the water in the beaker is 30 °C. A block of metal with temperature about 10 °C is immersed in the beaker of water as shown in the diagram below.



Describe what will happen to the temperature of the metal block and water (i) after 2 minutes and (ii) after 2 hours. Explain your reasoning.

(i) After 2 minutes

(ii) After 2 hours

My reasoning

3. An ice cube at temperature 0 °C is placed inside a freezer of temperature at – 10 °C. The door is then closed.

Describe what will happen to the temperature of the ice cube (i) after 2 minutes and (ii) after 2 hours. Explain your reasoning.

(i) After 2 minutes

(ii) After 2 hours

My reasoning

Below is the additional question that was added after administering the quiz to the earlier class.

4. A metal cube at temperature 0 °C is placed inside a freezer of temperature – 10 °C. The door is then closed.

Describe what will happen to the temperature of the metal cube (i) after 2 minutes and (ii) after 2 hours. Explain your reasoning.

(i) <u>After 2 minutes</u>

(ii) <u>After 2 hours</u>

<u>My reasoning</u>

Appendix B

Pattern of variation table for RL1

Critical aspects	Invariant	Variant	Discernment	Learning Activity
1. Temperature is a measure of the degree of hotness in a region.	Temperature	**1.** Material **2.** States of matter **3.** Mass **4.** Size **5.** Colour **6.** Texture **7.** Surface area	At room temperature, they all have the same temperature regardless of the variants.	1. Show that the temperature sensor is working by measuring the temperature of human body and hot water. The readings is shown on the screen. 2. Students predict the temperature of the surrounding air, water and several objects. 3. Measure and observe their temperatures. 4. Students discuss & explain why the temperatures are the same.
2. Any region can be a source of heat if it is of higher temperature than the surrounding.	Region of higher temperature and a region of lower temperature	1. Starting temperature of the heat source. 2. States of matter 3. Material 4. Mass	Heat always flow from higher temperature to lower temperature regardless of the variants.	1. Place a beaker of hot water in a beaker of tap water. 2. Students predict what will happen to their temperature. 3. Measure & observe their temperatures. 4. Students discuss & explain their observation. 5. Repeat with iced water and tap water. 6. Student wonder can the iced water be a source of heat. Students to discuss and explain using nearpod.

3. Two objects in contact will finally reach thermal equilibrium.	Region of higher temperature and a region of lower temperature.	1. Starting temperature of the heat source. 2. States of matter 3. Material 4. Mass	The hotter object's temperature will drop and the cooler object's temperature will increase until they are both the same.	Same as above

Appendix C

Lesson plan for research lesson 1

Name of Teacher:	MR CHIN CHII TARNG		**Date of Lesson (Day):**	30 MAR 2020, MON	
Subject:	PHYSICS		**Topic:**	TRANSFER OF THERMAL ENERGY	
Class:	2E3	**Venue:**	CLASSROOM	**Time:**	1155 TO 1305

Lesson Objectives:

1) Temperature is a measure of degree of hotness
2) Thermal energy flow from a region (or object) of higher temperature to a region (or object) of lower temperature until the two regions (objects) have the same temperature. They have reached thermal equilibrium.

[Key points:
1. Degree of hotness is independent of material. (Just show demo to verify) (show video enough. Possible to use SLS and cut down the video, about 5 min)
2. Thermal energy flow from hotter to colder region until thermal equilibrium. (Show demo and explain, still use Pasco temp sensor, 10 min)
3. Any object can be a source of heat as long as it is of higher temperature than the other object. (Show demo to verify, use sls to drag and drop answer and for discussion, can also control the pace. For discussion use pair work, 30 min), search for video or suitable demo)]

Classroom Instructions	Learning Activity	Duration
Introduction Hook	1. Administer pre-lesson quiz. 2. Settle the class down with instruction and give out worksheet for lesson. 3. Place 5 objects in front of the students. a. Metal ball	5 min 5 min 5 min

	b. Wooden ball c. Small beaker of water d. Big beaker of water e. Book Ask students which of these objects is colder? (expect some students to say water or metal ball) 4. Use PASCO wireless temperature sensor to measure the temperature of human body or cold water or hot water to show the students that the sensor is working. The readings can be shown on the screen using SPARK app. 5. Use the sensor to measure the temperature of air, and the 4 objects differing in states of matter (air, water, and solid), mass, size, colour and texture. Conclude that they are all at the same temperature. **Temperature is a measure of degree of hotness.** It does not depend on the material, mass,…] 6. Let's see why they are at the same temperature. 7. Place a beaker of hot water in a beaker of tap water. Measure their temperature simultaneously using the sensors and project the readings on the screen. Ask students to describe and explain what is observe. [At this time, draw the schematic diagram on the board] [Students should be able to say temperature of hot water decrease and temperature of tap water increase. Expect them to struggle with the explanation. One or two may be able to say energy.] 8. Explain that thermal energy flow from hotter to colder region until thermal equilibrium using a diagram on the board. Emphasize that the hot water is the source of heat. After some time both reach same temperature. Explain the difference between temperature and thermal energy by comparing the energy of the particles of a beaker of water and a	5 min 5 min 10 min 5 min 5 min 5 min 10 min 5 min 5 min

	basin of water of the same temperature. Average energy of each particle in beaker and basin is the same. Thus, temperature is the same. Total energy of all the particles in beaker is lesser than in basin. 9. Ask students can the **tap** water be a source of heat. What can it be a source of heat for? 10. Place a beaker of cold water in the tap water. Measure their temperature simultaneously using the sensors and project the readings on the screen. Ask students to describe and explain what is observe in the worksheet provided. a. Temperature of tap water ________________. b. Temperature of cold water ___________________. c. ______________ transfer energy to _____________. d. _______________ is the heat source. 11. Ask students can the **cold** water be a source of heat. What can it be a source of heat for? How about metal ball at 0ºC? 12. Pair discussion using Nearpod as a platform to input their responses. Ask the students: a. Can the cold water now be a source of heat to metal ball at 0ºC? i. Temperature of cold water _________________. ii. Temperature of metal ball ___________________. iii. ______________ transfer energy to _____________. iv. _______________ is the heat source. b. Can metal ball at 0ºC be a source of heat to a freezer at - 4 ºC? i. Temperature of metal ball _________________. ii. Temperature of freezer	70 min (1h 10 min)	

	____________________. iii. ______________ transfer energy to _____________. iv. _______________ is the heat source. c. Can ice cube at $0^{o}C$ be a source of heat to a freezer at - 4 ^{o}C? i. Temperature of ice cube _________________. ii. Temperature of freezer ____________________. iii. ______________ transfer energy to _____________. iv. _______________ is the heat source. 13. Refer back to point 9 which is still on the screen. It should be near to room temperature now. Student is then asked to link why the temperature increases after they are already at thermal equilibrium [room temperature] 14. Refer back to point 5. Therefore, all objects if left long enough in the same room will have the same temperature. 15. Summaries the lesson by asking students to complete the sentences. a) Temperature is a ………………………………………… b) Heat is a flow of th……………… e………………… from ……………… to ………………………. region. c) Heat will stop flowing when the temperature of the objects are the ………………………. The objects have reached ……………………….. 16. Administer post-lesson quiz using the same pre-lesson quiz. Estimated total duration.	

Appendix D

Pre and post lesson quiz

PHYSICS LEARNING STUDY **Mark:…………… / 10**
PRE/POST LESSON QUIZ **Duration: 15 minutes**

1. What does temperature measure?

……………………………………………………………………………………………… [1]

2. A packet of hot fried chicken of temperature 80 °C is placed inside a cooler box as shown below. The temperature of the air in the box is 30 °C. The cooler box is then covered.

(a) Describe what will happen to the

(i) temperature of the hot chicken,

…………………………………………………………………………………… [1]

(ii) temperature of the air in the cooler box,

…………………………………………………………………………………… [1]

(iii) temperature of both chicken and air in the cooler box after a long duration of time.

…………………………………………………………………………… [1]

(b) Explain your answer in terms of thermal energy.

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

3. A tray of ice cubes as shown below of temperature 0 °C is placed outside in the open air during very cold winter. The temperature of the surrounding air is minus 10 °C.

Ice cubes
(0 °C)

Surrounding air
(- 10 °C)

(a) Describe what will happen to the temperature of the ice cubes after a long duration of time.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

(b) Explain your answer in terms of thermal energy.

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Appendix E

Observers observation form

Lesson Observation & Feedback Form

Class:	2E1	**Teacher:**	Chin CT		**Date:**	/ 3/20
Subject:	Lower Secondary Science	**Sub-Topic:**	Transfer of Thermal Energy		**Time:**	9.00 am to 10.00 am

Enactment	**Observation & Feedback**	
	Strength	Area for growth / Suggestion
Lesson Introduction	- Using of Nearpod allow teacher to solicit feedback from students as lesson proceeds. - Good questioning to introduce the topic as well as to identify any misconceptions by the student.	- Students take some time to logon to the Nearpod platform.
Lesson Presentation	- Students are drawn towards the demonstrations. - Students eager to discuss the demonstrations with their peers is meaningfully engaged.	- Some issues with the connection between the wireless thermometer meant that not all students remain engaged. Students started to get bored while waiting. - Demonstrations takes a long time to show temperature changes. Some students lost attention and seems to be disengaged. - Significant lag time between toggling of slides and showing of temperature changes meant

		that students start to disengage from the class.
Lesson Conclusion	- Teacher sums up the class effectively through effective questioning. - Students have demonstrated that they are able to capture the big ideas in the lesson.	- Lesson extended beyond the allocated period.. - Could have parked discussions on the board to use during conclusion.

Appendix F

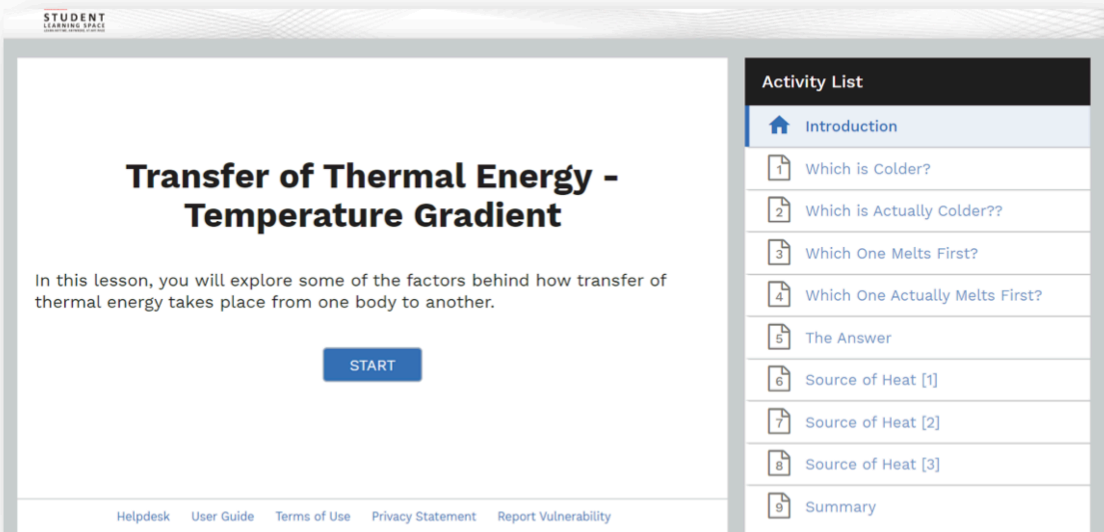
Patterns of variation table for research lesson 2

Pattern of variation

Critical aspects	Invariant	Variant	Discernment	Learning Activity
Temperature is a measure of the degree of hotness.	Temperature	1. Material 2. States of matter 3. Mass 4. Size 5. Colour 6. Texture 7. Surface area	At room temperature, they all have the same temperature regardless of the variants.	**1. Show YouTube video (Misconceptions About Temperature) https://www.youtube.com/watch?v=vqDbMEdLiCs&t=1s** **2. Use SLS as a platform for students to answer questions. (Use STW, POE)**
Any object can be a source of heat if it is of higher temperature than the other object.	Region of higher temperature and a region of lower temperature.	1. Starting temperature of the heat source. 2. States of matter 3. Material 4. Mass	Heat always flow from higher temperature to lower temperature regardless of the variants.	**1. Show video 1 (A beaker of hot water is immersed in a beaker of tap water and their temperature monitored using the temperature sensors connected to the laptop which shows the changing temperature in a graph form.) Students answer question on SLS. (Use STW)** **2. Show video 2 (A beaker of tap water is immersed in a beaker of ice water and their**
Two objects in contact will finally reach thermal equilibrium.	Region of higher temperature and a region of lower temperature.	1. Starting temperature of the heat source. 2. States of matter 3. Material 4. Mass	The hotter object's temperature will drop and the cooler object's temperature will increase until they are both	

			the same.	**temperature monitored using the temperature sensors connected to the laptop which shows the changing temperature in a graph form.)** **Students answer question on SLS. (Use STW)** **3. Show video 3** **(A beaker of ice water is immersed in a bucket of acetone (-19°C) and their temperature monitored using the temperature sensors connected to the laptop which shows the changing temperature in a graph form.)** **Students answer question on SLS. (Use STW)**

Screenshot below is the introduction page of the SLS lesson package of the RL2.



Appendix G

Lesson plan for RL 2

Name of Teacher:			**Date of Lesson (Day):**	
Subject:	PHYSICS		**Topic:**	TRANSFER OF THERMAL ENERGY
Class:	Secondary 2 Express	**Venue:** CLASSROOM	**Time:**	1h 10 min

Lesson Objectives:

1. Temperature is a measure of degree of hotness
2. Thermal energy flow from a region (or object) of higher temperature to a region (or object) of lower temperature until the two regions (objects) have the same temperature. They have reached thermal equilibrium.

Object of Learning:

Thermal energy flow from a region of higher temperature to a region of lower temperature until the two regions have the same temperature.

Critical aspects:

1. Temperature is a measure of degree of hotness and is independent of material.
2. Thermal energy flow from hotter to colder region until thermal equilibrium.
3. Any object can be a source of heat as long as it is of higher temperature than the other object.

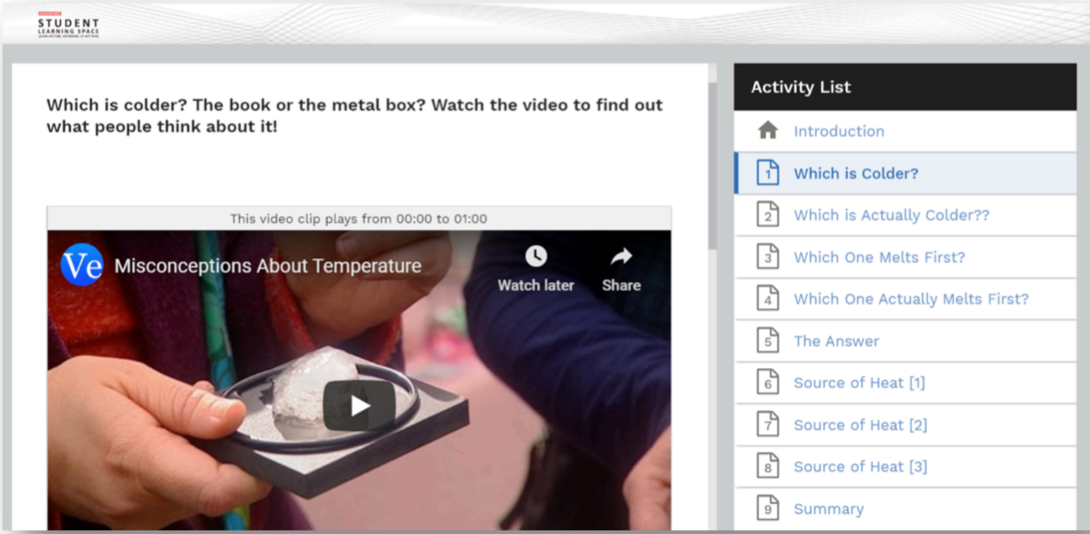
Overall consideration:

2. We used the **Five Es** (Engage, Explore, Explain, Elaborate & Evaluate) approach and the principle of **Variation Theory** in the general planning of the lesson.
3. We used the SLS as the main platform to deliver the lesson in the classroom.
4. We use the various "Thinking Routine" tools to build up the students' knowledge of the topic such as STW, POE, IRF (Initiation-Response-Feedback), …

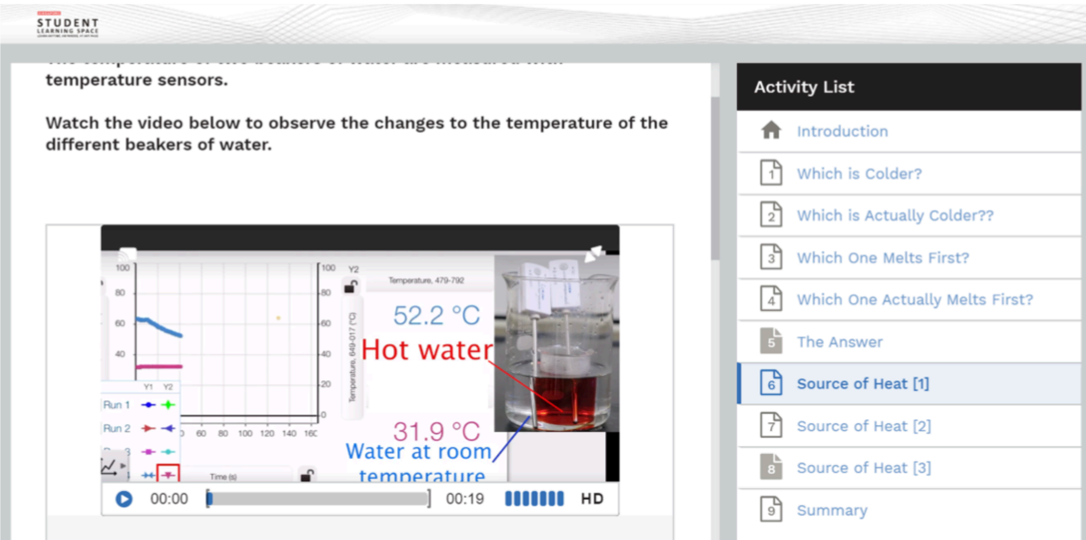
S/N	**Learning Activity**	**Duration**
1	**Conduct pre-lesson quiz.**	5 min
2	**Rate of heat flow to or from our body affects our sense of touch.** **Variation: Different materials, temperature of materials.** a.Show YouTube video (Misconceptions About Temperature 3_59)	10 min Engage

	https://www.youtube.com/watch?v=vqDbMEdLiCs&t=1s b. Students answer questions on SLS. [Use STW, POE] 1. Predict the outcome of measuring the temperature of a **book** and a **metal** box using IR thermometer. [pause video at 1:00] 2. Observe the outcome. [pause at 1:24] 3. Explain the outcome. 4. Predict the outcome of putting **ice** on plastic block and on metal block. [pause at 2:15] 5. Observe the outcome. [pause at 2:40] 6. Explain. 7. Listen to the correct explanation. [play video to the end] 8. Students try to re-explain their previous explanations. c. Note: all the above to be done on SLS platform in auto pilot mode. Student has control on the pace of the lesson.	
3a	**Source of heat flow.** **Variation: Different temperature of heat source.** a. **Show video 1** (A beaker of hot water is immersed in a beaker of tap water and their temperature monitored using the temperature sensors connected to the laptop which shows the changing temperature in a graph form.) b. Students answer question on SLS. (Use STW) 1. Describe what is observe. [1. Temperature of **hot water** decrease, temperature of **tap water** increase. 2. They reach thermal equilibrium. 3. After a long period of time, they will reach same temperature as the room temperature] 2. Explain this observation. [Hot water is the source of heat]	10 min Explore & Explain
3b	a. **Show video 2** (A beaker of **tap water** is immersed in a beaker of **ice water** and their temperature monitored using the temperature sensors connected to the laptop which shows the changing temperature in a graph form.) b. Students answer question on SLS. (Use STW) 1. Describe what is observe. [1. Temperature of **tap water** decrease, temperature of **ice water** increase. 2. They reach thermal equilibrium. 3. After a long period of time, they will reach same temperature as the room temperature] 2. Explain this observation.	10 min Elaborate

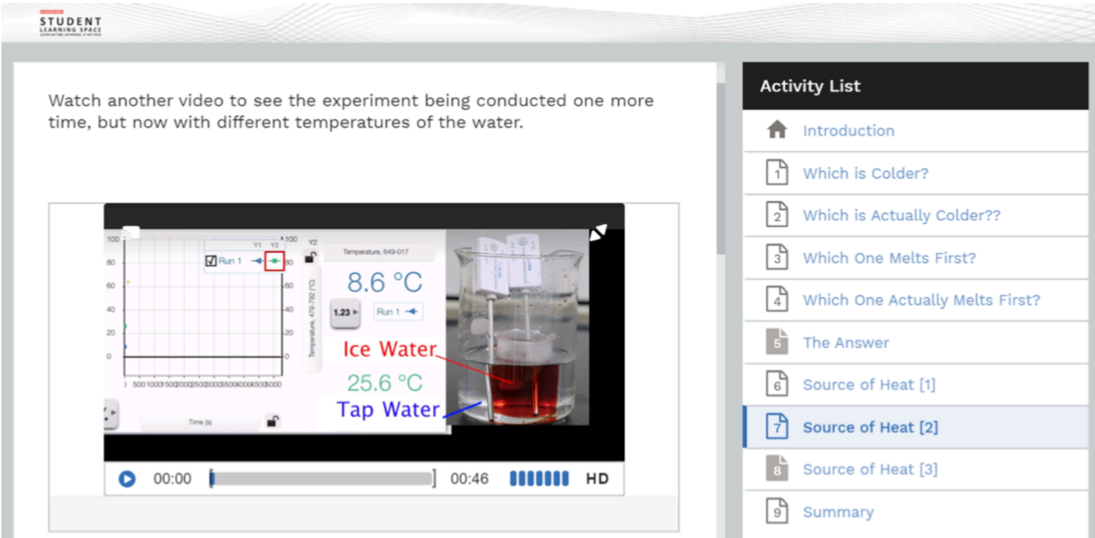
	[**Tap water** is now the heat source]	
3c	a. **Show video 3** (A beaker of **ice water** is immersed in a bucket of **acetone** (-19°C) and their temperature monitored using the temperature sensors connected to the laptop which shows the changing temperature in a graph form.) b. Students answer question on SLS. (Use STW) 1. Describe what is observe. [1. Temperature of **ice water** decrease, temperature of **acetone** increase. 2. They reach thermal equilibrium. 3. After a long period of time, they will reach same temperature as the room temperature] 2. Explain this observation. [**Ice water** is now the heat source]	10 min
4	a. Teacher leads the class discussion on their responses to all the observations using the IFR (Initiate-Feedback-Response) questioning technic. b. Teacher sums up the discussion as follow. 1. Heat always flow from higher temperature object to lower temperature object. 2. Heat stops flowing when the temperature of both objects is the same. They have reached thermal equilibrium.	10 min Explain
5	a. Students answer questions to evaluate their understanding on SLS. 1. Complete the sentences. a. Heat always flow from …………………………………………… b. Heat stops flowing when …………………………………………. 2. Describe and explain what will happen to their temperature when a metal ball at 0°C is placed in a freezer at - 4 °C. 3. Describe and explain what will happen to their temperature when an ice cube at 0°C is placed in a freezer at - 4 °C. 4. Write one thing you are still puzzle.	10 min Evaluate
6	**Conduct post-lesson quiz.**	5 min
	Total duration	70 min



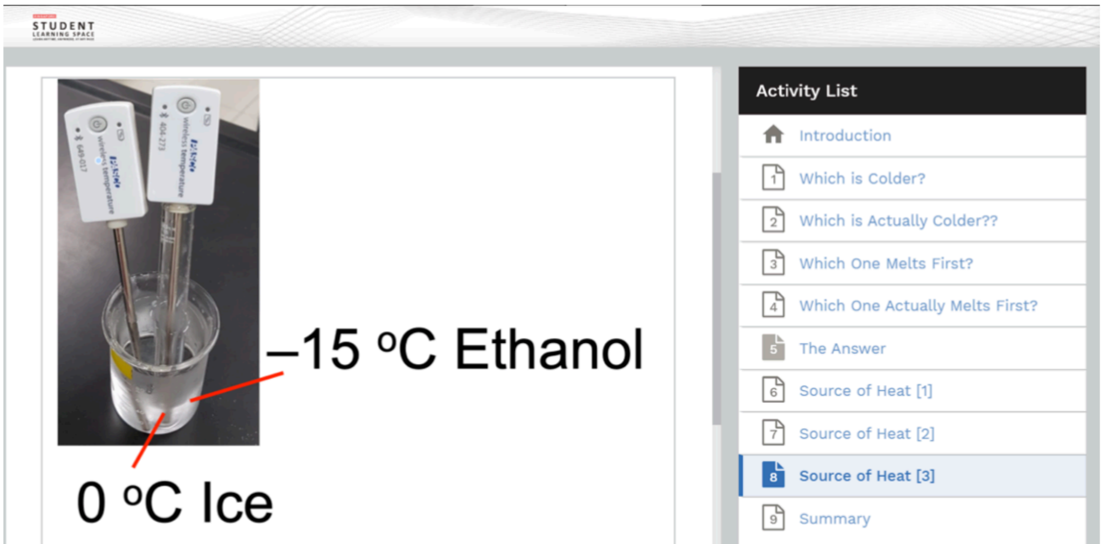
Discernment: at room temperature, all objects have the same temperature regardless of the material



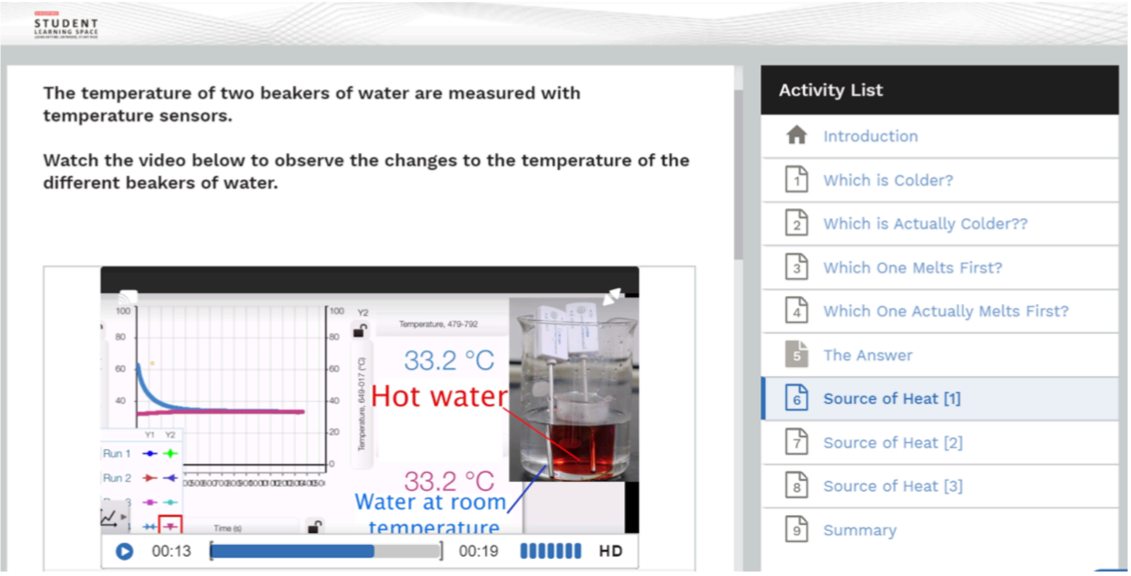
Discernment: thermal energy flows from higher temperature to lower temperature regardless of starting temperature of bodies



Discernment: thermal energy flows from higher temperature to lower temperature regardless of starting temperature of bodies



Discernment: thermal energy flows from higher temperature to lower temperature regardless of starting temperature of bodies



Discernment: temperature will arrive at "equilibrium" regardless of starting temperature

5. STEM Integration: Multi-, Inter- or Trans-disciplinary?

A Review of the Literature and Proposed Framework for Integration

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Abstract

STEM refers to science, technology, engineering, and technology. In recent years, several journals in STEM education have emerged and the number of STEM education articles have proliferated within a short period. However, the STEM education academic fraternity remains divided in deciding what constitutes "STEM". It is unclear how many of the four disciplines should be integrated and how they should be integrated. Given the diversity of the field, it is not surprising that teachers, who are interested in STEM curriculum-making, are confused about how they should go about designing and teaching integrated STEM lessons, and how they can go about developing competencies to teach STEM in integrated ways. Understanding how to develop an integrated STEM curriculum could help teachers design lessons that equip students with the knowledge necessary for problem-solving, and to meet the demands of the fourth industrial revolution.

In this paper, we analyse the STEM curriculum described in empirical papers published in seven STEM education journals to offer an overview of the state of STEM curriculum integration reported in the literature. The review unveiled three common themes that are related to the affordances of the STEM curriculum in the following areas: (1) increasing or maintaining students' interest and motivation to participate in STEM activities, (2) enhanced pedagogical approaches that also improves STEM subject scores, and (3) honing problem-solving and research skills and knowledge. Therefore, teachers who are designing STEM curriculum can use the following reviewed studies to draw information, ideas, and inspirations on how to achieve the specific goals or intent of the STEM curriculum. By referring to the three themes, teachers can draw their inspiration from the papers in the respective categories to meet their specific purposes.

Keywords: STEM integration, STEM curriculum, student interest and motivation, pedagogical approaches, problem-solving skills

Introduction

Many of the real-world problems that we face today are complex and require individuals working in teams to collaborate in the problem-solving process. Science, technology, engineering, and mathematics (STEM) education plays an important role in this aspect as students need to be afforded opportunities that allow them to apply multifaceted techniques and knowledge in solving authentic STEM-related problems.

In addition, there is strong socio-political advocacy for more people to be trained in STEM to meet the demands of the fourth industrial revolution (Chang, 2018). This implies the important role of schools in preparing future STEM professionals. However, most teachers are not trained in STEM teaching because most of them, have received mono-disciplinary education in mathematics, chemistry, physics, biology, and so on.

The underlying challenge, however, lies in the "proper" integration of the STEM disciplines such that the learning experience is substantially integrated. In addition, the STEM curriculum design must be relevant and allow students to develop 21st Century competencies (Nadelson & Seifert, 2017). It is thus important to support teachers in STEM curriculum design.

The current STEM articles in the literature that review STEM papers focused on the following themes: (1) the current outlook of STEM research, (2) the trend of STEM education, (3) policy in STEM education, (4) effective STEM pedagogies and how they affect student achievements, (5) the teacher's role in STEM education, their self-efficacy and competency, (6) teacher professional development, (7) Policy in STEM education, (8) cultural and gender issues surrounding STEM, and (9) the history, epistemology and perspectives about STEM and STEM education (Li et al., 2020; Margot & Kettler, 2019; McDonald, 2016). In this paper, we scan the existing STEM education literature to find out the status of STEM curriculum integration in the literature and classified them into various categories. With this information, teachers who are designing STEM curriculum can use the following reviewed studies to draw information, ideas, and inspirations on how to achieve the specific goals or intent of the STEM curriculum.

In this paper, we explored empirical STEM papers from the perspective of a teacher practitioner. We wanted to study the curriculum through multiple lenses to see what can be extracted to help teachers design integrated STEM curricula.

Methods

We conducted a literature search on papers published in seven STEM education journals. The total number of papers downloaded, and the period or year of publication are listed in Table 1 below.[1]

Table 1. Literature search in STEM-focused journals.

Journal	Period of Publication	Total number of publications
Journal For STEM Education Research	2018-2020	32
International Journal of STEM Education Research	2018-2020	159
Journal of STEM Teacher Education	2018-2020	11
Frontiers in Education: STEM Education	2018-2020	41
Journal of STEM Education: Innovations and Research	2018-2020	61
Journal of Research in STEM Education	2018-2020	30
Southeast Asian Journal of STEM Education	2020	5

[1] As of the time of writing, there are currently nine STEM education journals, two of which do not have papers published in them yet.

A total of 339 papers were downloaded. We selected papers that reported on empirical studies about a STEM curriculum. For example, the studies could be about the design, development, or enactment of a STEM curriculum for students. Papers that do not describe a STEM curriculum was rejected.

To ensure inter-rater reliability, one author took the first cut in identifying the relevant papers for review. The other author then independently goes through the papers to make sure that no relevant papers were left out. Commentaries, editorials, review articles, short reports, opinion pieces, case stories were not included. In addition, papers that reported STEM activities for teachers, teacher competency and self-efficacies, teacher training, policies in STEM education, trends in the number of research papers, cultural and gender problems surrounding STEM, and the history, epistemology and perspectives about STEM and STEM education were also not considered. Hence, a significant number of papers were not considered. A total of 61 papers were identified in this selection process.

An example of a paper that was not considered for this review is a commentary by Fletcher (2018). The commentary provided brief comments and reflections on Intelligent Tutoring Systems and their use in STEM education (Fletcher, 2018). This paper was not considered because it did not contain any empirical data.

An example of a paper that was considered for this review is a research paper by Miller (2018). The paper reported on a study where the impact of mathematical applications (iPad applications) on the learning of numeracy skills was studied. The research provided empirical data on the math scores of students before and after the intervention (Miller, 2018). Hence, this paper was considered in this review article.

In our review of the 61 papers, we looked at the extent of integration of the various STEM disciplines, the context provided to the students, the approach taken by the teacher, and the knowledge classification of the curriculum design. Again, to ensure inter-rater reliability, the first author reviewed every paper independently. The other author did a sampling of twenty per cent of the papers. Any discrepancy was negotiated until a 100 per cent consensus was reached.

Results and discussion

To discuss the state of STEM curriculum integration in the literature, we reviewed the empirical papers through various lens: (1) extent of integration of the various STEM disciplines, (2) the context provided to the students, (3) the approach taken by the teacher, and (4) the knowledge classification of the curriculum design.

Three distinct features were unveiled in the review of the 61 papers: (1) Curriculum that increases or maintain student interest and motivation to participate in STEM, (2) Improvements in pedagogical approaches to improve STEM subject scores, (3) Curriculum with problem-solving and research as its central theme. To further streamline the outcomes, we classified them into three different strands. The first strand is the improvement of student attitudes, which considers student interest and motivation towards STEM fields and activities. The second strand is the improvement of students' learning. This considers pedagogical designs and problem-solving tasks that aim to improve test scores. Finally, the third strand is the development of process skills, where the main aim of the curriculum is to allow students to develop skills such as critical thinking and creativity. The indexing of the papers into the respective categories is presented in Table 2.

The first distinct purpose of the reviewed STEM curricula is to improve student attitudes towards STEM fields. To foster higher retention rates and increase minority representations in STEM fields, many of the empirical STEM curricula targeted the improvement in attitudes of students towards STEM fields. Science summer camps, workshops and competitions were such examples to improve attitudes.

Table 2. Index of papers based on their outcomes (Improving attitudes, improving students' learning, and developing process skills).

Improving attitudes	Improving students' learning	Developing process skills
1, 3, 4, 16, 17, 21, 23, 25, 26, 28, 31, 32, 33, 35, 36, 37, 39, 43, 52, 56, 58	6, 8, 9, 13, 14, 15, 18, 19, 20, 22, 24, 27, 29, 34, 38, 40, 42, 45, 46, 47, 48, 49, 50, 53, 54, 57, 59, 60, 61	2, 5, 7, 10, 11, 12, 30, 41, 44, 51, 55

Yan et al. (2019) reported on a summer camp for African American high school students that aimed to foster their interest in engineering technology. In that study, they found that the summer camp was beneficial in altering the attitudes of the students. (Yan et al., 2019).

The second distinct purpose is to improve student learning. Pedagogical improvements and incorporation of different approaches and contexts aimed at improving the learner's experience and improve their test scores. Bridging programs, and utilisation of technology to teach scientific and mathematical concepts were such examples to help students achieve better test scores.

Ng et al. (2020) reported on two classroom-based technology-enhanced teaching interventions for inquiry-based learning of the relations among the number of vertices, edges, and faces of prisms and pyramids. One study involved the use of 3D printing pens while the other a dynamic geometry environment. The study aimed to find out which of the methods was more effective at enhancing student learning (Ng et al., 2020).

The third distinct purpose is to develop process skills. Some examples of process skills include observing, classifying, making inferences, predicting, interpreting data, making hypotheses, experimenting, creativity and critical thinking skills (Turiman et al., 2012).

However, while developing process skills apply to most of the empirical studies, only a handful of empirical studies focused on developing process skills as its main purpose.

Koch et al. (2018) reported on a curriculum where first-year college STEM majors took modules to enhance their process skills for STEM. An example of a course is *Introduction to Learning and Thinking in Science and Math*, which aimed to integrate literacy building concepts with a curriculum that enhances quantitative reasoning skills (Koch et al., 2018).

Hence, when designing a STEM curriculum, it is important to think about the intended outcome of the STEM curriculum. With the pre-determined intention and outcome of the curriculum, it should be easier to pick out the extent of integration, the tools, and the context for the curriculum.

The extent of integration of the various STEM disciplines

One approach to classify the papers is into 4 categories: monodisciplinary, multidisciplinary, interdisciplinary or transdisciplinary. A monodisciplinary curriculum refers to a discipline-based curriculum approach where the teaching practice is within one subject and encourages specialisation and depth of content knowledge. A multidisciplinary curriculum refers to one where the same topic is studied from the viewpoint of more than one discipline. An interdisciplinary curriculum is one where the connections between ideas and themes between the different disciplines are emphasized. Finally, a transdisciplinary curriculum dissolves the boundaries between conventional disciplines and centres the learning around real-world problems or themes (J. M. Chen & Luetz, 2020; English, 2016).

However, the classification of papers into mono-, multi-, inter-, and transdisciplinary is highly complex. This is so as the level of integration lies on a spectrum and hence it is difficult to categorise the curriculum into distinct groups (Klein, 2008). Therefore, we looked at the number of STEM disciplines that are incorporated into the curriculum of interest as one measure of the extent of integration of STEM disciplines. It was found that 24 per cent of the papers adopted the mono-disciplinary STEM approach.

In terms of the inter-disciplinary papers, 33 per cent had two disciplines, 23 per cent had three disciplines and 20 per cent had four disciplines integrated into their curriculum. The types of integration of the various disciplines came in different forms for different purposes. Two main purposes were identified – (1) teaching STEM content, and (2) problem-solving. The indexing of the papers into the respective categories (number of STEM disciplines integrated) is presented in Table 3.

Table 3. Index of papers based on the number of STEM disciplines integrated.

1 discipline	2 disciplines	3 disciplines	4 disciplines
1, 2, 9, 15, 16, 21, 22, 24, 27, 36, 42, 43, 44, 47, 50	5, 6, 7, 8, 10, 12, 13, 18, 19, 20, 25, 31, 40, 45, 46, 51, 53, 58, 60, 61	3, 4, 26, 29, 30, 32, 34, 37, 39, 49, 55, 56, 57, 59	11, 14, 17, 23, 28, 33, 35, 38, 41, 48, 52, 54

In the first category "teaching STEM content", two main forms were identified – (1) The utilisation of one discipline as a tool to teach another discipline, and (2) the teaching of content with more than one discipline. The remaining papers spanned from workshops to camps which contained curricula that encouraged students to take up STEM disciplines. Two examples were illustrated below.

Razonable (2020) reported on a curriculum that leveraged technology to teach Grade 10 chemistry concepts. It was found that using Chemistry and Physics Education Technology Project (PhET) computer simulations helped the students achieve an improvement in their test scores (Razonable, 2020). This is an example of how one discipline can be utilised as a tool as a medium to teach another discipline.

Talafian et al. (2019) reported on a STEM summer camp for middle school students which offered three different space-themed STEM tracks: astroengineering, astrophysics, and astrobiology. The content was taught through project-based pedagogies with collaborative, hands-on experiences (Talafian et al., 2019). This is an example of how two or more disciplines can be taught together within a curriculum.

The second category "problem-solving" consisted of research projects, problem-based learning curricula, inquiry-based learning curricula, and tasks that required the students to use one or more STEM disciplines to tackle problems. Problems, in this context, were defined either as research (which in its nature required answering research questions); or as contextualised problems presented to the students (where they devised solutions to the problems). Some problems centred around a core discipline, while some did not have a clear distinction as to which was its core discipline. The approach taken by the teachers will be discussed in a later section. Two examples were illustrated below.

Tan-wilson et al. (2020) reported on a year-long undergraduate research program where life science majors were paired with majors from the other STEM disciplines to work on interdisciplinary life science projects. Some projects involved the creation of new procedures, software, devices, while some required computational analysis of large datasets relating to questions of the life sciences. (Tan-wilson et al., 2020) This is an example of a problem centred around one core discipline.

Musavi et al. (2018) reported on a University of Maine Stormwater Management and Research Team (SMART) program, where students are trained in using science and engineering skills and technology to research water quality in their local watershed. Across the year, students collected stormwater data and connected with a diversity of STEM professionals. The students also presented their research publicly and engaged in outreach to schools and their local community (Musavi et al., 2018). This is an example of research that did not have any clear core discipline.

Hence, when designing a STEM curriculum involving the teaching of content, thinking about the number of disciplines involved and the type of integration used is crucial. On the other hand, when designing STEM problems or research, the integration across topics, regardless of whether there is a core discipline, must be made clear.

The context provided to the students

The STEM curricula can also be classified based on their context. The context of the task can be classified into two main categories: open and close. A task with an open context refers to one where divergent thinking was required, often in the form of an ill-defined task. On the other hand, a close context refers to one where convergent thinking was required, often in the form of a well-defined task. Divergent thinking is defined as the generation and application of many different ideas to solve a given problem, while convergent thinking is defined as the mental process of deriving the best or correct solution from available information(Sak & Maker, 2005).

It was found that 61 per cent of the papers had tasks that had open contexts, while 39 per cent of the papers had close contexts. The indexing of the papers into the respective categories (open or close context) is presented in Table 4.

It was observed that most of the tasks that were used to improve the attitudes of students towards STEM were of open contexts. By allowing the students to take ownership of the problem and generate solutions, it improved the attitudes of the students. In most of the papers, there was also a trickle-down effect where the improvement in attitudes led to an improvement in test scores.

Table 4. Index of papers based on their context (open and close).

Open context	Close context
1, 16, 21, 36, 43, 44, 47, 50, 8, 18, 20, 25, 46, 51, 53, 58, 61, 3, 4, 26, 29, 30, 34, 37, 39, 55, 56, 11, 17, 23, 28, 35, 38, 41, 48, 52, 54	2, 9, 15, 22, 24, 27, 42, 5, 6, 7, 10, 12, 13, 19, 31, 40, 45, 60, 32, 49, 57, 59, 14, 33

Furthermore, many close contexts were used when there was a specific learning outcome that the students had to derive from the lesson (such as the learning of specific STEM content). Hence, this suggests that the choice of context (open or close) depends mainly on the desired outcome of the task. Two examples were illustrated below.

Chen and Lo (2019) reported on a secondary school project which utilised the *Makey Makey* invention kit. The invention kit transforms any material that can conduct electricity into a physical interface for any software. Students were given the space to brainstorm ideas to design musical instruments using the kit (C. W. J. Chen & Lo, 2019). This example of allowing students to engage in divergent thinking is one where the context is open.

Chevalier et al. (2020) reported on an Educational Robotics curriculum that targeted the development of students' computational thinking skills. In one example, students utilised Thymio, an educational robot, to engage in a robot lawnmower mission where the robot had to pass over areas on a board without collision with a fence surrounding the board. Students were given a clear set of objectives to work towards (Chevalier et al., 2020). This is an example of a curriculum with close context.

Therefore, the choice of context (open or close) should be made after deciding on the outcome of the STEM curriculum as the efficacies depend on the desired outcome.

The approach taken by the teacher

The approach taken by the teacher refers to the choice of pedagogical tools implemented in the curricula. Single approach refers to one single straightforward pedagogy (e.g. note-taking and learning through a mobile application), while multi-faceted approaches include inquiry-based learning, problem-based learning and research where students have to approach a problem from multiple perspectives. Two examples were illustrated below.

It was found that 34 per cent of the papers had a single approach, while 66 per cent of the papers took on a multi-faceted approach. The indexing of the papers into the respective categories (single or multi-faceted approach) is presented in Table 5.

Table 5. Index of papers based on approach (single and multi-faceted).

Single approach	Multiple approaches
1, 2, 16, 21, 27, 36, 43, 44, 47, 50, 8, 10, 13, 19, 31, 4, 30, 34, 56, 59, 52	9, 15, 22, 24, 42, 5, 6, 7, 12, 18, 20, 25, 40, 45, 46, 51, 53, 58, 60, 61, 3, 26, 29, 32, 37, 39, 49, 55, 57, 11, 14, 17, 23, 28, 33, 35, 38, 41, 48, 54

Lichti and Roth (2018) reported on a study where students used Geogebra as a tool to learn mathematical concepts (Lichti & Roth, 2018). GeoGebra is an interactive geometry, algebra, statistics and calculus application, intended for learning and teaching mathematics and science (Majerek, 2014). This is an example of a curriculum where only a single approach was taken.

Ryu et al. (2020) reported on the Idaho drone league (iDrone) workshops where students worked in groups to design, program, build and fly drones. The students also interacted with local professionals who utilise drones in their work and were introduced to drone research applications. The students also got the chance to share and explore creative ideas for future drone applications and technologies (Ryu et al., 2020). This is an example of a curriculum where multiple approaches are taken.

It was also observed that single approaches were mainly used for classes where the task had a close context. As we consider the common features of the papers, the contexts of the tasks, and the approaches taken by the teachers, a few observations can be made – (1) when the outcome is to improve the attitudes of students, an open context with a multifaceted approach is commonly used; (2) when the outcome is to improve students' learning of the content, a close context with single approaches is generally preferred; and (3) when the outcome is to develop process skills, an open context with a multifaceted approach is often used.

Therefore, it is crucial to consider the pedagogical tools that are at our disposal when designing the STEM curriculum. For example, for lessons with a clear learning outcome of certain content, it might be more effective to use a single approach. Whereas for lessons with open contexts, a multifaceted approach might be more effective.

Knowledge classification of the curriculum design

Knowledge classification refers to the three knowledge domains for the 21st-century student. The three knowledge domains are foundational, meta and humanistic (Kereluik et al., 2013). Foundational knowledge refers to the facts that are taught to students. Examples include digital or ICT literacy, core content knowledge and cross-disciplinary knowledge. Meta knowledge refers to process skills where it allows the students to apply their knowledge. Examples include creativity and innovation, problem-solving and critical thinking, and communication and collaboration. Humanistic knowledge engages social skills, feelings, intellect, artistic skills, practical skills, and more as part of a student's education. Examples include life skills, ethical and emotional awareness, and cultural competence (Kereluik et al., 2013).

It is found that 77 per cent of the papers incorporated foundational knowledge, 77 per cent utilised the meta knowledge, while 41 per cent used humanistic knowledge. In addition, 25 per cent of the papers incorporated all three types of knowledge. A point to note is that many of the curricula that did not incorporate humanistic knowledge were those where the outcome was to improve student's learning of the content. The indexing of the papers into the respective knowledge types (foundational, meta and humanistic) is presented in Table 6.

Table 6. Index of papers based on the type of knowledge (foundational, meta and humanistic).

Foundational	Meta	Humanistic
9, 15, 16, 21, 24, 27, 36, 43, 44, 47, 50, 5, 6, 7, 8, 10, 12, 13, 19, 20, 31, 40, 45, 51, 53, 58, 60, 61, 30, 32, 34, 37, 49, 55, 56, 57, 59, 11, 28, 38, 41, 48, 52, 54	1, 2, 9, 15, 16, 22, 24, 42, 44, 47, 50, 5, 6, 8, 10, 12, 20, 25, 40, 45, 46, 51, 60, 61, 3, 4, 26, 29, 32, 37, 39, 49, 55, 56, 57, 11, 14, 17, 23, 33, 35, 41, 48, 54	1, 2, 15, 42, 6, 8, 10, 12, 18, 20, 25, 40, 45, 60, 61, 3, 32, 37, 39, 56, 11, 28, 33, 35, 54

Cançado, Reisel and Walker (2018) reported on a mathematics bridging program for incoming freshmen for an engineering program. The mathematics bridging program was done through ALEKS, a web-based assessment and teaching system that uses adaptive questioning to gauge the depth of a student’s understanding of a subject, and then designs the student’s lessons to address areas in which the student may lack understanding (Cançado, Luciana; Reisel, John R.; Walker, 2018). This is an example of a curriculum that uses foundational knowledge.

Sanchez and Usinger (2019) reported on a six-week program based on the Carnegie Mellon curriculum using VEX Robots™, where students were tasked to build and operate claw bots (Sanchez & Usinger, 2019). This is an example of a curriculum that uses meta knowledge.

Century et al. (2020) reported on a study where the students learned computer science content through with the other STEM disciplines as a context. For example, in one of the 4th-grade modules titled *Invasive Species*, students had to generate solutions to the problem of invasive species in the local ecosystem. Through the module, students learnt biology concepts and computer science simultaneously and engaged their problem-solving skills (Century et al., 2020). This is an example of a curriculum that uses both foundational and meta knowledge.

Sharma et al. (2019) reported on a course-based undergraduate research experience (CURE) where students learned about the research process and applied skills of scientific computing to study climate change and its impacts. The students learned more about the topic of climate change and worked together in groups for this research project. Through the experience, students also learned climate change policies (Sharma et al., 2019). This is an example of a curriculum that integrates all three forms of knowledge.

Therefore, it is important to decide on the knowledge domains within the STEM curriculum design. A good mix of foundational, meta and humanistic knowledge can be used when students learn and apply new content while seeing the relevance of what they are learning in the real-world context.

Additional Notes

It was worthwhile to note that the empirical papers were representative of curricula for all age groups, as there was a good spread of papers covering all age groups. This meant that the curriculum design can be effective for students of all different age groups. Thus, it is important to acknowledge that STEM skills can be honed and taught at different stages of a student's schooling years, albeit at different levels of complexity.

Furthermore, the length of the various STEM curriculum is varied. There were STEM curricula that span across a year, while some were short-term (e.g., a summer camp). Most studies that showed a significant improvement in test scores and attitudes towards STEM had programs that were of a longer period. Therefore, while designing a STEM curriculum, the time taken to achieve a specific goal must be considered.

Conclusion

In the process of reviewing the empirical papers, we realised that the curriculum planned by teachers had three distinct outcomes, either to improve attitudes, improve students' learning or develop process skills. From that, the outcome will determine the choice of context and the approach taken by the teacher. A different mix of the different types of knowledge (foundational, meta and humanistic) can be determined based on the nature of the task and the desired outcome. For example, if the development of 21st-century skills were desired, an open context that required divergent thinking would be well suited for the students to apply the foundational and meta knowledge that they have picked up in class.

The integration of STEM may not require a complete overhaul or radical change. Instead, teachers can use the tools in their existing pedagogical toolbox (problem-based learning, inquiry-based learning, research) to design integrated STEM curricula. However, the need for a clear outcome and deliberate integration of the various STEM disciplines is important. It is also crucial to take into account the time and medium (workshops or integration into the curriculum) required to conduct a STEM program or lesson. The challenge ahead would thus be one where we can effectively design integrated STEM curricula with the tools at our disposal, while at the same time integrating them seamlessly into the mainstream school curriculum.

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Appendix

Paper Indexes and Titles

Index	Title
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1	Using a Multifaceted Robotics-Based Intervention to Increase Student Interest in STEM Subjects and Careers (Hudson et al., 2020)
2	Cultivating Design Thinking of Middle School Girls through an Origami Steam Project (Boakes, 2020)
3	STEM Identity Exploration through an Immersive Learning Environment (Talafian et al., 2019)
4	From Teacher-Designer to Student-Researcher: a Study of Attitude Change Regarding Creativity in STEAM Education by Using *Makey Makey* As a Platform for Human-Centred Design Instrument (C. W. J. Chen & Lo, 2019)
5	How to Foster Functional Thinking in Learning Environments Using Computer-Based Simulations or Real Materials (Lichti & Roth, 2018)
International Journal of STEM Education Research	
6	Exploring Differences in Primary Students' Geometry Learning Outcomes in Two Technology-Enhanced Environments: Dynamic Geometry and 3D Printing (Ng et al., 2020)
7	Fostering Computational Thinking Through Educational Robotics: a Model for Creative Computational Problem Solving (Chevalier et al., 2020)
8	Finding Time for Computer Science in the Elementary School Day: a Quasi-Experimental Study of a Transdisciplinary Problem-Based Learning Approach (Century et al., 2020)

9	The Use and Effectiveness of Colorful, Contextualized, Student-Made Material for Elementary Mathematics Instruction (Kaminski & Sloutsky, 2020)
10	Changes in Students' Mental Models from Computational Modeling of Gene Regulatory Networks (Dauer et al., 2019)
11	Vigilante Innovation (VIX): Case Study on the Development of Student Skills Through a Team-Based Design Process and Environment (Oliver et al., 2019)
12	Developing Numeracy Skills Using Interactive Technology in a Play-Based Learning Environment (Miller, 2018)
13	Incorporating Industrial Design Pedagogy Into a Mechanical Engineering Graphics Course: A Discipline-Based Education Research (DBER) Approach (Newton et al., 2018)
14	Electronixtutor: An Intelligent Tutoring System with Multiple Learning Resources for Electronics (Graesser et al., 2018)
15	Development and Application of a Multi-Modal Task Analysis to Support Intelligent Tutoring of Complex Skills (Skinner et al., 2018)
16	Science in the Learning Gardens (Scilg): a Study of Students' Motivation, Achievement, and Science Identity in Low-Income Middle Schools (Williams et al., 2018)
17	Changing the Face of STEM with Stormwater Research (Musavi et al., 2018)
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18	Becoming a Maker Teacher: Designing Making Curricula that Promotes Pedagogical Change (Becker & Jacobsen, 2020)

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20	STEAM Maker Education: Conceal/Reveal of Personal, Artistic and Computational Dimensions in High School Student Projects (Lindberg et al., 2020)
21	Soil and Water Iron Microbes in North Carolina (SWIMNC) Outreach: Positive Impact of Combining Classroom and Field Experiences to Promote Learning and Shift Attitudes (Andrews et al., 2020)
22	Curriculum Development for Explorative Proving in Lower Secondary School Geometry: Focusing on the Levels of Planning and Constructing a Proof (Miyazaki et al., 2019)
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23	An Undergraduate STEM Interdisciplinary Research Program (Tan-wilson et al., 2020)
24	Changing the Paradigm in Teaching Statics (Boylan-ashraf, 2020)
25	Idaho Drone League (Idrone) to Stimulate STEM Workforce (Ryu et al., 2020)
26	MACES Undergraduate Research Fellowship Program: Integrating Research and Education (Gueorguieva et al., 2020)
27	A Novel Hybrid Approach to the Foundational Digital Systems Curriculum by Including FPGA Technology and Valuable Hands-on Experience (Ochoa et al., 2020)
28	Data Science Outreach Educational Program for High School Students Focused in Agriculture (Sami et al., 2020)

29	Designing an Interdisciplinary Field and Lab Methods Course in Hydrology to Integrate STEM Into Undergraduate Water Curriculum (Iqbal & Clayton, 2020)
30	Engineering Design Innovation through C-K Theory Based Templates (Pidaparti et al., 2020)
31	Building STEM Career Interest through Curriculum Treatments (Bryanne Peterson, 2020)
32	Improving Persistence of STEM Majors at a Liberal Arts College: Evaluation of the Scots Science Scholars Program (Gibson et al., 2019)
33	Learning, Leaders, and STEM Skills: Adaptation of the Supplemental Instruction Model to Improve STEM Education and Build Transferable Skills in Undergraduate Courses and Beyond (Achat-Mendes et al., 2019)
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35	Effects of MSTI Summer Camp Program on Students' Perception on STEM Learning (Yan et al., 2019)
36	Enlightening STEM Engagement During High School – Make it Real Banana Peel (Scott-Parker & Barone-Nugent, 2019)
37	An Evaluation of a Pilot Robotics Program (Sanchez & Usinger, 2019)
38	The Liberal Arts Science Scholars Program: a Multidisciplinary Model for Supporting Science and Mathematics Students through the First Year (Chapman et al., 2019)
39	The STEM Gender Gap: an Evaluation of the Efficacy of Women in Engineering Camps (Schilling & Pinnell, 2019)

40	Impact of OER Materials on Students' Academic Performance in Undergraduate Astronomy Course (Mathew & Kashyap, 2019)
41	An Integrated STEM Introduction to Increase Interdisciplinary Thinking and Research Preparation (Kramer & Walston, 2019)
42	Comparison of Students' Readily Accessible Knowledge of Reaction Kinetics in Lecture- and Context-Based Courses (Jeffery et al., 2019)
43	Undergraduate Research Experience in Cybersecurity for Underrepresented Students and Students with Limited Research Opportunities (Yang et al., 2019)
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47	Utilizing Multivariate Analysis for Assessing Student Learning through Effective College-Industry Partnerships (Burns et al., 2018)
48	Mentorship, Mindset and Learning Strategies: an Integrative Approach to Increasing Underrepresented Minority Student Retention in a STEM Undergraduate Program (Lisberg & Woods, 2018)
49	Impacts of a Summer Bridge Program in Engineering on Student Retention and Graduation (Cançado, Luciana; Reisel, John R.; Walker, 2018)
50	Outcomes of an Academic Scholarship Program at the City University of New York – New York City College of Technology (Jang, 2018)

51	Enhancing Learning Power in First-Year Courses for Students Majoring in STEM Disciplines (Koch et al., 2018)
52	STEM Focused High School and University Partnership: Alternative Solution for Senioritis Issue and Creating Students' STEM Curiosity (Icel & Davis, 2018)
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53	STEAM Programming as a Pathway to Foster Positive Academic Self-Efficacy and Positive Self-Concept (Best et al., 2019)
54	Evaluation Approach: Practice-Focused Middle School Science Modules (Klein, 2008)
55	Focusing on Data: Year 5 Students Making STEM Connections (Fitzallen et al., 2019)
56	"Can We Build the Wind Powered Car Again?" Students' and Teachers' Responses to a New Integrated STEM Curriculum (Anderson et al., 2019)
57	A Summer Stem Outreach Program Run by Graduate Students: Successes, Challenges, and Recommendations for Implementation (Schwab et al., 2018)
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60	Students' Conceptual Change in Chemistry Using Computer Simulation-Based Instruction (Razonable, 2020)

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6. Towards a Reverse Engineering Pedagogy (REP) in Physics Classrooms

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Abstract

Applying physical principles is important for designs of various products with tailored performances. However, one of the long-standing issues of the students' design projects (or school's interdisciplinary projects) is the post-hoc imposition of the knowledge learned in their content subjects. This post-hoc imposition significantly diminishes the authenticity of designs through the lens of first principles provided by science and mathematics, but also reflect the fact that many students could not see the connections between these physical first principles and their design decisions and therefore could apply them in their designs. To overcome this problem, we propose the concept of reverse engineering in physics classrooms. This work describes the framework for our proposed reverse engineering pedagogy (REP), where students embark on a series of activities, where they (i) dissemble the device, (ii) analyse the inner physical principles of the device and its components, (iii) appreciate the design principles involved in such device, (iv) augment their understanding of the physical principles by repeating the process through a virtual dissection, and (v) incorporate the process in their own design projects. We will also discuss how such approach may be implemented in a physics classroom, as well as its significance in contributing to a design-centric learning environment.

Introduction

There has been a significant drive towards multi-disciplinary curriculum in the recent years, with much attention being given to the work in STEM education (National Research Council, 2014). Such a direction is necessitated by the changing workforce climate, which demands the workforce not only have disciplinary expertise, but also a multi-disciplinary outlook. In the face of the Fourth Industrial Revolution, the labour market is expected to face a disruption, with many new job opportunities that do not exist today being created, but at the same time many of the roles will be made obsolete by automation (World Economic Forum, 2020). Indeed, it is under such a backdrop, the traditional mode of disciplinary learning may no longer be sufficient, but instead students must acquire a breadth of knowledge and be able to tackle a complex problem from multiple lens and viewpoints. As a result, there has been a greater desire to incorporate problem-based, project-based, and design-centric learning within the curriculum (Telenko, et al., 2016; Kazerounian & Foley, 2007; Klukken, Parsons, & Columbus, 1997).

A manifestation of such learning is in the form of *designettes* (Wood, et al., 2012) within Singapore University of Technology and Design (SUTD), where students engage in “intense periods of design or planning activity” to tackle a real-world challenge. A prominent feature of such activity is that the instructors of different courses come together to derive a cohesive problem statement and tasks that allow students to incorporate the knowledge that they have learnt in their courses coherently in the designette projects. An example of such project has been demonstrated by Koh et al. (2021) for the year 1 undergraduate curriculum, where the students in their groups are tasked to design a scaled-down chemical launcher to launch a projectile that mimics the food delivery to a city under siege. Students have to make use of a multitude of concepts, such as kinematics and energy in physics, numerical methods and optimization in mathematics, chemical energetics in chemistry, as well as ethics, strategies, and impacts of war in their humanities and social science classes to holistically tackle the problem. Similarly, in the 2nd term of the undergraduate curriculum, students will be exposed to the design thinking as part of a formal course (Budig & Elara, 2021), where students have a greater freedom to identify problems that they would like to tackle under a prescribed general theme and to create prototypes as a potential solution to their identified problem.

Challenges in Cohesive Implementation of STEM Activities

The activities discussed in the previous section could be viewed as examples of practical implementation of integrated STEM education, where the students acquire scientific knowledge, synthesise the scientific and mathematical knowledge into their engineering product design processes, and create technological prototype to solve problems. However, unlike traditional disciplinary learning where there is distinctive learning goals and well-agreed problems to tackle, such integrated STEM activities are diffused (Toulmin, 1972) with problems that are open and need not necessarily have any set solutions. Furthermore, as summarised by Tan et al. (2019), the integrated STEM education faces the problems of (i) the lack of operational knowledge in execution, (ii) disciplinary-based assessment and (iii) infrastructure that still largely supports mono-disciplinary forms of learning. While problem (i) can be gradually overcome, albeit partially, with experience in execution, as in the case of the Koh et al. (2021) and Budig & Elara's (2021) implementation within the university, problems (ii) and (iii) are more structural and would require extremely significant paradigm shift across all education levels, both at pre-tertiary and tertiary levels.

One could further argue that given that the notion of multi-disciplinary education and STEM education are relatively young compared to the deeply entrenched disciplinary education systems and curriculum, such shifts are challenging for the implementers, namely the instructors and administrators, whose pre-conception of education and learning is rooted on their own experiences. The persistent self-feedback loop between institutional and curriculum structure with the stakeholders own pre-conception therefore makes any changes almost immutable.

It is in this backdrop that the multi-disciplinary education, at the current stage, is one that builds upon the foundation of disciplinary-based education. Indeed, Tan et al. (2019) mentioned that "to expect a science or mathematics teacher to carry out a truly integrated STEM curriculum that require in-depth knowledge of engineering and use of technological tools is unrealistic", given the necessity of any stakeholders to hold a wide array of working knowledge and perspective in order to meet the ideal demand of delivering such courses. As such, a more pragmatic approach would be to retain the disciplinary core but for stakeholders to work together in tandem to deliver a cohesive multi-disciplinary curriculum. Again, this requires a deliberate and concerted effort, rather than one that can happen organically without intervention.

Returning to the students' learning, the result of such general climate would be the limited opportunities for students to relate the disciplinary-based theory in class with the real-world context, which are typically highly complex and requires the analysis through multiple domain knowledge viewpoints *concurrently*. Even if there are various physical applications that are discussed, they often stop at the using the theory to provide an explanation on how the applications work. As a result, there appears to be an apparent disjoint between the theories afforded by the sciences and the real-world problems and solutions. When finding solutions to a problem, the ability to incorporate the first-principle physical concepts into their design consideration of the problem becomes limited.

The Idea of Reverse Engineering Pedagogy (REP)

To this end, this article calls an introduction of reverse engineering pedagogy (REP) in the physics classrooms. Reverse engineering has been practised in the industry to understand more about their competitor products through the dissection of the products and has since been explored in the education setting (Dalrymple, Sears, & Evangelou, 2011). Much of the work so far has been investigated within engineering education (Bothe, 2001; Wood, Jensen, Bezdek, & Otto, 2001; Calderon, 2010; Rad, 2012; Barr, Schmidt, Krueger, & Twu, 2013; Ogot & Okudan, 2006; Toh, Miller, & Simpson, 2015; Wiesen, et al., 2018; Bertoni, 2018), though there has also been studies within computer sciences (Aycock, Groeneveldt, Kroepfl, & Copplestone, 2018; Klimek, Keltika, & Jakab, 2011; Asghar & Luxton-Reilly, 2018) and programming classes in high schools (Hodge & Steele, 1995). Much of the existing works focuses on teaching engineering design through reverse engineering, and typically study students' self-efficacy and engagement from participating in such activities. Given the roots of reverse engineering in industry practices, it is of little doubt that such activity would be translated and explored in the engineering education context. From the lens of physics education, there has been limited discourse (Badraslioglu, 2016; Stansell, Tyler-Wood, & Stansell, 2016) on the use of reverse engineering within the curriculum as a hands-on activity.

As such, the REP activities that are discussed below aims to fill the following gaps: (i) a translation of physics concepts and theory into real world application and (ii) building the ability for students to view design through the lens of physics principles. In other words, one would go beyond *understanding* how it works and *apply* the knowledge into their everyday problems. Indeed, this is in line with the 21st century skills proposed by World Economic Forum (2015), where the various foundational literacies provide for affordance in terms of "how students apply core skills to everyday tasks". Through the REP activities, this creates an enabler for students to connect their product development and design processes through the lens of first-principle physics.

In practice, what REP aims to overcome is the post-hoc imposition of physics concepts within the problem-based design projects. In many of such multi-disciplinary assignments, students often tackle the problem from a high-level overview perspective, deriving ideas and solutions based own their own experiences and encounters. To associate the project with disciplinary domain knowledge, the assessment rubrics typically explicitly include components where students must consider incorporating such knowledge. Ironically, the need to assess the use of disciplinary knowledge often result in post-hoc imposition of the disciplinary domain knowledge *after* the problems and solutions to the project have been fully framed by the students. This therefore reduces the authenticity of design processes through the lens of first principles provided by the disciplinary subjects. This further signals at the students' inability to see the connections between the disciplinary subjects and their design process. As such, one could argue that a guided process to view the multi-disciplinary product development and design process via the lens of first-principle disciplinary subjects such as physics would be necessary to build up students' capacity to develop the connections.

DA^{3}D Framework in Guiding REP Activities

To guide the development of the REP activities, a framework which extends from the works of Ogot and Kremer (2006) is proposed. In the original framework, the reverse engineering process consists of 3 steps: dissemble, analyse, and assemble. The first three steps follow the physical steps of tearing down of a device, where the tasks aim to develop the students' manual dexterity and curiosity, and to expose them to functional products and processes in engineering. The proposed DA^{3}D framework therefore extends the current framework by introducing two more steps: augment and design. The last two steps serve as an extension of the in-class DAA activity where they would explore other objects that requires similar physical concepts to function, and then to elaborate on how the renewed understanding can help them in their design process.

More concretely, the key guiding questions within the DA^{3}D framework can be framed as follows:

- *Dissemble*: What are the parts in the object?

1) *Analyze*: What are physical principles for the part to work? How are the parts related?
2) *Assemble*: How does the physical principles enhance or limit the device?
3) *Augment*: What are other objects that uses similar physical principles?
4) *Design*: What kind of insight can this relate to your own prototype/project?

What is noteworthy is that in the step 4, the students are expected to perform the tasks outside of classes as part of their self-directed exploration. In practice, such an activity can be performed in the form of a virtual dissection, where students find existing dissection videos that are available online and follow through the dissection and analysis process. The step has been deliberately designed to be an off-class activity to reinforce the experiences that they have learnt in class, and to be able to see the connection between the use of physics in product design in other contexts. Step 5 could be investigated through the students' engagement in their design projects or multi-disciplinary projects that they are concurrently undertaking in the term.

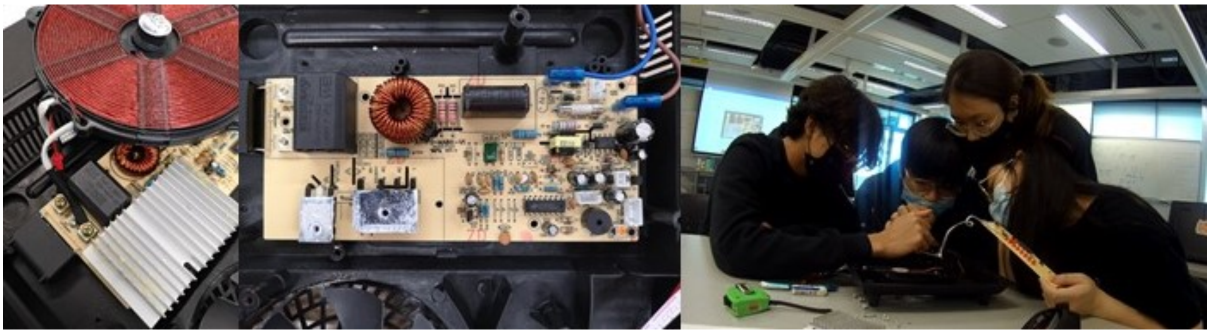
The framework has been implemented in the design of the REP activities in the physics classroom within the university, this will be further articulated in the next section.

Examples of REP Activities in Physics Classrooms

As a pilot study, the REP activities are implemented in the recent run of a 14-week compulsory introductory electromagnetism course, Technological World, for the undergraduate year 1 students in SUTD, which took place in Spring 2021. In consultation with two other faculty members who are instructors for the course, two dissection activities, aluminium electrolytic capacitor and induction cooker are designed. To balance between the need of delivering the course and the implementation of the REP activity, the activities are designed to last for approximately an hour long. In addition, the activities are introduced almost immediately after the relevant topics are covered in class, so that the concepts remain fresh in the mind of the students. Within the class the students are asked to complete a set of worksheets that guides them through the working principles and design of the product from the physics perspective. The activity is then followed up with a homework exercise related to the in-class activity.

Figure 1

The dissection of induction cooker



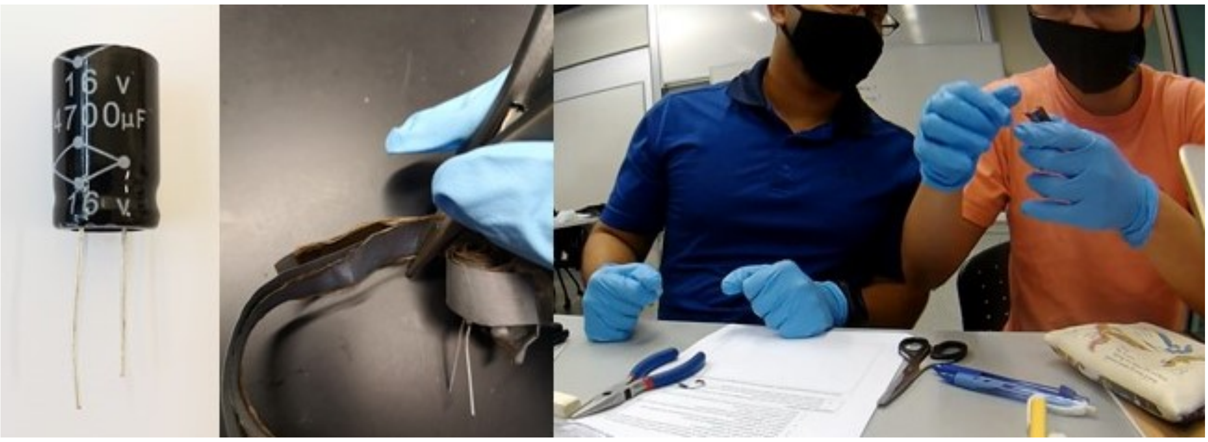
Error! Reference source not found. shows the REP activity of dissecting an induction cooker by the students in the class. Before the dissection, students are tasked to discuss and think about the components within the induction cooker that allows it to work. To guide the students, they are asked to consider the potential safety hazards, the types of circuits that are in place and the possible role of the parts that they have suggested in making the device to work. The expectation is for students to think about the inner workings of the induction cooker based on the knowledge of circuits that they have learnt earlier in the class. Once this pre-activity step is done, students are asked to open the induction cooker.

During the dissection activity, students are tasked to analyse the components that makes up the induction cooker, such as the induction coil, circuit board, fan etc. From the product design perspective, students are asked to identify ways in which the induction cooker prevents itself from overheating. Again, the question is deliberately framed such that students think about the ideas that they have learnt earlier, for example, the relationship between resistance and thermal loss. The result of this association is for students to relate the design of a thermal fuse with how it cuts off the current in the event of overheating. To relate the induction cooker to the physics concept of LC circuit that the students have learnt earlier in the class, they are also asked to figure out the capacitor that forms the LC circuit with the induction coil and then estimate the oscillating frequency. To relate this to product design, students are followed up with a question to consider why the oscillating frequency are designed to be at high frequencies. It is with this calculation and further investigation that students are made aware the ingenuity of such design decision based on physics, i.e., that such high frequency will significantly reduce the form factor due to the smaller inductance and capacitance values needed; and that the frequency is significantly above the audible frequency, to reduce the noise for the users.

A similar activity of the dissection of the aluminium electrolytic capacitor is introduced to the students as well (before the induction cooker activity). Given the significantly smaller form factor and cost of a single capacitor, the students are asked to perform the activity in pairs for this activity. Again, students are similarly tasked with the objective to understand how the physics concepts that they have learnt earlier in the class comes into play in the design of the capacitor.

Figure 2

The dissection of aluminium electrolytic capacitor



Outlook and Future Works

In the previous section, two examples of REP activities are demonstrated, implemented in the classrooms, and integrated within the course. As highlighted earlier, the key aim of such activities is to go beyond how things work, and to create an opportunity for students to explore how the physics can influence product designs, and by extension, their own design process. This has been illustrated through a careful design of such form of guided reverse engineering process, as in the case of induction cookers and capacitors.

From the practitioner point of view, the immediate next step would be to design more of such activities given the initial success of the project. In the pilot, the designed REP activities are based on concepts in electromagnetism, but the repertoire of activities can be further expanded to include other areas of physics, such as mechanics and thermodynamics. Furthermore, while the current implementation is in physics (as the research team consists mainly of instructors who are teaching physics or with some form of physics or engineering background), the natural extension would be that if it is possible to perform similar REP activities to support the learning of other disciplinary subject and then relate the subject to the design process. As an illustration, a potential implementation would be for machine learning be undergo the same steps as prescribed in the DA^{3}D framework for students to appreciate the fundamentals of calculus, while at the same time, demonstrate how calculus influence the design or strategies in such application.

From the theoretical or research aspect, one could ask what sort of framework or theory could be derived to guide and further develop such activities? What sort of affordance does REP provides for the students' design iterations and processes through the lens of first-principle disciplinary subjects such as physics? For example, the affordance could be in terms of students' ability to connect physics in design thinking, their ability to perform engineering tasks, the shift in their class engagement, or skills development. The ability to answer these questions would inform researchers the overall experience of the students in terms of their cognitive development, affect and dexterity.

In addition, given the recent outbreak of the pandemic, much of the teaching activities has been brought online, including the activities within the university (Tan & Chen, 2020). A paradigm shift would be needed to continue to engage in these physical activities such as the REP activities in a sustainable manner. Furthermore, the pandemic has led to one to rethink how a classroom should be structured and transcend beyond physical spaces. While such idea has been explored in the context of hybrid or blended learning and widely studied in literature, the pandemic has inevitably catalysed the desire to implement these concepts into operations. As such, the question lies in how would one be able to conduct such activities online, if they could be done in the first place, and what kind of modifications would be needed? To what extent would the shift of such activities from physical to online changes students' perception in their learning and skills acquisition?

In this article, the concept of REP has been discussed and explored. Its implementation within the university physics classroom has been described. Given that this is an on-going study, it is expected that there will further outputs that will arise from this work. To conclude, while the activities described thus far has been implemented within the university physics setting, given the commonality of the physics across levels, the activities can be easily translated to pre-tertiary levels with light modifications.

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7. South African Life Sciences Teachers' Beliefs on Cloning

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Abstract

Cloning is one of the controversial topics found within the South African Life Sciences curriculum. The South African teacher corps is diverse, and many contemporary religions are practiced amongst teachers. A major challenge of teaching controversial topics is that, due to its disconcerting nature, it ignites discussion in the classroom which may be contradictory to the teachers and other learners' beliefs and this may lead to discomfort felt by the teacher or other learners. As religious convictions may profoundly influence teachers' beliefs, it stands to reason that multiple approaches to teaching a topic like cloning exist. Thus, this study explored South African Life Sciences teachers' beliefs on cloning by adopting the sociocultural model of embedded belief systems by Jones and Carter (2007). According to this framework, teachers' beliefs influences their instructional practices and this impacts the learners learning of the topic. A case study approach was adopted as it allowed the researcher to focus on detailed exploration of how teachers' beliefs on cloning influence their teaching practice. Furthermore, this allowed the researcher to explore differences and similarities amongst different cases of the grade 12 teachers. A total of 9 lessons (3 lessons/teacher) were observed and 3 interviews were conducted. The findings of this study show that beliefs may differ amongst teachers. Teachers who were open minded, felt more comfortable and had neutral beliefs towards teaching cloning had adopted instructional practices which allowed for learner engagement with the topic. However, teachers who felt uncomfortable teaching cloning, adapted the instructional practice which restricted learner interaction. Thus, teachers' beliefs on cloning, do influence their teaching practice, consequently impacting on learners' learning about the topic. The research is significant in that it provides empirical evidence clarifying the interactions between teachers' beliefs and their teaching of cloning. Implications for science teacher education are discussed.

Keywords: Teacher beliefs, teaching practice, controversial topic, cloning and life sciences

Introduction

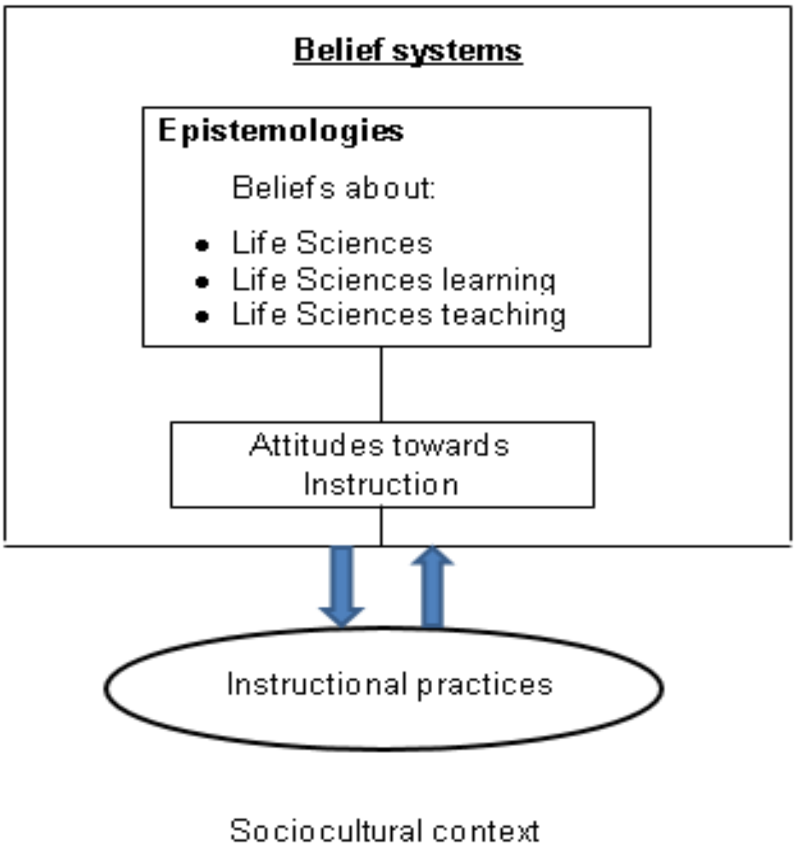
Research illustrates that when a teacher employs a controversial issue to classroom instruction, their arguments and reasoning is often wittingly or unwittingly misleading (Owens, Sadler & Zeidler, 2017). Teachers' reasoning emerges from what they believe to be true (Cobern, 2003). Beliefs stem from deeply rooted personal experiences (Keys, 2005). In the South African CAPS curriculum, controversial topics range from a wide variety of topics such as the use of stem cells, genetically modified organisms (GMO), evolution, and cloning (Boerwinkel, Yarden, & Waarlo, 2017; Siani & Assaraf, 2016). However, the curriculum is unable to direct the Life Sciences teachers and students to scientifically reliable sources for the teaching of such topics (Mnguni, 2013). This study focuses on the importance of teacher beliefs on the controversial topic of cloning and how its influences their teaching practice. The teachers' knowledge of a subject and their beliefs about teaching a certain topic plays a significant role in shaping teaching practices (Wessels & Steenkamp, 2009). Therefore, exploring Life Sciences teachers' beliefs about cloning and the influence it has on their teaching of the topic is important.

Framework

For this study, the researcher adapted the sociocultural model of embedded belief systems by Jones and Carter (2007). This model was used to target the belief systems of Grade 12 Life Sciences teachers when teaching the topic of cloning. The adapted sociocultural model of embedded belief systems focuses on the epistemologies by closely looking at teachers' beliefs on cloning and their influence on teachers' attitudes towards their instructional practice. The researcher used the adapted sociocultural model to better understand the relationship between teachers' beliefs and their classroom practice, and whether these affect learners' learning of the topic of cloning.

Figure 1

Adapted sociocultural model of embedded belief systems from Jones and Carter (2007)



The framework was used as a lens to interpret the findings of the study and to seek validation between teachers' beliefs and their classroom practices. The adapted sociocultural model of embedded beliefs system by Jones and Carter (2007) was used while coding the data in such a way that it allowed the researcher to identify teachers' beliefs through the interviews and view their classroom practices during the observation. The researcher was able to make links and see if the interview answers corroborated with the data found in the observation through the lens of the adapted sociocultural model.

Methodology

This research applied a case study approach in exploring South African Life Sciences teachers' beliefs on cloning. Purposeful sampling was employed in carrying out this study

(Patton, 2002) based on the criterion that the teachers are qualified to teach grade 12 Life Sciences, and are familiar with the topic of cloning. Patton (2002), describes purposeful sampling as substantial, as it allows for a selection of participants which may provide information-rich cases. This type of sampling method allowed the researcher to make choices regarding the types of participants most suitable for the study (Scott & Morrison, 2005). For this study, three Grade 12 Life Sciences teachers situated at schools in Johannesburg, South Africa were chosen purposefully. A Grade 12 Life Sciences teacher teaching Grade 12 learners is expected to have a good knowledge of the entire syllabus, in this case specifically, cloning.

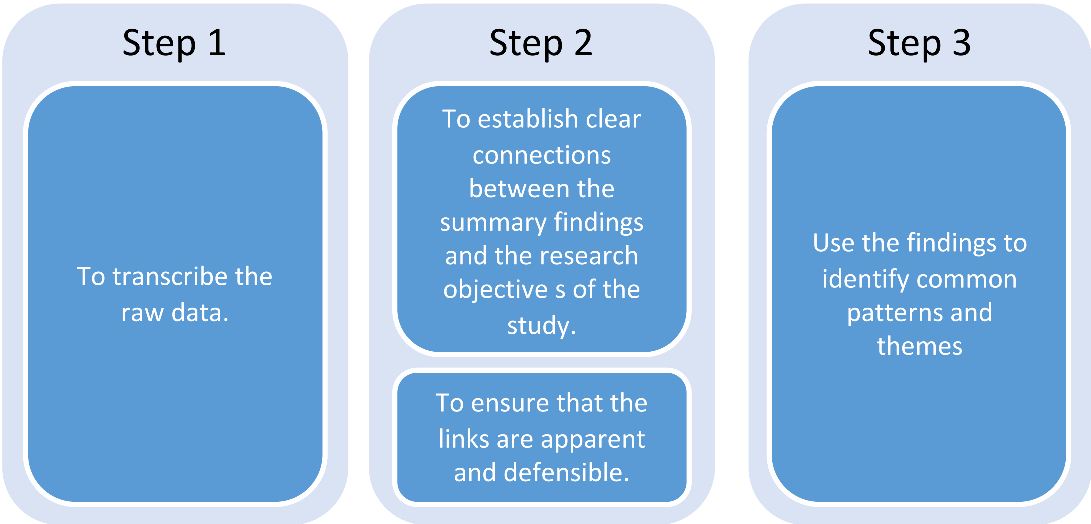
Data were collected by means of classroom observation and semi – structured interviews (three classroom observations per teacher and one semi-structured interview per teacher). The data were then transcribed and coded using the Saldana (2009) coding technique. Codes were assigned to various statements on the transcripts. Thereafter, codes that shared similar features were grouped together to develop categories, from which themes emerged.

Data analysis

An inductive approach was used for the data analysis. An inductive approach can be regarded as an orderly technique for analysing qualitative data in which data is guided by the research objectives (Thomas, 2006). To analyse the data, the researcher began with an inductive coding process after the data had been gathered and transcribed. The process of codifying data allowed the researcher to organise data in a systematic order, which resulted in common patterns, themes, and categories (Saldaña, 2013). The themes discovered from the transcribed lesson observation and interview data were based on the research questions of the study. Figure 2 indicates the coding process of the data.

Figure 2

Diagram representing inductive approach analysis adapted from The Coding Manual for Qualitative Researchers by Saldaña, (2013)



Three themes emerged from the coded data:

- **Theme one:** Teachers' beliefs on the controversial topic of cloning in Life Sciences
- **Theme two:** Teachers' classroom practices when teaching the topic of cloning
- **Theme three**: Teachers' recognition of learners' diverse religious and cultural backgrounds and its influence on their learning.

Findings

The comparison Table 1 below highlights the differences and similarities between the three cases. The differences and similarities assisted the researcher to answer the research questions which states:

1. What are teachers' beliefs on cloning?
2. How do the teachers' beliefs on cloning inform the way they teach cloning?

This table compares the findings of the study according to the three themes discovered. The data of the themes is organised according to each case which separates the different participants. In qualitative data, the analysis is interpretive, therefore adopting an interpretive approach. From this cross-case analysis, it is evident that the findings from the three main themes are coherent. The themes flow from one theme to the next and this illustrates the validity of the data findings.

Table 1: Cross-case analysis table

Themes	Sub-themes	Case 1 Mrs Snowy's summary of findings.	Case 2 Mr Rocky's summary of findings.	Case 3 Mr Yen's summary of findings.	Conclusion
Theme 1	Open to teaching the controversial topics.	Mrs Snowy was open to teaching controversial topics.		Mr Yen was open to teaching controversial topics.	2 out of 3 teachers were open to teaching controversial topics.
	Not open to teaching controversial topics.		Mr Rocky was not comfortable with teaching controversial topics.		1 out of 3 teachers was not open to teaching controversial topics.
Theme 2	Constructivist approach (teaching style).	Constructivist approach to teaching was		Constructivist approach to teaching was	2 out of 3 teachers adopted the constructivist approach when

		adopted by Mrs Snowy.		adopted by Mr Yen.	teaching the topic of cloning.
	Scaffolding.	Scaffolding was evident through Mrs Snowy's classroom observation.		Scaffolding was evident through Mr Yen's classroom observation.	2 out of 3 teachers scaffolded learner understanding during the lesson.
	Teacher – centred approach (teaching style).		Mr Rocky adopted a teacher – centred approach to teaching.		1 out of 3 teachers strictly adopted the teacher-centred approach.
	Representation of science CK – (**multiple resources** including technological tools).	Mrs Snowy presented CK using multiple representations and use of technological tools.		Mr Yen presented CK using multiple representations and use of technological tools.	2 out of 3 teachers made use of multiple representations to present the lesson and integrated the use of technological tools.
	Representation of science CK – (**single resource**		Mr Rocky presented CK using a single		1 out of 3 teachers made use of a single resource to conduct

	used – textbook only).		resource (textbook only).		the lesson on cloning.
Theme 3	Recognising learners' diverse views and opinions.	Mrs Snowy recognised and integrated diverse learner views and opinions.		Mr Yen recognised and integrated diverse learner views and opinions.	2 out of 3 teachers recognised and accommodated diverse learner views and opinions.
	No recognition of learners' diverse views and opinions.		Mr Rocky refrained from integrating learner views and opinions.		1 out of the 3 teachers did not integrate learner diversity.
	Development of skills from the recognition of learner diversity in the classroom.	Acknowledged that learners gain different skills through the engagement with the topic. Engagement with the topic was evident.		Acknowledged that learners gain different skills through the engagement with the topic. Engagement with the topic was evident.	2 out of 3 teachers acknowledged that through recognition of learner diversity, there is development of skills such as communication, debating, and argumentation skills.

Theme 1: Teachers' beliefs on the controversial topic of cloning in Life Sciences.

This theme centres around teachers' beliefs on teaching the controversial topic of cloning. The data collected suggests that teachers who were open to teaching controversial topics applied a constructivist teaching method as opposed to the teacher who was not open to teaching a controversial topic. This is illustrated in the paragraph below with excerpts to highlight the three teachers' responses.

Mrs Snowy from Case 1 accommodated diverse views of learners during her classroom observation and she stated in her interview that she allows for learner opinions during her lesson and refrains from her own views: *"I ask for the learner's opinion and refrain from saying my opinions to the learners."* Similarly, Mr Yen from Case 3 also catered for diverse beliefs of learners during his lesson. This was evident from his classroom observation and Mr Yen further acknowledged this during his interview in which he specified: *"The learners should be learning about cloning in Life Sciences as it allows them to decide upon themselves whether they agree or disagree. The learners may have a clear insight about the process. Since it is a controversial topic, this allows the learners to argue differently and bring about different ideas and this is how they develop some of the skills which can be used in the future by the learners."*

However, Mr Rocky from Case 2 did not allow for any learner interaction during the teaching of cloning. He also indicated this during the interview that he does not allow for learner interaction, as he does not feel comfortable: *"No, I don't feel comfortable because there are a lot of debates when it comes to the controversial topics."*

The findings suggest that two out of three teachers were open to teaching the controversial topic of cloning. This was an important finding for this study as it affects the teaching approach adopted by the teacher. This will be illustrated in the next theme.

Theme 2: Teachers' classroom practices when teaching the topic of cloning.

Theme 2 centres on the teaching practices of teachers when teaching the controversial topic of cloning. The findings suggests that the teachers' beliefs affected the way in which they conducted their lessons. The two teachers (Mrs Snowy and Mr Yen) whose beliefs were open to teaching the controversial topic, illustrated an enhanced constructivist approach. On the other hand, the other teacher (Mr Rocky) illustrated a teacher-centred approach to teaching. This is illustrated in the paragraph below with excerpts to highlight the three teachers' responses.

Mrs Snowy from Case 1 adopted a constructivist approach whereby teacher-learner interaction was evident and the teacher scaffolded the learners' learning. During the interview, Mrs Snowy mentioned the importance of adopting the constructivist approach: *"Ideally you can have small groups and the learners can interact, do research and come up with their own information but due to the large number of learners in the classroom, and deadlines to finish the Grade 12 curriculum and certain topics it becomes difficult to teach it the way you wish to teach it".* Mrs Snowy adopted the constructivist approach however, she reasons why she was unable to incorporate many other aspects of the constructivist approach during her lesson.

Mr Yen from Case 3 also adopted the constructivist teaching approach. This was evident from his classroom observation as he integrated collaborative learning by allowing for group discussion between learners. During the interview, Mr Yen acknowledged the importance of leaner involvement: *"I also believe in learner involvement in the classroom in which they can argue and understand the different point of views of others and also have their own imagination and tend to explore different ideas and this is how they understand the topic better".* Mr Yen's interview response corroborated his observed lesson in which a constructivist approach was evident.

However, Mr Rocky from Case 2, deliberately chose the teacher-centred approach to teach cloning as he was not comfortable teaching a controversial topic. He said this during his interview: *"When teaching cloning, I become more teacher-centred due to the facts that at times when you become to open to this topic, the learners will not listen to the facts about the topic"*. Mr Rocky's interview response supported his classroom observation as he adopted a teacher-centred approach in which there was no evidence of learner involvement.

The important finding from Theme 2 revealed that teachers' teaching practices are influenced by the teachers' beliefs on teaching the controversial topic of cloning. Mrs Snowy and Mr Yen, who adopted the constructivist approach, also scaffolded learners' understanding about the topic of cloning, and this was associated with their openness to teaching topics of a controversial nature. However, Mr Rocky, who adopted the teacher-centred approach, had a teaching style that was also influenced by his enclosed beliefs and discomfort with teaching a controversial topic. Thus, this illustrates coherency between Theme 1 and 2.

Theme 3: Teachers' recognition of learners' diverse religious and cultural backgrounds and its influence on their learning.

Theme 3 centres on teachers' recognition of learner diversity in order to obtain the learning outcome from the Life Sciences CAPS curriculum which are beneficial to learners. According to the CAPS document, the purpose of studying Life Sciences is to promote skills such as critical thinking, reasoning, and communicating, as such skills prepare the learners to actively participate in a democratic society (Department of Basic Education, 2011). The evidence suggested that two of the three teachers, (Mrs Snowy and Mr Yen), recognised learners' diverse views and opinions to ensure the learners achieve the skills mentioned above as they were open to teaching the controversial topic of cloning. However, learner diversity was not evident in Mr Rocky's case as his beliefs caused him to be not open to teaching cloning.

This is illustrated in the paragraph below with excerpts to highlight the three teachers' interview responses.

Mrs Snowy from Case 1 and Mr Yen from Case 3 accommodate diverse learner views and opinions. Consequently, benefits of learner diversity through skills development were achieved. Their responses from the interview transcript provide evidence of this below:

Mrs Snowy: "*Besides it helping the learners certain facts about cloning, this topic also allows the learners to engage with this topic and understand different viewpoints of others. It allows the learners with gaining of skills such as debating, understanding, and respecting views of others.*"

Mr Yen: "Since it is a controversial topic, this allows the learners to argue differently and bring about different ideas and this is how they develop some of the skills which can be used in the future by the learners."

According to Mrs Snowy and Mr Yen, the learners should engage with topics which are controversial, as leaners have different viewpoints and ideas and therefore argue differently. Mrs Snowy and Mr Yen's interview responses were supported by their classroom observations as they allowed the learners to voice their views and opinions. In contrast, Mr Rocky did not accommodate any learner views and opinions and the learners were simply passive recipients of knowledge. The interview transcript provides evidence below:

Mr Rocky: "*It is important to keep in mind that the facts are the ones which are more valuable when teaching cloning. The facts will be asked in an exam or in a test so I don't allow for learners views.*" Mr Rocky avoids any learner interaction and strictly focuses on transmitting CK to the learners. CAPS stipulates that science is more than just learning facts. Science is a process which requires a deep understanding of the topic which is achieved through active participation and interaction in the classroom.

Thus, it is apparent that two out of three teachers, Mrs Snowy and Mr Yen, were open to teaching controversial topics which allowed for these lesson outcomes to be met. However, Mr Rocky, who was not open to teaching the controversial topic, could not meet the Life Sciences CAPS outcome. This latter finding is cause for concern, and teachers need to take note that their beliefs affect the experiences that learners gain within the classroom.

In conclusion, the research findings obtained from the classroom observations and the interviews revealed that two of the three teachers, (Mrs Snowy and Mr Yen), were open to teaching the controversial topic of cloning. Their open beliefs to teaching the controversial topic of cloning influenced their teaching practices in the classroom. Mrs Snowy and Mr Yen therefore adopted a constructivist teaching style in which scaffolding was also evident. This resulted in learner diversity within Mrs Snowy's and Mr Yen's classrooms in which the learners actively participated in classroom discussions. Active participation results in learners gaining skills such as critical thinking skills, argumentative skills, and the skills to understand and respect the views of others within a social cultural context, as stated as being a key aim of the teaching of life sciences in the CAPS document. Whereas, Mr Rocky, who was not open to teaching the controversial topic of cloning, his beliefs also influenced his teaching practices. Mr Rocky's enclosed beliefs on teaching a controversial topic resulted in a teacher-centred teaching practice. The teacher-centred approach further restricted the learner diversity in the classroom.

It is of paramount importance to mention that the theoretical framework of the sociocultural model of embedded belief systems by Jones and Carter (2007), and the cross-case analysis, has highlighted one of the key findings on the relationship between the Life Sciences teachers' beliefs on cloning and their instructional practices. According to the model by Jones and Carter (2007), instructional practices are affected by the epistemological beliefs of teachers, which include teachers' beliefs about Life Sciences, Life Sciences teaching and learning, as well as their attitudes towards classroom instructions found within the social cultural context and vice versa. The key findings from the three cases revealed that Life Sciences teachers' beliefs on cloning had an influence on their instructional practices found within the sociocultural context. Therefore, the findings can be interpreted in terms of the three cases presented in this chapter, which confirm the adapted conceptual framework that is articulated in the sociocultural model of embedded belief system by Jones and Carter (2007).

Discussion

The discussion answers the two research questions of this study.

What are teachers' beliefs on cloning?

The analysed data gathered from the participants of this study showed that beliefs may differ from teacher to teacher. Teachers' beliefs are rooted in personal experiences and therefore their reasoning emerges from their beliefs of what they believe to be true (Cobern, 2003). In this study, two of the three teachers, (Mrs Snowy and Mr Yen), had shown an openness to teaching the topic of cloning. Their openness and neutral beliefs were evident as these teachers were comfortable with teaching this topic and they also allowed the learners to interact and share their views on cloning. As the learners shared their personal views, Mrs Snowy and Mr Yen ensured that they remained neutral by not imposing their personal views on cloning during the lesson.

Mrs Snowy and Mr Yen comfortably allowed for learners' diversity in the classroom. This was evident through the classroom observation as these two teachers continuously created a learning environment which allowed the learners to actively engage with the topic of cloning. Such learning environments allowed the learners to critically discuss the controversial issues pertaining to cloning and it further encouraged skills in learners with regard to understanding and respecting the different views in the classroom. Consequently, this illustrates that Mrs

Snowy's and Mr Yen's openness to teaching the controversial topic of cloning led to promoting diversity in the classroom amongst learners.

However, Mr Rocky, who was not open to teaching the topic of cloning, restricted the learners from sharing their personal views and opinions on cloning. Mr Rocky had confined beliefs on cloning as he did not feel comfortable with teaching a controversial topic, as he stated during his interview response. Studies by Hodson (2003) and Owens et al. (2017) state that many teachers may find difficulties teaching controversial and ethical natured topics and therefore may feel discomfort teaching such topics, which may in turn affect learners' learning, thus depriving them of achieving their full potential. Mr Rocky's restricted beliefs on cloning affected the sharing of diverse views in the classroom, as the learners were not given a platform to engage with the topic. According to Mr Rocky, shared views amongst learners could lead to differences amongst learners. As the learners were not given a chance to engage with the topic, these learners may only have a narrow view of the topic at hand. Mr Rocky also believes that the learners may choose to give more importance to their religious beliefs than to the CK received from the teacher. From an educational perspective, the researcher believes that the learners do not need to take the CK with respect to the topic of cloning as "truth" but rather be able to understand it and its controversies from various point of views. According to the Department of Education (2011), one of the objectives of South African science education aims to create learners who are able to think critically, and not be passive receivers (p. 4). Given the importance of creating learners who are critical thinkers, it is of concern that if Mr Rocky had allowed for learner interaction, learners would gain skills of tolerating and respecting the views of others and being open to different viewpoints as stated in the general aims of the South African curriculum. The purpose of the National Curriculum Statement (NCS) is to equip learners with knowledge and skills that will be beneficial to them and allow for meaningful participation in society. Indeed, education should encourage an active and critical approach to learning.

How do the teachers' beliefs on cloning inform the way they teach cloning?

The analysed data from the study displayed that the teaching practices differed and were adopted according to the teachers' beliefs about teaching the topic of cloning. A constructivist approach to teaching was commonly observed by Mrs Snowy and Mr Yen, the teachers who promoted inclusivity of learners' views and opinions in their lesson enactment. Thus, the findings from this study point out that teachers who are comfortable and open to teaching controversial topics adopt a constructivist teaching approach. However, Mr Rocky, who had excluded the learners from sharing their views on the topic of cloning, had strictly adopted the teacher-centred teaching approach. This teaching style was adopted to restrict the learners from sharing their personal views as Mr Rocky did not feel comfortable teaching a controversial topic. Hence, Mr Rocky's teaching practice was affected by his confined beliefs on teaching the controversial topic of cloning. Studies by Bahcivan and Cobern (2016) and Rokeach (2003) also advocate that teachers' beliefs have an influence on their teaching practices which in turn affect learners' learning in the classroom. Therefore, the findings from this study suggest that teachers enact the teaching approach according to their beliefs about that particular topic. These findings can also be explained in terms of the adopted sociocultural model of embedded belief systems framework by Jones and Carter (2007), which highlights that instructional practices are affected by the epistemological beliefs of teachers, which in this case, include teachers' beliefs about Life Sciences, Life Sciences teaching and learning, as well as their attitudes towards the classroom instructions found within the social cultural context and vice versa. Therefore, the findings from this study confirm the results that are articulated by Jones and Carter's (2007) sociocultural model of embedded belief systems.

Therefore, it is evident that teachers' beliefs influence their teaching of topics. Teachers who are open minded, feel more comfortable and have neutral beliefs towards teaching controversial topics such as cloning, and adapt their instructional practice which allows for learner interaction and engagement with the topic. However, the teachers who are uncomfortable teaching controversial topics, such as cloning, rather adapt their instructional practice to restrict learner interaction in the classroom. Similarly, Luft and Roehrig (2007) assert that a teacher's belief discloses the way they view science knowledge which then causes them to enact certain instructional practices.

Hence, it can be concluded that Life Sciences teachers' epistemologies, which include Life Sciences teachers' beliefs on teaching the controversial topic of cloning, influence their preferred teaching practices.

Conclusion

This study was based on the teachers' beliefs on the controversial topic of cloning and its influence on their teaching. In light of the above, the teachers' beliefs on cloning displayed a link with their instructional practices adopted in the classroom, which also impacted on the learners' learning experience. The emphasis in this case, is that teachers' beliefs on the controversial topic of cloning influences their teaching practices, which eventually will impact on the learners' learning experiences. For instance, teachers who adopt the constructivist teaching approach are open to teaching controversial topics. This teaching approach benefits the learners providing them with the opportunities to gain or improve certain skills such as critical thinking and reasoning, and respecting the views of others. These skills may help the learners to become well informed citizens and benefit them to function effectively in society. Whereas, the teacher who adopted the teacher-centred teaching approach has confined beliefs and was less likely to be open to teaching controversial topics. In fact, a traditional teaching method may hinder learners' learning experience in the classroom, as the teacher may restrict learner engagement. The researchers argue that controversial topics such as cloning, play an important role in learners' learning as they need to be exposed to such topics to gain skills such as: critical thinking, debating, accepting and / or tolerating the views of others. Hence, the manner in which the teacher enacts the lesson influences whether and how learners gain certain skills. It is essential to acknowledge teachers' beliefs about cloning, as it influences their teaching of the topic which further makes an impact on the learners' learning. The findings of this study could be used to inform teacher-training programmes. Teachers within the same cluster or district can engage in professional learning communities where they can share their pedagogical practices for teaching controversial topics such as cloning.

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Authors' biographies

Umme kalsum Anjum is a high school educator teaching Maths and Science. Her qualifications are: BEd in Senior Phase and FET Teaching (Grades 7-12) majoring in Physical Sciences and Life Sciences, BEd Honours in Science Education and Masters in Science Education – with a focus on teachers' beliefs and its influence on their teaching practices.

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Originality of the work

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The Higher Degrees Administrative Structures and Processes Policy states in:
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This serves to confirm that I, Umme kalsum Anjum ____________ (Full Name(s) and Surname)

ID Number: 9403071361080

Student number: 201312642 ____________ enrolled for the

Qualification: MEd in Science Education ____________ in the Faculty of Education.

Herewith declare that my academic work is in line with the Plagiarism Policy of the University of Johannesburg, which I am familiar with.

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How Life Sciences teachers' beliefs about cloning influence their teaching of the topic

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Signed at NORWOOD **on this** 20 **day of** January 2021.

Signature ____________ **Print name** UMME KALSUM ANJUM

STAMP COMMISSIONER OF OATHS **Affidavit certified by a Commissioner of Oaths** This affidavit conforms to the requirements of the JUSTICES OF THE PEACE AND COMMISSIONERS OF OATHS ACT 16 OF 1963 and the applicable Regulations published in the GG GNR 1258 of 21 July 1972; GN 903 of 10 July 1998; GN 109 of 2 February 2001 as amended.	**STAMP** SUID AFRIKAANSE POLISIEDIENS STATION COMMANDER 20 JAN 2021 CLIENT SERVICE CENTRE NORWOOD SOUTH AFRICAN POLICE SERVICE

Ethics clearance

NHREC Registration Number REC-110613-036

UNIVERSITY OF JOHANNESBURG

ETHICS CLEARANCE

Dear Umme Kalsum Anjum

Ethical Clearance Number: Sem 1 2019-076

How Life Sciences teachers' beliefs about cloning influence their teaching of the topic

Ethical clearance for this study is granted subject to the following conditions:

- If there are major revisions to the research proposal based on recommendations from the Faculty Higher Degrees Committee, a new application for ethical clearance must be submitted.
- If the research question changes significantly so as to alter the nature of the study, it remains the duty of the student to submit a new application.
- It remains the student's responsibility to ensure that all ethical forms and documents related to the research are kept in a safe and secure facility and are available on demand.
- Please quote the reference number above in all future communications and documents.

The Faculty of Education Research Ethics Committee has decided to

☒ Grant ethical clearance for the proposed research.
☐ Provisionally grant ethical clearance for the proposed research
☐ Recommend revision and resubmission of the ethical clearance documents

Sincerely,

Dr David Robinson
Chair: FACULTY OF EDUCATION RESEARCH ETHICS COMMITTEE
2 June 2019

8. Case Studies Examining Teachers' Adaptive Practices in Two Singapore Schools

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Abstract

This research examines four teachers of adaptive practices as manifested with their professional noticing of classroom events while they are teaching with eye-tracking glasses. Adaptive practices refer to the actions that a teacher takes in response to the different trigger events in the classroom and the coding of recorded lessons was conducted with a well-established coding guide. Our findings reveal that the four teachers tended to notice students' expressions and responses, physical objects of the surrounding and students' progress when they are left to do individual work. They would then prompt students to respond and modify their instructions according to the students' needs. There was also a lack of variation in the adaptive practices demonstrated. In addition, our analysis shows that teachers with facilitative teaching style were more likely to demonstrate adaptive practices than teachers with didactic teaching style in the classroom. While having long years of experience is also more likely to demonstrate adaptive practices, the teaching style is more prominent than the years of experience in predicting adaptive practices. The findings of this study could provide concrete guidance to teachers in developing their adaptive practices, initiate conversations about the lack of variation in adaptive practices and promote facilitative teaching style in the professional development courses.

Introduction

Teaching is a cognitively demanding and complex task as teachers often must deal with simultaneous demands in a classroom that require their critical judgement to assess the situations, and thereby apply their professional knowledge differently (Bransford, Darling-Hammond, & LePage, 2005; Kennedy, 2006; Shulman, 2004;). Therefore, it is imperative for teachers to remain adaptable and responsive to meet the demands of their job and continuously improve their professional knowledge to be an effective educator (Fairbanks et al., 2019). With a better understanding of adaptive practices in teaching, teachers will be able to develop a deeper appreciation and a consciousness to improve and apply these practices in the classroom.

According to Loughland (2019), adaptive practices are the actions that teachers take in response to the different trigger events in the classroom, which can vary from personal, environmental, to student's behaviours. Loughland's definition was chosen in this study because it encapsulates the elements of adaptive practices in overt teaching actions, as opposed to how other researchers have defined¬¬ adaptive practices – as the opposite of routine practices (Bowers et al., 2020; Crawford et al., 2005; Yoon et al., 2015). Moreover, his research on adaptive practices through classroom noticing is comprehensive and relevant ¬to the context of our study.

An adaptive teacher is one who takes into account students' responses during their lessons and responds appropriately to what they noticed and fosters creativity and critical thinking skills in the students (Loughland, 2019). From the teachers' point of view, a teacher needs to be adaptive to navigate through unforeseeable situations and variables, recognise problems and identify possibilities of solutions in different situations (Bransford, Darling-Hammond, & LePage 2005; Fairbanks et al., 2010). For teachers to be adaptive, they should also be proficient in their professional noticing skills, which encompass four main aspects of skills (Gibson & Ross, 2016) – detect subtle behaviours, assess the behaviours of students, make sense out of the data, and implement instructional moves accordingly. This research focuses on adaptive practices that teachers demonstrate due to classroom events. While an aspiring educator will find much literature on classroom teaching methods, the attempt to implement such practices in concrete spaces is complicated and involves making many difficult choices by the teacher (Dunetz, 2005). Currently, there are only a few well-established studies that investigate how adaptive practices in teaching are exhibited in classroom practices, amongst them are Loughland's (2019) and Yoon et al. (2015). The other literature focuses on the structural aspect of education such as reforms and content structuring in the lens of adaptive practices (Bowers et al., 2020; Crawford et al., 2005; Schipper et al., 2020) and the adaptability of teachers. For example, Crawford and his team (2005) focused on content structuring, that is, what inferences teachers make from the correctness of their students' answers in a biology test, with reference to their lesson plans. This helps teachers to gain clarity in their adaptiveness in the form of forward reasoning and causal reasoning of their lessons to the students' responses so that they can adapt their content to fit the learning more effectively. However, it does not focus on the teacher's moment-to-moment actions on events happening in the classroom. Hence, research on adaptive practices in response to classroom events is a relatively new topic that deserves further exploration. This research aims to uncover the underlying reasons for the varying proficiencies of the teachers in the adaptive field and their noticing abilities.

Teaching and learning are tasks that are highly specific to the social context that it is taking place (Tiberius & Billson, 1991). Social cognition theory suggests that environment affects a person through their cognition and their behaviour, and in the context of a teacher, multiple factors would interact and thereby affect a teacher's motivation, disposition and behaviours (Bandura, 1997; Loughland, 2019). Therefore, the social context of Singapore's education system would inherently influence the adaptive practices of our teachers and they would differ from the adaptive practices in other countries. The number of research done on the local school context in the lens of adaptive practices is also astoundingly low, which would make the findings of this research prominent and significant. It would be able to identify the nuances in the adaptive practices between what has been studied in other countries and what has been done in the local school context and add clarity to the adaptive practices that teachers display in their classrooms.

In the studies of adaptive practices, many pieces of evidence show how years of professional teaching experience would decrease the chance of adaptive practices taking place in the classrooms (OECD, 2009; Männikkö & Husu, 2018; Yoon, 2015). However, these effects are not consistently manifested in different cultures and is dependent on the social context (Bandura, 1997; OECD, 2009;). Therefore, this research would shed some light on how years of professional experience would impact the likelihood of adaptive practices taking place in our local teaching climate.

Research Questions

This research aims to address the relative silence in the literature on adaptive practices in teaching in the Singaporean context. The research questions focus on exploring the observable moment-to-moment adaptive practices in local public schools' classrooms:

- What do teachers notice in classrooms and how do they respond to emerging events in their classrooms?

1. To what extent are different types of adaptive practices demonstrated in classrooms in the Singapore context?
2. What possible factors are in play that are associated with adaptive practices in teaching?

Literature Review

Adaptive Practices

The concept of adaptive practices was first proposed by Hatano and Inagaki (1986) as a contrast to the widely observed expertise in Japanese public schools - routine expertise. Hatano and Inagaki (1986) found that individuals are sometimes deemed to be experts because of their procedural skills, which are effective in solving everyday problems in a stable environment. However, they lack the flexibility and adaptability to improvise or find a new solution. In contrast, experts who demonstrate adaptive practices will be able to engage the unfamiliar in an effortful and time-consuming but valuable process, to come up with viable alternative solutions. Routine experts demonstrate speed and accuracy in solving problems that are based on their past actions in similar encounters. However, due to the rapidly changing nature of the classroom environment (Sherin & van Es, 2005), possessing solely routine expertise would not be sufficient for teachers to handle the needs in the classroom. Moreover, focusing too much on efficiency in classroom practices may hamper our ability to provide effective responses to students and their problems.

Adaptive practices research is further explored in a different context (Bowers et al. 2020; Crawford et al., 2005; Männikkö & Husu, 2018; Yoon et al., 2015), for example, by Loughland (2019), who has relevant findings on adaptive practices in classroom practices. Loughland (2019, p.4) regards adaptive practices as the "potential behavioural expressions of the model of adaptive teaching" and the model of adaptive teaching is one that "relies on the positive interaction between the triad of personal, environmental and behavioural aspects". It means that adaptive practices are the actions that an adaptive teacher takes in response to the different trigger events in the classroom. The likelihood of its occurrences is determined by an array of internal and external factors - teachers' personal adaptability, perceived autonomy support and the teachers' self-efficacy (Loughland, 2019). Loughland (2019) has also presented a comprehensive teacher adaptive practices coding guide. For its relevance in the classroom practices context, it was modified and adapted to suit Singapore's classroom practices in this study.

A review of research on adaptive practices in teaching shows that some of the personal determinants, like the teaching experience of a teacher, have not been thoroughly researched. While there is research that has shown a potential relationship between the years of teaching experience and the likelihood of teachers exhibiting adaptive practices (Männikkö & Husu, 2018), it is yet to be verified in our school context. The research from Loughland (2019), while laid the foundation for the studies of adaptive practices in classroom practices, could be extrapolated with studies in our local context.

Teacher Noticing

Teacher noticing is an essential prerequisite for adaptive practices (Gibson & Ross, 2016). The adaptive practices involve adaptation of a teacher's instruction to suit the needs of the students, what the teacher notices about the responses of the students, how the teacher interprets and understands the meaning of his or her observations, and how this information is used to adapt his or her responses to the students (Jacobs et al., 2010). As such, the teacher noticing ability is central to the adaptive instructions of the teacher.

According to Sherin & van Es (2005), teacher professional noticing involves three processes:

(1) identifying what is important in the classroom

(2) drawing links between specific classroom interaction with a broader concept and

(3) using their knowledge of the teaching context to rationalise a situation

As the classroom is a complex environment with different interactions going on simultaneously, a teacher will not be able to channel his or her attention to all the matters that are taking place in the classroom. Thus, the teacher must be able to assess the situation and identify what is important and be selective in which interactions to attend to. Secondly, noticing involves drawing links between a specific classroom interaction with a broader concept, such as equity, fairness or classroom norms, factors that critically determine and influence classroom interactions (Mustapha et al., 2010). By doing so, teachers will realise the important relationships among events that have occurred. Lastly, noticing involves the use of the knowledge of the teacher of a specific teaching context to rationalise a situation. As individuals gain expertise within a domain, they become more proficient at rationalising the situation that occurs within the domain (Chi et al., 1988).

Essentially, different studies of teacher noticing show one common feature—it is more than the mere noticing of classroom activities. Critically, it entails the thinking process that teachers have to go through to assess the reasons behind the students' actions for instance, or why certain activities have taken place in the classroom by reference to the social and cultural background of the environment.

This research paper focused on identifying aspects of noticing amongst Singapore teachers, for example, what teachers notice in the classroom.

Eye Tracking

This research used eye-tracking device to detect the attentional activities of the teachers. This method was chosen because of its promising affordance to track the gaze patterns and fixation points of teachers, which provide information for inferring cognitive processes in learning (Rodrigues & Rosa, 2017).

Vision has historically been a primary means for humans to obtain information from our surroundings and to carry out activities in our daily lives (Rosa et al., 2011). It is also the most important sensory channel to express our desire, cognitive processes, and emotional states (Underwood & Foulsham, 2006), even before the advent of writing (Rosa et al., 2015). Therefore, vision is an important tool that we rely on continuously to advance and make progress, as we constantly learn and receive information through our eyes.

Research has shown that the ability to pay attention or stay "on task" is an essential criterion of the learning of an individual. According to Banovic, Gamito and Rosa (2014), the ocular scanning of the visual scene is an important selective process in visual perception. This means that we are selective in what we choose to put our attention on. We scan through a series of items before deciding to stop at one to devote our attention to. This happens because our brain has a limited capacity to process information and all visual environments are characterised by complexity and information overload. Therefore, the tracking, recording and analysing of eye movements of our participants give us an excellent indication of the cognitive processes of our participants (Rosa, 2015).

Typically, there are two eye movements that are associated with cognitive processes – saccades and fixations (Yarbus, 1956), which would also be used as a measure in this study. Saccades are eye movements with the purpose of repositioning gaze (Ross et al., 2001). It is reported to take place multiple times per second as we view our surroundings (Snowden et al., 2012) and around 30ms to complete, it also usually represents a shift in attention of a person (Rodrique & Rosa, 2017). On the other hand, eye movements that support the idea of an individual having a focus of attention, are termed as fixation, which usually lasts for around 200-300 ms (Findlay & Gilchrist, 2003).

While the tracking of eye movement is useful to determine the cognitive process of an individual, it also has its limitation just like every other methodology. The measures of eye movements can be misleading as it does not take into account the peripheral view of an individual which makes up 98% of the human visual field. Therefore, it is important for researchers to acknowledge that the ocular fixation of the learners may not be representative of what they actually see (Rosa, 2015).

Methods

This research study adopted a case study method. The use of case study in educational research not only creates knowledge but also helps the reader to gain experience through exposure to an idiosyncratic phenomenon (Timmons & Cairns, 2009). Moreover, the case study is also best used for adding to the "existing experience and humanistic understanding" (Stake, 1978, p. 23), therefore it is a suitable method for this study that builds on the current construct of adaptive practices. This study adopts an instrumental case study approach, in which the cases (four teachers) were chosen to facilitate understanding of issues related to adaptive practices in classrooms.

The ethics clearance has been granted by the NTU-IRB (IRB-2018-01-030-06).

This research is part of a larger study. The data collection methods include classroom videos (which were recorded from 2018 to 2020) of five pairs of teachers from five different schools: each pair comprising a senior and a novice teacher. The more experienced teachers had more than three years of teaching experience and regarded as senior teachers in their schools, in contrast to novice teachers who had less than three years of ground experience. In this study, a subset of two pairs of teachers was analysed and Loughland's (2019) coding guide was used as a foundation guide, additional coding and specifications were added based on the empirical data. For example, we observed many instances of teachers infusing objects in their physical surroundings into their teaching, which was not in Loughland's guide.

The data allowed us to compare the capabilities of experienced and novice teachers in classrooms and a general perception of how adaptive practices are used to benefit students' learning. In addition, the videos are coded by two researchers to enhance the inter-coder reliability of the results. Inter-coder reliability (ICR) is a numerical measure of the agreement between different coders regarding how the same data should be coded based on a set of coding guides established between the coders. Having an ICR assessment also allows us to assess the rigour and transparency of the coding guide (MacPhail et al., 2016) and fosters reflexivity and dialogue within the research team. Cohen kappa's calculation was used because of the nominal data in this study (Nili et al., 2020). The Cohen kappa calculation is 0.87, which is of very high agreement (Landis & Koch, 1977). The researchers reconciled any discrepancies and inconsistencies in the coded data to develop a more explicit and well-defined coding guide (O'Connor & Joffe, 2020).

Eye tracking devices were used on the participants and the gazes were recorded, analysed and categorised to be either "saccades" or "fixation", depending on the duration that the gaze lasted on the students. For instance, we would record a gaze on multiple students within a second to be a saccade and a gaze on a specific student for more than a second to be a fixation.

Participants

The participants of this research were chosen via purposive sampling to give us the most useful findings for the research questions. These participants were science teachers with varying years of experience. The varying years of experience allow us to compare the differences in the adaptive practices of novice and expert teachers, and having the same teaching subject also set a common basis for comparison in their practices. These teachers are Ms Ada, Mrs Brooklyn, Mr Edmund and Mr Ivan (pseudonyms).

Ms Ada and Mrs Brooklyn were teachers from the same school, while Mr Edmund and Mr Ivan were teachers in another. Ms Ada, Mr Edmund and Mr Ivan were considered novice teachers with about 2, 4 and 3 years of experience respectively, while Mrs Brooklyn had 15 years of experience. Interestingly, Mrs Brooklyn was the mentor of Ms Ada, and we could see similarities in their teaching styles in the recorded lessons.

Findings

In this section, we present the findings from each of the recorded teacher noticing videos. The findings are presented in order of the research questions.

1. What do teachers notice in classrooms and how do they respond to emerging events in their classrooms?

The following analysis was gathered from the data in Appendix 2 and specifically by observing the similarity and patterns of columns B and C of each teacher.

Students’ expressions & wrong answers

One of the common themes that arise from the teachers is the noticing of students’ expressions and their verbal responses. It was usually triggered by the students giving the wrong or vague responses to the teacher’s questions. After which, the teachers would usually follow up with more questions to probe deeper into the vague responses or change their questions to elicit a response from students when they are stuck.

Physical objects in the surrounding to enhance teaching

In addition, Mrs Brooklyn, Mr Edmund and Mr Ivan had the tendencies to notice physical objects in the classroom to aid in their teaching. Mrs Brooklyn used the arrangement of the tables in the classroom as an analogy to have an organised transport system. Mr Edmund used the juice bottles from students to illustrate sucrose in our daily lives and lastly; Mr Ivan used plush toys to illustrate the concept of splitting potential differences among components in series circuits.

Students' progress while doing individual work

The teachers would also notice their students' work when the students are tasked to complete stipulated individual work. This was evident from Ms Ada and Mr Ivan. When students were unable to complete the task to the teachers' expectation or when students were stuck, the teachers would take over the lesson and guide the class or go to each student and coach them individually.

2. To what extent are different types of adaptive practices demonstrated in classrooms in the Singapore context?

Table 1

Comparison of the instances for each category across the teachers

Teacher	Questioning	Teaching	Assessment	Total coding instances
Ms Ada	1	3	0	4
Mrs Brooklyn	7	7	0	14
Mr Edmund	10	4	0	14
Mr Ivan	11	5	4	20

Prompting students for responses and modifying instructions were commonly used

Mr Edmund and Mr Ivan tended to prompt students for responses in class while Ms Ada and Mrs Brooklyn tended to modify their instructions as an adaptive practice towards the classroom events. We also noticed that Ms Ada and Mr Ivan would provide individualised instructions for students when they realised the students faced challenges in their work.

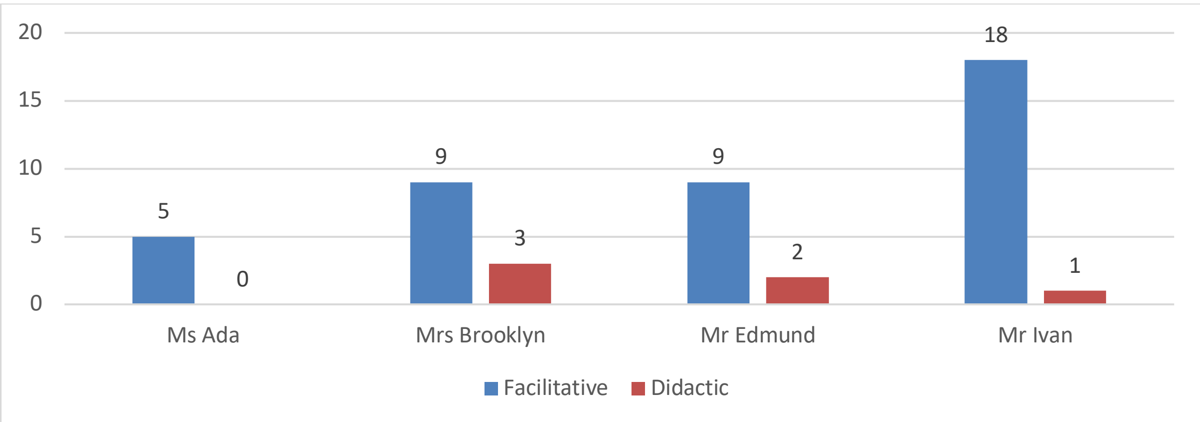
Assessment category adaptive practices were rarely practiced in class

According to table 1, we observed that adaptive practices from the assessment category were rarely demonstrated, and it was observed only in Mr Ivan's classroom. While questioning and assessment categories have some similarities, the assessment category is different in terms of its purpose. It is about assessing the understanding of the students and then making changes in class based on that assessment. In contrast, adaptive practices in the questioning category were for students to construct deeper meanings on their own when the teachers follow up with more questions.

3. Factors that might predict or encourage adaptive practices in teaching

Figure 1

Comparison of the instances categorized as either facilitative or didactic across the teachers



Facilitative teaching style more likely to demonstrates adaptive practices in teaching

During our coding process, we observed two distinct teaching styles demonstrated by the teachers. Mr Edmund and Mr Ivan tended to adopt a facilitative teaching style in their lesson, while Ms Ada and Mrs Brooklyn favoured the didactic teaching style. The facilitative teaching style is noted by the characteristics of getting students to answer questions and engaging with their hidden assumptions, while the didactic teaching style involved a mainly unidirectional transfer of knowledge from the teacher to the students. The examples could be seen from Mr Edmund and Mr Ivan, who had a higher number of facilitative instances than Ms Ada and Mrs Brooklyn, as noted in figure 1. The instances were categorised based on the criteria in Table 2.

In each of these teaching styles, we also observed that teachers with the facilitative teaching style were more likely to demonstrate adaptive practices in teaching than the didactic teaching style as noted by the frequencies of the adaptive practices demonstrated in appendix 3, whereby Mr Edmund and Mr Ivan had a higher number of adaptive instances than Ms Ada and Mrs Brooklyn.

Table 2

Criteria of facilitative and didactic

Facilitative	Didactic
Ask students open-ended questions	Ask students rhetorical questions
Expect students to give a response	Students are not needed to give response
The teacher reacts to students responses	The teacher does not make meaning out of students' responses
Constant feedback and interaction from students	Didactic; unidirectional transfer of knowledge from teacher to student

Experienced teachers are more likely to demonstrate adaptive practices in teaching

Mrs Brooklyn displayed more adaptive practices instances as compared to Ms Ada in table 2, even though both of them adopt the same teaching style. Given the significantly huge difference in the years of experience between Ms Ada and Mrs Brooklyn (2 years and 15 years respectively), the years of experience seems to be associated with the occurrence of adaptive practices of teachers.

Discussion

With respect to the first research question, the findings of the teachers noticing students expressions and answers and their individual work were consistent with the findings from Floro and Bostic (2017), where the teachers also noticed students' struggles and mistakes while they were teaching mathematical concepts. In contrast, noticing physical object in the surrounding was not found in other literature. This finding could stem from the widely lauded concrete-pictorial-abstract heuristic in Singapore, where Singapore teachers would use concrete objects in order to illustrate the abstracts (Merttens, 2012). By identifying the types of noticing that Singapore teachers have in general, it provides a common basis for teachers to discuss and further improve on their noticing practices.

In terms of the second research question on the findings of the adaptive practices of the teachers. The result of prompting students for responses and modifying instructions suggests that teachers have the tendencies to be adaptive in their teaching and even for the teachers who adopts a didactic approach, we could see attempts of them adapting the content delivered to the needs of the students or based on the current situation of the lesson. The lack of assessment adaptive practices demonstrated could suggest two reasons – the knowledge of assessment adaptive practices is lacking among teachers or that teachers are simply not demonstrating the assessment adaptive practices for some reasons. These reasons require further verification through future studies, and it could signal a change in the curriculum of the Singapore teacher education and professional development.

Lastly, the findings from the last research question imply that teaching style is more closely associated with adaptive practices compared to the years of teaching. It implies that adaptive practices could be developed regardless of teaching experience, which is prominent in shaping future professional development of current teachers and the education of preservice teachers with more discussion on teaching styles.

Conclusion

Adaptive practices in teaching are essential for teachers to cope with the myriad of cognitively demanding and complex tasks in a classroom. In this case study, we have examined the teachers' adaptive practices in two Singapore schools. The teachers in this study shared similarities of noticing students' facial expressions and wrong answers in the classroom, physical objects that aids teaching and the work of students were during seatwork. In response, teachers demonstrate the adaptive practices of prompting students for responses and modifying their instructions according to the needs of students. However, we also noted the lack of variations in the adaptive practices and observed that having a facilitative teaching style was more likely in demonstrating adaptive practices, compared to just possessing longer teaching experience. This research concretises the common adaptive practices that Singapore teachers demonstrate and form a common basis of understanding for conversations and discussions of adaptive practices to take place. The potential lack of motivation of teachers to demonstrate different adaptive practices could also promote changes in the professional development of teachers and the general education landscape in Singapore. As this research was done on a small sample pool, hence the generalizability of this research is limited. Future research could be done on a bigger pool to obtain a more conclusive result in the adaptive practices of teachers. Moreover, future studies could also aim to explore the possible reasons for the lack of assessment adaptive practices demonstrated among the Singapore teachers.

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Appendix

Appendix 1: Coding Guide with Criterions

No.	Indicator	Criterions
Assessment		
1	The teacher negotiates learning activities/assessments with students, ensuring these are aligned with learning goals.	1. Discuss with students the learning activities to do 2. Aligned to students learning goal/objective
2	The teacher uses formative assessment to differentiate their responses to individual students.	1. Give a formative assessment (eg. Questions) and see who the weaker/stronger students are. 2. Differentiated responses/feedback; asking weaker students further questions or wait for the weaker student.
3	The teacher creates groups of students based upon formative assessment.	
Questioning		
4	The teacher prompts students to discover key concepts through responsive open-ended questions.	1. Teacher asks an open-ended question 2. Students will attempt to give responses

		3. Teacher will have to clarify the concept behind the question; students find out the answers themselves 4. Students have not learnt the concept yet.
5	The teacher prompts students to express their thinking and used this as a springboard for learning activities.	1. Teacher asks students to clarify their initial response 2. Lead to new ideas 3. Follow up response with teaching 4. Students have vague response/ no response that require clarification 5. Students ask some questions and then jump into new activity
6	The teacher uses questions to prompt deeper exploration of concepts or skills.	1. It is a clear indicator of a routine: following step by step 2. Student may/may not be familiar with the procedures 3. Students already learnt the concept, and hence probing for deeper exploration
7	The teacher prompts students to demonstrate open-mindedness and	

	tolerance of imaginative solutions to problems.	
8	The teacher provides a synthesis of class-generated ideas.	1. Gather ideas from students 2. More than one student responded 3. The teacher gathers the ideas and synthesise them under a single concept"
9	The teacher links when appropriate lesson concepts to previous chapters	1. Prompting students to link to previous chapters
Teaching of content		
10	The teacher provides new ideas or topics in response to student's question	1. Students ask questions beyond scope and syllabus 2. Teacher provides new ideas/ topics for discussion that may not be aligned to the original learning goal"
11	The teacher modifies their instructions during the lesson to increase learning opportunities.	1. The teacher observes a situation/problem from students 2. Made changes in the teaching approach 3. Change their approach or tweak their explanations, because they

		were not working and based on students' needs
12	The teacher provided imaginative suggestions to increase learning opportunities.	1. Use an analogy to illustrate a concept 2. Use teaching aid to illustrate a concept 3. To allow the concept to be more memorable for students"
13	The teacher demonstrates flexible pacing of lesson in response to student learning needs.	1. Make assessment of the situation (eg check whether students are on track while they are doing their own work or checking the time) 2. Decide whether or not to continue with the lesson"
14	The teacher demonstrates responsive use of literacy/numeracy interventions.	1. Breaking down a complicated word into their root words and explaining the meaning.
15	The teacher modifies homework in response to lesson progress.	
16	The teacher uses the surrounding as part of teaching material.	1. Use resources that are readily available in class 2. Resources were not prepared beforehand

		3. Use the object/resource to illustrate concepts or to make a point"
17	The teacher responds to students' questions and lead them to the concepts that they are teaching	1. An attempt to respond to student's question 2. Lead them to the concepts that the teacher is teaching

Appendix 2: Coding Results

Ms Ada

Indicator **(A)**	Trigger event **(B)**	Evidence of noticing **(C)**	Actions **(D)**
Teaching of content			
The teacher modifies their instructions during the lesson to increase learning opportunities.	Students were not making progress in their group work (0:36:30.7)	Fixated gaze on the work of individual students	Gave clues to the class
The teacher responds to students' questions and lead them to the concepts that they are teaching	Students in their small groups having difficulty to complete the tasks (0:38:43.5) & (0:43:32.7)		Answers each individual questions until the students understood
Questioning			

The teacher prompts students to discover key concepts through responsive open-ended questions.	Confusion about student's drawing (0:37:57.9)	Fixative gaze on student's drawing	Asking student to clarify and direct her towards the supposed concept

Mrs Brooklyn

Indicator **(A)**	Trigger event **(B)**	Evidence of noticing **(C)**	Actions **(D)**
Questioning			
The teacher prompts students to discover key concepts through responsive open-ended questions.	Asking students what the meaning of transport is (0:01:49.8)	Saccades gazes from Mrs Brooklyn and waiting for response	Responding to students according to their responses
The teacher prompts students to demonstrate open-mindedness and tolerance of imaginative solutions to problems.	Seeing that students were not responding to her question (0:03:47.2)	Saccade gaze on students and waiting for responses.	Asking students to make guesses
The teacher provides a synthesis of class-generated ideas.	Asking students what the main parts of plant are (0:11:35.0)	Saccades gazes on students and waiting for their responses	Responding to their answers and

			guiding them to answer
The teacher links when appropriate, lesson concepts to previous chapters.	Student asked a question about the features of a diagram that was shown (0:15:17.0)	Mrs Brooklyn stopped to listen to the question	Mrs Brooklyn linked content that students have learnt in the past and asked them if they can recall
	Diagram of sucrose on the whiteboard (0:21:16.3)	Fixated gaze for 1 second on the diagram	Prompt students to recall their knowledge of amino acids
Teaching of content			
The teacher uses the surrounding as part of teaching material.	To give example of transport system (0:06:10.1)	Fixated gaze in the classroom	Used the furniture arrangement in the classroom as an example
The teacher provided imaginative suggestions to increase learning opportunities.	Noticed that the diagram drawn resembles a leaf (0:08:26.1)	Fixated gaze on the diagram	Asking students what the diagram resembled

	Mrs Brooklyn used her own hand to illustrate the transport system of a plant (0:16:52.5)		Guide students through a thought process and use her hand for students to visualise
The teacher demonstrates flexible pacing of lesson in response to student learning needs.	Lesson time was ending (0:21:51:2)	Mrs Brooklyn turned to the clock multiple times to check the time	Moved on to the summary of the lesson
The teacher provides new ideas or topics in response to student's question	Student asked a question that was out of syllabus (0:22:47.8)	Fixated gaze on student and	Gave the student a simplified answer.
The teacher modifies their instructions during the lesson to increase learning opportunities.	Clueless faces of the students (0:18:30.6)	Saccades gaze on students and repeating her questions	Gave the students two options to choose

Mr Edmund

Indicator **(A)**	Trigger event **(B)**	Evidence of noticing **(C)**	Actions **(D)**
Questioning			

The teacher prompts students to discover key concepts through responsive open-ended questions.	To engage the whole class with the skittle packets (0:34:3.3)	Saccades gazes on multiple students in the class and check whether they are following	Asking students how to test whether skittles contains sugar
	Students were focusing on their books when Mr Edmund was speaking (0:04:08.2)	Saccades gaze on all students	Ask students to close their books and focus on thinking on the spot
	Student mentioned "solvent" in her answer (0:04:51.8)	Fixative gaze on student	Mr Edmund asked the student to explain what a solvent is, to test whether she really understands the concept.
The teacher prompts students to express their thinking and used this as a	Student mentioned "detoxify" in his answer (0:06:11.1)	Fixative gaze on student	Mr Edmund asked the student to explain the concept of

springboard for learning activities.			detoxify and extended the question.
	Students were focusing on him and seem like they understood the concept already (0:26:25.8)	Saccades gaze on students	Mr Edmund asked students why sugar cane derives a negative test for sugar
	Students brought in the example of Milo into the discussion on precipitate (0:36:59.9)	Fixated gaze on student	Mr Edmund linked the example of milo to their previous discussion on sugar
	Some students suggested using blood as a test sample (0:38:04.3)	Fixated gaze on student for 6 seconds	Mr Edmund brought in the example of urine from previous experience and gave the students a question about the example

	Student suggested using blood as test sample (0:39:18.1)	Fixated gaze on student for 6 seconds	Mr Edmund asked the class about the problems that may arise with using blood as a test sample.
Teaching of content			
The teacher provided imaginative suggestions to increase learning opportunities.	To explain the meaning of the word "saccharide" (0:19:50.5)	Saccades gaze on students	Mr Edmund describes a scenario and associate it with the meaning of the word
The teacher demonstrates responsive use of literacy/numeracy interventions.	Introduce the word "hydrolysis" (0:24:07.0)	Saccades gaze on students to see whether they are focusing	Break the word up into its constituent meaning.
The teacher modifies their instructions during the lesson to increase learning opportunities.	Students were unable to answer Mr Edmund's question (0:08:00.4)	Saccades gaze for students to answer	Provide clues for students

	Student gave a one-word answer (0:11:31.4)	Fixated gaze on student for 10 seconds	Drilled the student and asked him to explain his answer
The teacher uses the surrounding as part of teaching material.	To introduce the concept of sucrose (0:33:53.4)	Saccades gaze on students and asked students for candies	Using a skittles packet from a student to explain

Mr Ivan

Indicator **(A)**	Trigger event **(B)**	Evidence of noticing **(C)**	Actions **(D)**
Assessment			
The teacher negotiates learning activities/assessments with students, ensuring these are aligned with learning goals.	To match the level of difficulty of question to the students' proficiencies (0:21:39.6)	Listening to students responses when he asked the students what level of difficulties	Starting with an easier question then move on to a difficult question

		do, they want to be quizzed	
	Mr Ivan sees that the second question of the worksheet was very similar to the question that he just gone through (0:31:15.0)	Asking students if they are okay to try questions on their own	Letting students try the questions on their own
The teacher uses formative assessment to differentiate their responses to individual students.	Some students answered Mr Ivan's question faster than the rest (0:22:32.2)	Saccades gaze on students who have not answered	Wait for the slower students and get a student to explain how he got his answer
	Some students were still trying the questions while Mr Ivan wanted to move on (0:29:07.2)	Saccades gaze on students who were still doing	Letting them continue with the work while he moves on
Questioning			

The teacher prompts students to discover key concepts through responsive open-ended questions.	To lead students into giving him the desired equation/ answer (0:06:58.7)	Fixative gaze on the whiteboard	Give students a problem to solve, which is what signs should he change in the equation
The teacher prompts students to express their thinking and used this as a springboard for learning activities.	Student stuttered while answering Mr Ivan's question about current being the same at every point (0:04:43:0)	Fixative gaze on student while she was responding	Pick out the crux from her answer and got students to observe the point that the student brought out
	Seeing that there were multiple wrong answers on the whiteboard (0:13:28.0)	Fixative gaze on the answers	Explain the thought process to why certain answers can be eliminated immediately
	Students were not responding to his question (0:00:59:8)	Fixative gaze on students	Ask the student questions to give them a direction to work with

	Students answered the first question with ease (0:18:52.4)	Writing students answer on the whiteboard	Improvise the question to challenge them further
	Students gave wrong answers for a basic question (0:00:49.2)	Mr Ivan was surprised by the wrong answer	Ask students why they got the answer and lead them through a thought process
The teacher uses questions to prompt deeper exploration of concepts or skills.	To challenge the students after they were able to answer the previous question (0:11:24.0)	Fixative gaze on the whiteboard	Change the values of its original question and ask the students to attempt by themselves.
	Changing a variable in the stimulator (0:05:25.3)	Fixative gaze on student for 3 seconds	Ask the students to predict the effect of the change in variable
	A student requested to repeat Mr Ivan's teaching as he did not understand (0:25:38.2)	Fixated gaze on student for 7 seconds	Lead student to challenge the useful of the given formula and to manipulate it

	Extrapolate what students have learnt from current to voltage (0:20:48)	Fixative gaze on students for their responses	Ask students if characteristic of potential difference behaves the same way as current in series circuit
	Students were shouting wrong answers (0:10:09.8)	Fixative gaze on students	Asking the students how they got the wrong answers and lead them through a thought process that contradicts the wrong answer.
The teacher provides a synthesis of class-generated ideas.	Students were shouting random answers in a messy fashion (0:12:31.6)	Stopping students and wrote their responses on whiteboard	Writing down their responses on the whiteboard
Teaching of content			
The teacher provided imaginative suggestions to	To illustrate how PD will be different across	Fixated gaze on students	Compare the resistance using analogy of a gym

increase learning opportunities.	different resistance value (0:15:00.0)	while explaining	goer and a frisbee player and associated their muscle mass with voltage
	Illustrate how PD is split across resistors (0:08:05.9)	Using soft balls to represent voltage.	Giving an equal number of softballs to each student
	To visualise current in a series circuit (0:03:21.3)		Give the analogy of a car and the road
The teacher modifies their instructions during the lesson to increase learning opportunities.	Sees that question 1 was too basic (0:24:04.6)	Fixated gaze on the worksheet	Asking students to skip the question to reduce time wasted
The teacher demonstrates flexible pacing of lesson in response to student learning needs.	Mr Ivan realised some students were not able to do their questions, while walking around to check their work (0:28:24.6)	Saccades gaze on the work of students	Cut short the time the students were given to work on their own and discuss the questions as a class

9. *Metacognitive Skills and Self-efficacy of STEM Students in Science Subjects and their Implications on Gender Inclusivity*

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Abstract

The low number of female students who want to pursue STEM-related careers have been attributed to stereotyped gender roles built by culture and society. In the Philippines, only 36% of the population of STEM graduates are female, placing the country as 52nd out of 114 economies. Current gender difference studies have demonstrated that female students have lower self-efficacy than male students in general science and STEM classrooms. Despite having comparable academic achievements, female students may still regard themselves as less competent than their male counterparts. Past studies have shown a positive correlation between self-efficacy and metacognition. These cognitive constructs are deemed as good predictors of academic proficiency. When students become aware of the knowledge they acquire and the processes involved in gaining such knowledge, they have a stronger self-belief about performing better in class. In this paper, we investigated self-efficacy and metacognition of senior high school STEM students using a validated Self-efficacy and Metacognition Inventory - Science (SEMLI-S) instrument. The results indicate high levels of metacognition and moderate levels of self-efficacy for both genders. A positive correlation was found between the two constructs but, notably, there were no significant gender differences in them. Implications on the promotion of metacognitive skills, improvement of self-efficacy, and further studies on factors affecting gender inclusivity are discussed in the paper.

Keywords: metacognitive skills, self-efficacy, STEM students, gender inclusivity

Introduction

A survey by Emerson Electric Co. reported by *The Manila Times* (2019) showed that 91% of Filipinos are inclined to pursue professions related to Science, Technology, Engineering, and Mathematics (STEM), with 80% being encouraged to do so. However, data from the UNESCO Institute for Statistics (Wadhwa, 2019) showed that only 36% of STEM graduates in the Philippines are female, ranking 52nd in 114 economies. The still lower participation rate of females in fields dominated by males has been attributed to gender stereotyping that casts greater competence, and self-efficacy, to males than females (Tellhed et al., 2017)

Self-efficacy refers to a person's belief about their skills and abilities to succeed or produce a satisfying outcome in a specific event or aspect in their lives. A person with a strong sense of efficacy perceives challenges as an achievable goal. They commit themselves to acquire sufficient knowledge and skills to overcome a failure or setback. In contrast, people who associate themselves to a lower competence tend to avoid difficult tasks (Bandura, 1994). MacPhee et al. (2013) found a low self-efficacy among women during admission to STEM education despite similar academic performances. Equivalent scores of men were only observed during graduation, which suggests the growing capability of women to regard themselves as equally competent to their male colleagues in STEM careers. In another study by Marshman et al.(2018), female STEM students with similar academic achievement had lower self-efficacy compared to males in a two-semester introductory physics class. Similar to Tellhed et al. (2017), they posit the effect of societal and cultural beliefs that lead to the formation of gendered stereotypes among STEM students.

A positive relationship exists between academic self-efficacy and metacognition (Hermita & Thamrin, 2015). Students who are conscious of their learning or only beginning to develop such consciousness have greater belief in their capacity to problem-solve, thus performing better in class. Other studies report metacognition and self-efficacy as domains which can predict academic motivation (AL-Baddareen et al., 2015) and achievement in STEM subjects (Habib Al Huseini, 2015). Metacognition, or “thinking about thinking,” is the ability of a person to apply higher order thinking skills to create the best solution to a problem. Thomas et al. (2008) classified two subdomains of metacognition in science learning: (1) constructivist connectivity; and (2) monitoring, evaluation & planning. Constructivist connectivity refers to a student’s ability to view science knowledge and information in a more holistic manner going beyond the traditional classroom and laboratory setting to apply their learning. Monitoring, evaluation, and planning pertain to a student’s capability to incorporate strategies in learning science to other subjects.

Given that there are limited local studies, this paper focuses on the differences among male and female senior high school students' metacognition and self-efficacy. Our goal is to determine the association between the domains of metacognitive skills (MS) and science learning self-efficacy (SE) of STEM students and understand their implications on gender inclusivity in STEM education. We adopted the division of MS into two subdomains, constructivist connectivity (CC) and monitoring, evaluation, and planning (MEP) from Thomas et al. (2008). In their study, the authors discovered the positive correlation of the two subdomains to SE. Our research attempts to determine the reliability of the instrument to local respondents. Specifically, this study pursues shedding light on the following research questions:

- What are the levels of metacognitive skills and science learning self-efficacy of STEM students?
- Is there a significant relationship between metacognitive skills subdomains (constructivist connectivity and monitoring, evaluation, and planning) and science learning self-efficacy of STEM students?
- Is there a significant difference between male and female STEM students with respect to metacognitive skills and science learning self-efficacy?

Research Methodology

This section of the research discusses the research design, research locale, instrument, data gathering procedure and data analysis.

Research Design

Since the main purpose of the research study is to determine the association between the metacognitive and self-efficacy domains of SHS students and compare across males and females, this research utilized a descriptive correlational research approach. Gay et al. (2012) characterizes quantitative research as a method that depends on the collection and investigation of numerical data sets to state, describe situations, elucidate relationships between variables, or predict the outcome of an investigation based on the variables studied. Fraenkel and Wallen (2012) also labels quantitative research as having a "singular perspective" which operates widely on a series of agreed steps and serves as a guiding point for researchers in conducting research endeavors.

More specifically, the study employs a descriptive correlational design. Descriptive correlational studies describe, discover, and measure the variables and the relationships among them (Choy, 2014). A correlational research design allows multiple variable analyses for relationships or association of variables. This was deemed acceptable for the study since it explores the question of difference and association among variables presumed to be related to gender differences.

Research Instrument

The survey Metacognition, Self-efficacy, and Learning Processes of STEM Students in Science Subjects, adapted from Thomas et al. (2008) was used. The survey, previously developed and validated, contains 30 items on various aspects of science students' metacognition, self-efficacy, and learning processes. We sought permission from the authors to utilize the research instrument.

Research Locale and Participants

Grade 11 STEM students from an institution in Makati City, Metro Manila, Philippines were recruited through convenience sampling. This institution is one of the first Higher Education Institutions to offer Senior High School, and its academic tracks in the Philippines. Students who pursue the STEM strand here are further classified according to their preferred future careers. A total of 122 valid responses from the survey were collected. Participants were all STEM students who plan to pursue various fields in science and technology such as multimedia arts (13.9%), engineering (36.1%), information technology (34.4%), and pure science (15.6%). The sample in the study, regardless of preferred career choice, consisted of 69 male and 53 female students.

Data Gathering Procedure

The survey was given to 122 STEM students from December 14, 2020 to January 11, 2021 using Google Forms. Each item in the survey was answered based on the students' self-assessment scale of 1- *never or almost never*, 2- *sometimes*, 3- *half of the time,* 4 – *frequently*, 5 – *always or almost always*. The survey consisted of five dimensions: (1) constructivist connectivity (CC), (2) monitoring, evaluation, and planning (MEP), (3) science learning self-efficacy (SE), (4) learning risk awareness, and (5) control of concentration (Thomas et al., 2008). For the purposes of this paper, authors will report only the results for CC, MEP, and SE. The results of the survey were tallied and encoded automatically through Microsoft Excel.

The research study safeguards data confidentiality by assigning respondents codes outrightly during data clean-up. Coordination from the institution and the class advisers was made possible by conveying participants as well as to teachers about the purpose of the study. In addition, participants' willingness to be a part of the research undertaking was the main consideration in carrying out the survey process.

Data Analysis

After encoding and clean-up, the collected data was analyzed using SPSS. Correlation coefficients of paired variables were determined to assess the nature and strength of association between them. Analyses from the obtained values were used to establish relationships between variables. The level of significance was initially set at 0.05.

For research question 1 which aimed to determine the metacognitive and self-efficacy levels of STEM students when taken as a whole and according to sex, mean and standard deviation (SD) were used.

For research question 2 which sought to determine the relationship between CC, MEP and SE, Pearson-r correlation between domains was utilized.

For research question 3 which is intended to compare the differences between the three dimensions used in terms of male and female STEM students, *t*-test for independent sample was employed.

Results and Discussion

The aim of this study was to ascertain the level of metacognition and self-efficacy of STEM students. It also aimed to determine if there are differences in the three dimensions with respect to sex and to assess interrelationships.

Metacognition and Self-Efficacy of STEM Students

Table 1 below shows the descriptive statistics of STEM students' level of metacognition and self-efficacy. Results revealed that the MC yielded a mean level of 3.53 with a standard deviation of 0.76 and was interpreted as high (Thomas et al., 2008). On the other hand, the SE has a mean level of 3.20 with an SD of 0.75 and was interpreted as moderate. The small dispersion of the responses of the students as reflected in the standard deviation of the data set suggests that STEM students generally have a high level of metacognition and moderate level of self-efficacy.

Table 1

Level of Metacognition and Self-efficacy of STEM Students in terms of Sex (n = 122)

Domain	**Dimension**	**Gender**	**Mean ± *SD***	**Qualitative Interpretation***
Metacognitive Skills	CC	Male	3.47±0.71	High
		Female	3.64±0.89	High
			3.54±0.79	High
	MEP	Male	3.47±0.70	High
		Female	3.58±0.74	High
			3.51±0.72	High
	Grand Mean		3.53±0.76	High
Self-efficacy	SE	Male	3.25±0.73	Moderate
		Female	3.13±0.78	Moderate
	Grand Mean		3.20±0.75	Moderate

*1.00-1.79 very low, 1.80-2.59 low, 2.60-3.39 moderate, 3.40-4.19 high, 4.20-5.00 very high

It can be noticed in the CC and MEP dimensions of the metacognitive skill domain that the mean of the males and females are close to each other having the same set of interpretation as high. Further, in the SE dimension of the self-efficacy domain, both sexes perceive moderate level of self-efficacy. The results suggest that students' perception of their metacognitive and self-efficacy skills is similar. In terms of the metacognitive domain, Thomas (2015) argued that the main goal of developing learners' metacognition in science is to assist them in becoming independent and effective learners who can adapt their thinking and learning structures to the progressing science content beyond their high school years. Thomas et al. (2008) stated that CC explore students' acuities as they construct meaningful connections between the information and knowledge across various scientific learning disciplines. MEP on the other hand mirrors traditional metacognitive perspectives which are important in learning science contents (Thomas et al., 2008). Studies carried out by Belet and Guven (2011), Rico and Ertmer (2015), Diaz (2015), and Alt (2015) across various disciplines noted that learners having high level of metacognition can properly control learning to construct their understanding. It was also illustrated in the studies that metacognitive awareness improves learning ability, retention, and achievement. As implied by various research conducted, high level of metacognitive awareness of STEM students allows them to easily conceptualize, control and regulate their science learning processes which guides them to better understand science content as they develop critical thinking about learning.

Self-efficacy has been shown to affect academic achievement, perseverance, and self-regulation (Trujillo & Tanner, 2014). In particular, self-efficacy and academic achievement were found to be highly correlated (Aurah, 2017). The moderate level of self-efficacy of STEM students towards learning science subjects, as shown in the table above, suggests a need for STEM teachers to provide learning experiences that foster self-efficacy.

Relationships among Constructivist Connectivity, Monitoring, Evaluation & Planning, and Science Learning Self-efficacy

Table 2 presents the relationship of the dimensions of the metacognition and self-efficacy. When compared with each other, MEP (r=0.454; $p<0.01$) and SE (r=0.375; $p<0.01$) both are significantly related to CC. Moreover, the results demonstrate a significant relationship between MEP and SE (r =0.507; $p<0.01$).

Table 2

Relationship of Constructivist Connectivity, Monitoring, Evaluation and Planning, and Science Learning-Self efficacy Domains (n = 122)

		MEP	SE
	Pearson Correlation	.454*	.375*
CC	Sig. (2-tailed)	.000	.000
	N	122	122
	Pearson Correlation	1	.507*
MEP	Sig. (2-tailed)		.000
	N	122	122

*correlation is significant at the 0.01 level

The inferential statistics results indicate a weak positive significant association among MEP and SE with regard to CC and a moderate positive significant association between MEP and SE. This means that students with high levels of CC are most likely to have high levels of MEP and SE. This significant link between metacognition and self-efficacy recalls the earlier research studies of Kirbulut and Gökalp (2014), Thomas and Anderson (2014), Ridlo and Lutfiya (2017), Tian et al. (2018), and Kirbulut and Uzuntiryaki-Kondakci (2019). Critical and individual thinking, which are all associated with metacognitive ability, aids learners in developing a greater sense of self-efficacy (Cera et al., 2014).

Gender-based Comparison of Metacognition and Self-efficacy of STEM Students

An independent sample *t*-test was utilized to compare the levels of MC and SE of the students in terms of sex. Results shown in Table 3 indicate no significant difference between sexes with respect to the three variables analyzed. Statistical results yielded the following: (1) SE; $t(120)= 0.848$, $p= 0.398$, (2) MEP; $t(120)= -0.832$, $p= 0.407$ and (3) CC; $t(120)= -1.219$, $p=0.225$. Since all $p>0.05$, we accept the null hypothesis of no significant difference between males and females.

Table 3

Difference on the Level Metacognition and Self-efficacy of STEM Students according to Sex

Domain	Sub domain	t	*p*-value	Decision	Interpretation
Metacognitive Skills	CC	-1.219	0.225	Accept H_o	No significant difference
	MEP	-0.832	0.407	Accept H_o	No significant difference
Self-efficacy	SE	0.848	0.398	Accept H_o	No significant difference

The results above suggest that the male and female groups were equivalent in terms of the levels of the three dimensions of the learning processes. The MEP and CC imply no significant variation between males and females. The findings of the statistical analysis imply that the metacognitive ability of males and females does not differ when learning STEM related content. Since there is scarcity of studies in general that evaluate the metacognition of students in STEM education, several studies across various disciplines of STEM exhibited dissimilar outcomes when it comes to gender-based comparison of metacognition. In physics, Sagala et al. (2019) found out that males have a higher metacognitive ability than females while in mathematics and chemistry, Misu et al. (2017) and Ahmed et al. (2019) found no significant differences in the metacognition between sexes. In the research study, since no significant variation between sexes was demonstrated, it recognizes the need to further investigate on the metacognitive ability of the students in STEM education here in the Philippines in particular to assess the metacognitive skills and self-efficacy of STEM students and their implications into teaching and learning science related contents.

Many international studies have reported that females tend to have a lower self-belief than men in terms of STEM relevant activities, including math and sciences (Huang, 2013; Marshman et al., 2018; Mozahem et al., 2020; Nissen, 2019). Women have been found out to be less involved in STEM careers than men because of gender stereotyping, which is perceived to be a major social practice influencing gender differences in STEM (Makarova et al., 2019; Maltese & Cooper, 2017; Pietri et al., 2019; Robnett, 2015). Another way that gender stereotyping is reinforced is the boosting of a masculine image of STEM and its related fields resulting to females showing less interest in science-related disciplines.

However, the result of the self-efficacy aspect of the study is in contrast with the findings of the studies presented above. Our study found out no significant difference in the SE of male and female STEM students. The result imply that the SE domain of males and females are equal, and it is not likely to contribute to gender disparities and stereotype in STEM education. In the Global Gender Gap Report 2020 of the World Economic Forum, the Philippines remains the top country in Asia and ranked 16th out of 153 nations in the world with the thinnest gap between men and women (World Economic Forum, 2020). In addition, the report indicated that the literacy rate for both sexes is above 98% and that there is a larger percentage of women pursuing secondary and higher education when compared to other countries. However, 41% of women are taking IT related course and 43% make up STEM enrolments. The current scenario thus demands the commitment to improve education and bridge gender gap through various non-profit organizations and educational initiatives like *Sulong EduKalidad* that heeds the Department of Education forward by introducing aggressive reforms to globalize and expand the quality of basic education in the Philippines and Education 2030 Framework for Action adopted by 184 UNESCO member states, including the Philippines to advance an inclusive, equitable quality education and lifelong learning for all, empowering women to be involved more in STEM-related careers (Commission on Higher Education, 2017; Department of Education, 2020).

Conclusion

In the study, the researchers determined the positive correlation between metacognitive skills and self-efficacy of STEM students. The positive significant relationship suggests that students have higher belief in their capability to solve problems when they are aware of the processes taken to acquire scientific knowledge. High levels of metacognitive skills, exhibited by data gathered from CC and MEP subdomains, indicate the students' appreciable degree of awareness of their learning. To maintain this behavior, teachers are therefore encouraged to engage their students in activities that promote self-reflection. In contrast, relatively moderate self-efficacy scores indicate that students are conscious of the information they receive, however, they are still apprehensive of their ability to effectively provide a solution to a problem. Implications on pedagogy include the practice of consistent positive reinforcement towards behavior and learner-centered teaching techniques such as peer mentoring, problem-based learning, and inquiry-based laboratory experiments. Gender-based analysis of data showed that male and female students did not have a significant difference with respect to metacognitive skills and science learning self-efficacy. Therefore, these variables do not present as determining factors to issues on gender differences in STEM education. Further research is suggested with consideration to other factors affecting gender inclusivity such as gender perception, masculinity/femininity index, and self-regulated learning (Majere et al., 2012; Popp et al., 2019; Wild, 2015).

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10. Students’ Use of Representations in Physics Problem Solving

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Abstract

Students solve problems when they are learning physics. Even though students are learning the same set of physics content knowledge, different students experiences different success in problem solving. While studies have shown that woe of the attribution to students' successes in physics problem solving is the competence in the use of representations, there is not enough study on the actual process of how multiple representations are used during the problem solving process. Thus, this study looked at students' use of representations during problem solving. Each student solved a problem through a semi-structured interview which was transcribed. The data were analyzed using open coding and through perspective of social semiotic theory of multimodality. It is found that successful problem solvers use representations in a series of coherent representational passes to shift meaning making from concrete to abstract and from general knowledge of a phenomenon to specific context of the problem. This study may encourage teachers to be more aware of how students use representations to solve problems and how meanings are made through an ensemble of representations. Such heightened semiotic awareness should help teachers to give better feedback to students on how they can better use representations to solve problems.

Keywords: Representations, problem-solving, social semiotic, multimodality

Introduction

One activity that everyone does in everyday life, in professional job settings and in schools is problem solving. Many curricula around the world have included problem solving as an important learning outcome to develop (e.g., Ministry of Education [MOE], 2019; Australian Curriculum, Assessment and Reporting Authority [ACAR], 2020; New Zealand Ministry of Education, Te Kete Ipurangi [TKI], 2020). Not all problems are the same. There are ill-structured problems that consist of multiple possible solutions, multiple ways to get to the solutions, and may not have definite concepts, rules or principles that can be applied to determine their solutions (Jonassen, 2000). Scientists developing a vaccine for a virus is one such ill-structured problem. On the other hand, students typically work on well-structured problems that have convergent solutions, require the application of a limited number of concepts and rules within well-defined parameters. Students engage in problem-solving in the course of learning physics concepts.

Solving well-structured problems does not mean that they are easy. Several problem solving studies (e.g. Chi et al., 1981; Hardimen et al., 1989) showed different degree of success in solving the problems when experts and novices were provided with the same well-structured problems. This differing problem solving capability is also suggested in the annual national examinations. Despite students learning the same physics content knowledge, students obtain a spread of results which might indicate the different students' successes when come to problem-solving.

Studies have shown that students' representational competence affects how well they solve problems. For example, Rosengrat et al. (2009) found that students who drew free-body diagram tend to solve problems more successfully than those who do not. Representations can be considered as artefacts that stands for something else (Tang, et al., 2014). For example, a symbol "λ" can stand for the wavelength of a wave and "λ" can be manipulated in an equation during calculations. Representational competence refers to a set of skills and practices for students to use representations to think about and communicate the meaning imbued in these artefacts (Kozma & Russell, 2005).

While the importance of using multiple representations in problem solving is well known, there are few focus on how representations are used or connected to one another. There was also a lack of documentation of how meanings were extended within the same mode of representations – how the structure of a text representation bring out meaning from a macroscopic description to an abstract account. In Kress's (2010) words, the *transduction* of meanings made from one mode to the other and the *transformation* of within the same type of representations are not studied in detail.

The objective of this study was to investigate how students use the different types of representations to make meaning during physics problem solving. The investigation to how students use various types of representations that are interconnected might provide insights as to why some students are successful in their problem solving but some are not.

This study aims to address one key research question:

- What and how were multiple representations used by students during successful and unsuccessful solving of physics problems in the topic of wave superposition?

The findings in this study may be of interest to educators in the STEM (Science, Technology, Engineering and Mathematics) classroom. This study may encourage teachers to be more aware of the behavior of how students use representations to mediate their thoughts, have a better idea of how meanings are made through an ensemble of representations and therefore provide feedback for students' improvement. This study also complements popular problem solving strategy such as the Poyla's four step process for problem solving:

1. Understand the problem. Problems are presented through representations, thus the meaning making through the use of representations starts off in the understand of the problem
2. Devise a plan. For example, equations are formed; diagrams or graphs were sketch to derive relations, hence the thinking of a plan is mediated by the use of representations
3. Carry out the plan. This could mean how one type of representations leads to other types of representations and how meanings were made and extended through such transitions.
4. Look back. This step is to evaluate students' answers to the problems. Perhaps, the checking of answers is through triangulations with multiple representation to make a coherent description of the phenomenon.

Hence, the study provides descriptions of more detailed behaviours to achieve the steps described above, so that teachers can give advice to students for improvement.

Theoretical Framework

This study draws on Kress' (2010) social semiotic theory of multimodality and Jonassen's (2000) typology of problem and problem solving to inform its theoretical framework. The theory of multimodality is applied to how students use representation. It assumes that communication is always multimodal; representations are socially constructed and students *select* representations that are most apt to them in working on the task(s) at hand. These assumptions are applicable to the learning of physics. Physics ideas are communicated through multiple modes of representations – text, graphs, diagrams and mathematical equations. There are formal language with which people within the physics community use to communicate and build knowledge with one another. Thus, learning of physics in school also involves acquiring the skills to interpret meaning from these formal languages and use them to solve problems. In addition, under the theory, students' *use* of representation is seen as a *selection* of representations that are most apt to them. In a typical science classrooms that discuss on the formal languages of science, students usually do not create a representation to describe new scientific discovery like how scientist such as Michael Faraday constructed new representations to communicate his discovery (Gooding, 1983). It is also to note that this study views the use of representation is note limited to just communication, but also thinking, as language tools such as representations mediate thinking (Vygotsky, 1978).

Jonassen's (2000) typology of problem and problem solving is applied in how this study view *problem*. A problem consists of an unknown and finding the answer to that unknown is beneficial to the problem solver (Jonassen, 2000). The problem described in this study is quite different from those faced by scientists. The problem in this study is known as "Story Problem", also known as word problem that has embed algorithms, rules, and procedure of solving into a context (Jonassen, 2000). Such stories problems are well-structured and have pre-determine answers. Therefore, the success of solving story problems is determined whether the answers match pre-determined answers either as numerical values or in written texts. These problems are similar to those that students usually face in textbooks or during examinations.

Methodology

Semi-Structured Interview

Students were invited to a one-to-one think-aloud interview with the researcher in order to observe the problem solving process. During each interview, the students solved a problem, followed by a semi-structured question-and-answer session to clarify the use of representations. The question-and-answer session served as a members' check (Barriball & While, 1994), allowing the researcher to clarify the meaning of the representations imbued by the students and verifying his own interpretation of the representations used by the students. The interviews were video and audio recorded. The students were encourage to voice out their thinking process during the problem solving. The video camera allowed the sequence of their use of representations while the audio recorder captured students' verbal explanation clearly. The video and audio data were then transcribe in such a way that the verbal speech, written text, diagrams, equations, gestures and any other semiotic resources used were presented in parallel in a chronological order (as seen in Bezemer & Mavers, 2011)

Field Site

This study was carried out in a junior college (JC) in Singapore. The JC programme is a two-year course, in which students will sit for the Singapore-Cambridge General Certificate of Education Advanced Level (GCE A-level) examinations. One of the subjects offered at the GCE A-level examinations is the Higher 2 Physics (H2 Physics). The students enrolled in this JC have obtained an average score based on their L1R5 (1 Language and 5 Relevant subjects) in their GCE Ordinary level – also a national based examination.

Students

There were 17 students that took part in this study. They were all in their final year of the JC programme (JC2). These students were purposefully selected because they have completed the teaching instructions of all the required content knowledge of the H2 Physics syllabus and have revised the content and skill to solve physics problems. This study would like to look at how students solve problems.

The Problem

The problem was purposefully crafted in this study for the students to exhibit problem solving behaviour using multiple representations. In this study, the topic on Wave Superposition was selected due to the need for multiple types of representations to solve problems. For example, there are wave profile for stationary waves in a tube as shown in figure 1, as well as the usual wave equation that relates the frequency, wavelength and speed of the wave. The problem is attached as Appendix A at the back of this write-up for reference.

Data Analysis

The analysis of the data focused on the representations that were externalised and captured on different media of data collections as mentioned earlier. This study is interested in looking more intently on how one type of representation was linked to other representations, as well as how the meaning through the use of different types of representations are extended.

Open Coding was used in this analysis. The use of the representations was classified into categories: "sequence of representations"; "problem solving behaviour"; "types of representations"; "functions of representations"; "transition"; "abstraction level" and "context". A consolidated codes used are summarised in table 1.

Table 1

Codes for Analysis of Data

Categories	Codes
Sequence of representation	• One Chain • Branches
Problem Solving Behaviour	• Identify Entities • Introduce Entities • Description (Text) • Description (Diagram) • Relating • Calculating

Types of Representations	• Text • Diagram (Object) • Diagram (Phenomenon) • Equation • Gesture
Functions of Representations	• Description • Naming • Link abstract to concrete (2D) • Link abstract to concrete (3D) • Algebraic Manipulation • Relation • Calculation / Conclusion / Final Answer
Transitions	• Transformation • Transduction
Abstraction Level	• Abstract • Concrete
Context	• General • Specific

Findings

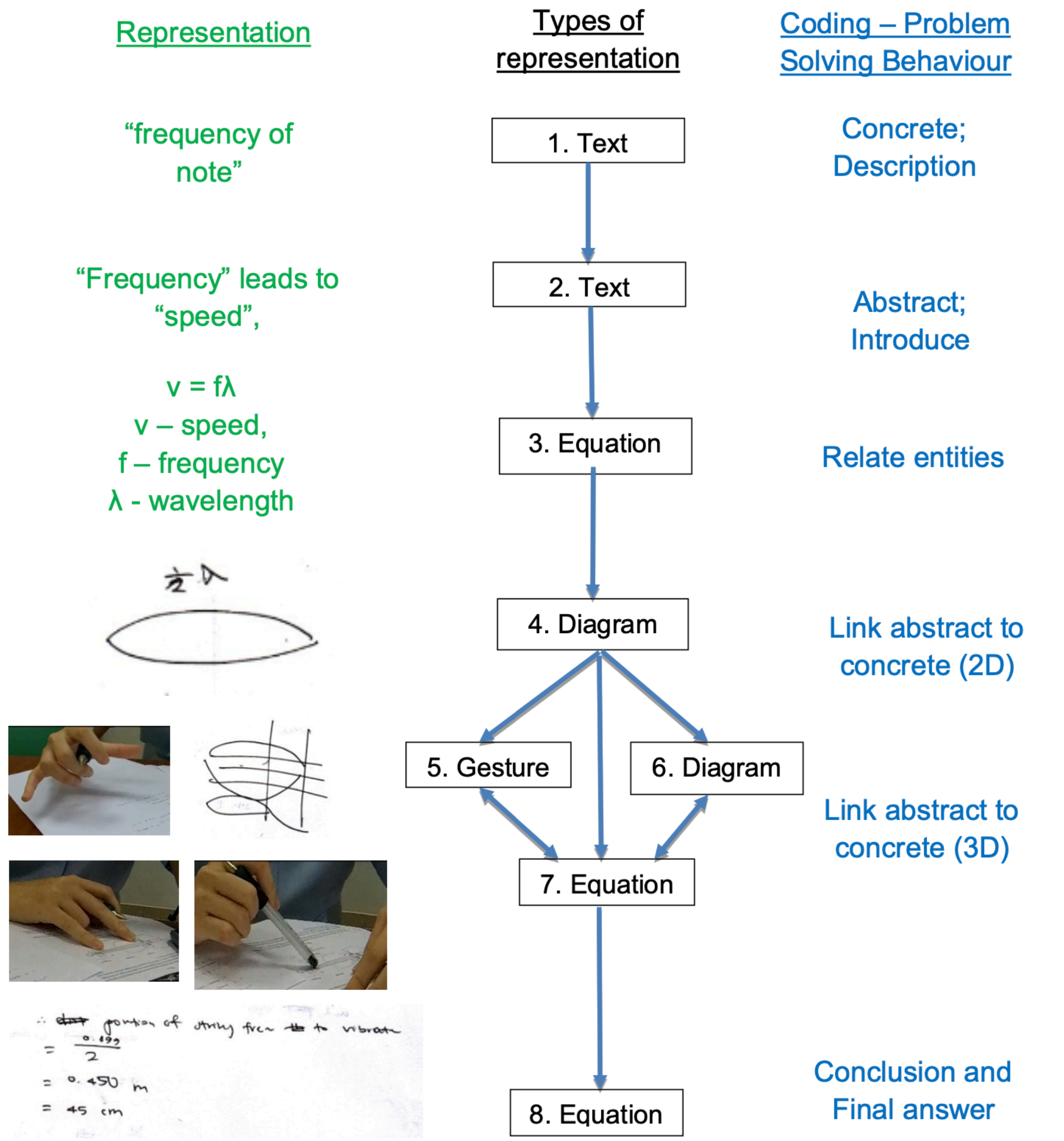
This study investigate how students use representations during physics problem solving. Out of the 17 students interviewed, 9 students were successful in their problem solving and 8 students were unsuccessful. The sole criterion for success was whether the students obtain the correct value for the final answer.

Successful Problem Solvers

One of the successful problem solvers was student 16 and her sequence of representation used is as shown in figure 2. Student 16 started off with saying the phrase "frequency of note" which is a text representation (1.Text). Since the frequency of the note was provided in the problem, the student worked in the concrete description of the problem. Then, she articulated "frequency leads to speed" (2. Text), in which she introduced an entity that was not found in the given problem. Then, she related the quantities that were in the problem and those that she introduced in a mathematical equation, $v = f\lambda$ (3.Equation), thus using the representations to relate entities. Up until this point, the representations used were considered general – frequency, speed and wavelength are inherent properties of waves and can be applied across different context. Student 16 drew a diagram (4. Diagram) that resemble half a wavelength and constrains the diagram's meaning of half a wavelength by writing $\frac{1}{2}\lambda$. In drawing this diagram, it was an attempt to link the abstract quantities that she had written in the equation to the concrete aspect of the wave. In particular, she drew more diagram (6. Diagram) that had a wave profile over the violin string. This diagram was an overlap between the concrete length as well as the invisible stationary wave, thus suggesting that she was trying to link the abstract to the concrete aspects of the phenomenon. Furthermore, her gesture of two finger spanning across a distance on the string of the violin further supports the idea that she was trying to link abstract to the concrete, but this time in the 3-dimensional space. Her gesture was done outside of the confinement of the 2-dimensional paper. It is to note that there are double arrows in the figure to show that student 16 went back and forth through the representations that she had selected to link the abstract and the concrete. Finally, since the problem requested for a numerical unknown, student 16 selected equations to manipulate and calculate for her conclusion and final answer.

Figure 3

Student 16 successful problem solving sequence



In other words, students 16 use of representations was only one series of coherent physics sense making, where the meaning is made and extended with each subsequent use of representations. In her problem solving, her coherent representational passes in her move from concrete macroscopic aspects to the abstract descriptions of the phenomenon and form the abstract description to the final concrete answer of the length of the string. Her application of general knowledge about the topic to the specific context of the problem can be identified through her diagrams, equations and even gestures.

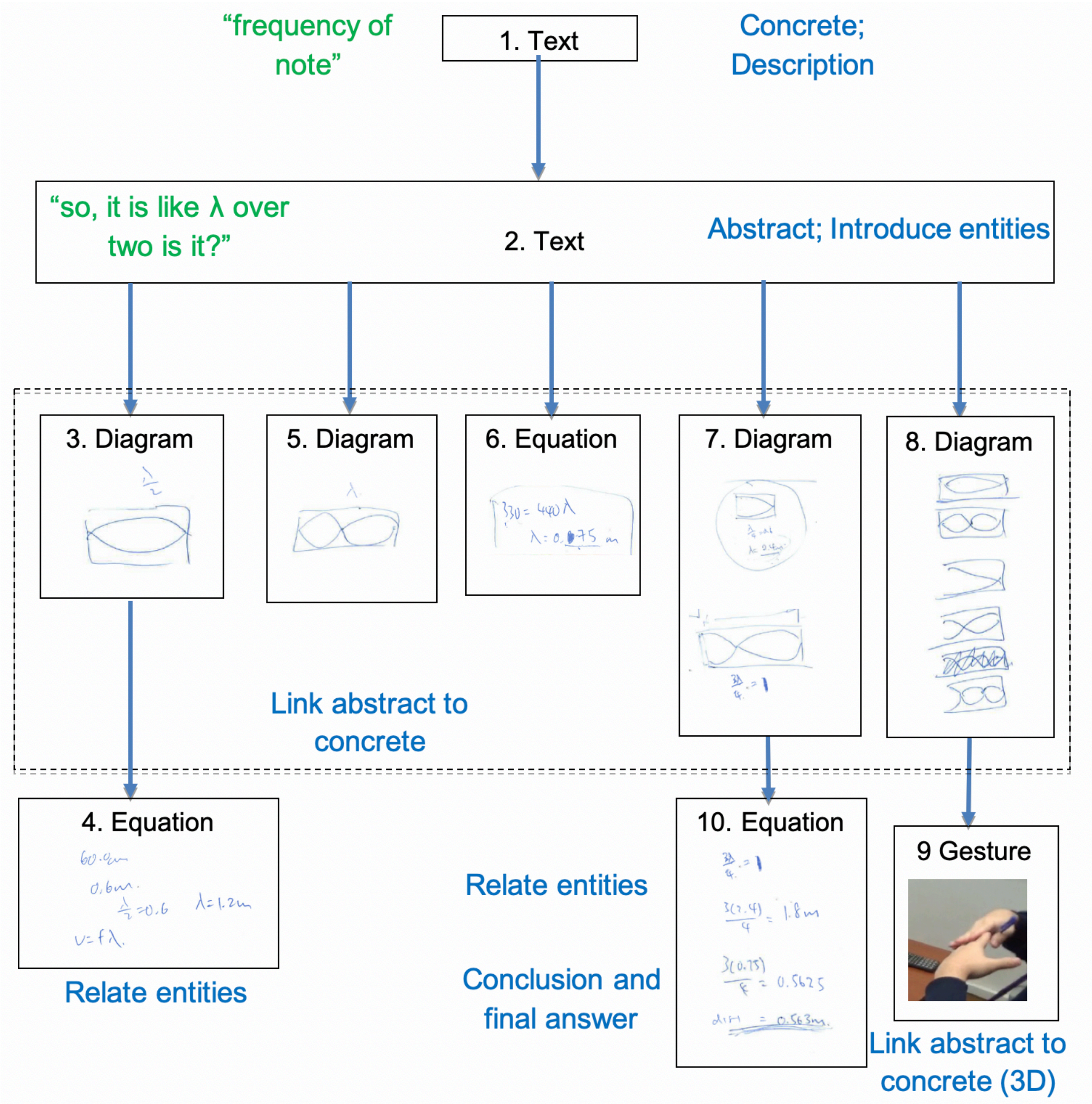
Unsuccessful Problem Solvers

One of the successful problem solvers was student 4 and his sequence of representation used is as shown in figure 3. Student 4 started his problem solving in a similar manner as student 16. He articulated descriptions of the problem through the frequency of the notes (1. Text) and introducing entities (2. Text) through verbal text representation. Next, he drew diagram of half a wavelength profile (3. Diagram) and a mathematical equation (4. Equation) to constrain the meaning made in the previous diagram. Somehow or another, he proceed to draw diagrams (5, 7, 8. Diagram) with almost no link with (3. Diagram) and (4. Diagram). He also used gesture (9. Gesture) to explain the phenomenon of superposition. At last, he chose to complete his answer through extending the meaning from (7. Diagram) by using equations to relate numbers together.

In other words, students 4's use of representations consisted of multiple series of representational passes that were not linked. Looking back at the representations that student 4 had used, they were replicates of the canonical representations that can be found in textbook. That is to say, the representations reflected that student 4 had yet to move into the specific context from his pool of general knowledge about the phenomenon. All his branches of representations seemed to be in search of the right set of representations to solve the problem, but was eventually unable to get to the specific context of the phenomenon. This branch-like behavior is very similar to the "backward search strategy" (Priest & Lindsay, 1992) in which students look for the "right" representation to get an answer out of the many representations that the students generated based on the end goal of the problem. Dhillon (1997) documented such behaviour by the unsuccessful problem solvers who focused on solving the problem while the successful problem solvers tried to visualise the problem.

Figure 2

Student 4 unsuccessful problem solving sequence



A Model of Representations used for Successful Problem Solving

Figure 3

A model of representations used for successful problem solving.

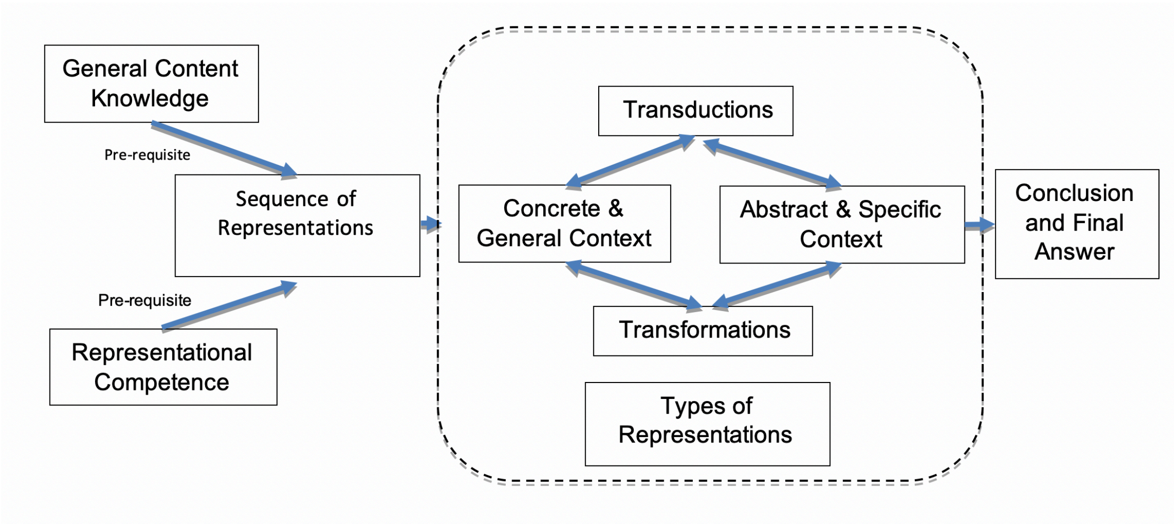


Figure 3 shows a model of representations used for successful problem solving.

One main different that was seen between successful and unsuccessful problem solving is whether the process is just one series of coherent representational passes or multiple branches of representations use without a coherent link to the specificity of the context of the question. In successful physics problem solving process, I observed that there was no one definite sequence in terms of a student must follow from equations to graphs or graphs to equations. However, successful problem solving process goes back and forth between concrete and general context, and abstract and specific context through the use of representations, through the process of *transduction* and *transformation*. Transduction is where there is meaning is made across different types of representations while transformation is where the meaning is made with the same type of representations. There are other factors that affected unsuccessful problem solving, such as the representation competence and the general content knowledge.

Conclusion

Key Findings

All successful problem solvers use representations as a series of coherent representational passes in which the meanings made during the process of problem solving shifts from concrete to abstract and vice versa. Students select the different types representations for the affordances to extend their meaning making process and construct fuller descriptions of the physics phenomenon. On the other hand, some unsuccessful problem solvers used multiple series of representational passes in which the meanings made in one series might not necessarily be consistent with the meanings made in another series. The fluent shift in meanings from concrete to abstract and from general to specific was also lacking in unsuccessful problem solvers' use of representations. This study also concur with the literature that students' representational competence also plays a part in their success in problem solving.

Implication for Practice

As successful problems solvers use different types of representations and undergo a series of representational passes, teachers could focus and plan on developing rich descriptions of the physical phenomenon presented in the problems through different types of representations. Teachers could focus on the unique affordances of each type of representations and how representations are introduced in various steps of problem solving and help students shift their meaning making process from concrete to abstract and from general to specific (and vice versa). It is also hoped that teachers are able to spot students who are stuck in the process of physics meaning making through their use of representations and identify students using the "backward search strategy" so that appropriate feedback could be given.

Teachers could also use the findings to facilitate students' self-directed learning and exploration in a STEM education. This study provides insight to a phrase that is commonly seen in learning outcomes, "apply <certain physics concepts> to solve problem", and how this application actually looks like. Such insights may bridge the gap in students who say that they "know" the concepts, but they do not know how to "apply". Rubrics can be develop so make students aware of the need of coherent representational passes to shift meaning making between concrete and abstract, and between specific and general, allowing students to reflect about their problem solving behavior and improve.

Future Work

Small number of 17 students may not be enough to generate a robust theory on the use of representations. Furthermore, only one topic on wave superposition is studied. More study is required to see whether the problem solving behaviours are also seen in other topics. Lastly, ia very possible next step beyond the development of a propose theory on successful physics problem solving would be to design actions in instructions to students, so that we can move students from a state of unsuccessful problem solver to a successful one.

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Appendix A

The Problem

When the violinist presses one of his fingers onto the string along the fingerboard, the portion of the string that is free to vibrate is the section in between the bridge and the violinist's finger.

One of the strings sounds a musical note of frequency 440 Hz when the violinist draws the bow across the string with none of his fingers pressing on the string of the finger board. The portion of this string that is free to vibrate is 60.0 cm long.

If the violinist were to play a musical note of frequency 587 Hz, determine the distance from the bridge that his finger should be placed along the fingerboard. Assume that the string vibrates in its fundamental frequency when both the musical notes of frequency 440 Hz and 587 Hz are played.

11. The Formation of Engineers in the Research Lab: A Cognitive Ethnographic Study

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Abstract

Studies of students' research experiences have shown benefits in STEM education in K-16 setting. However, few studies of research experiences have focused on graduate-level STEM education and on students working in research labs. Here we report preliminary findings of an ongoing study, the purpose of which is to explore how learning occurs in the research lab, particularly among graduate students. Our primary methodology is cognitive ethnography, an ethnographic approach combined with cognitive science to study cognitive processes *in situ*. A participant observer is embedded in engineering labs, collecting data through field notes, informant interviews, online observation, and autoethnographic journals. Preliminary data analysis indicates that learning in the research lab basically operates as self-regulated learning. In addition, several intriguing phenomena were noticed: (1) organic instructional strategies facilitate learning in the lab, (2) person-to-person interaction is critical in the learning process, and (3) online lab meetings filled critical needs of students during the pandemic. In (1), we identified several cases of scaffolding strategies that are organically implemented, in other words, occurred without planning. In (2), we noticed that graduate students in the lab primarily learn what they need to learn through person-to-person interaction. We believe that this is one of the benefits that students obtain by joining the research lab. In (3), we noticed that during the pandemic, the lab meeting was the intellectual, emotional, and social gathering that holds the lab members together. In addition, we briefly described the impacts of the COVID-19 pandemic to learning in the engineering lab.

Keywords: STEM education, engineering education, research experiences, cognitive ethnography, learning processes

Introduction

Authentic research experiences are generally believed to play an important role in high-quality STEM education. Students are encouraged to take courses that imitate real world research settings or to work in research laboratories to experience authentic research. In higher education studies, most of the previous studies on students' research experience has focused on undergraduate students who chose to participate in actual laboratory research (Undergraduate Research Experience: URE) or courses with designed research experience (Course-based Undergraduate Research Experiences: CURE), and rarely included graduate students. Moreover, those studies usually focused on learning outcomes of URE and CURE rather than focusing on the learning process (Linn, et al., 2015; Madan & Teitge, 2013).

Most of the reported studies were based on the pretest—treatment—posttest design, reflecting the comparisons of outcomes before and after participating in URE or CURE (Linn, 2015). These studies often relied on surveys, test-based assessments, and grade-point averages (Slovacek, at al., 2012). To measure outcomes, various methodologies including retrospective surveys, mixed methods, interviews, study groups, and focus groups were used (Murdoch-Eaton et al, 2010). Only one study out of 60 had a core methodology that included a qualitative method of direct observation (Linn, 2015).). In CURE, the learning goals and learning outcomes are mostly well-defined, therefore surveys and knowledge/skills assessment may be sufficient to measure them. In URE, however, measuring outcomes of authentic research experiences depends on specification of learning goals in a given laboratory context. If authentic research experiences are not tailored to pre-specified learning goals, one cannot simply measure the learning outcomes. In such a case, cognitive ethnographic approach can help identify both *what* is learned as well as the specific learning processes. Cognitive ethnography is a particularly well-suited methodology for studying the complex social processes of research laboratories, including the learning that takes place within and by the laboratory system (Hutchins, 1995).

The purpose of this study is to discover how learning processes occur in engineering research labs through student research experience. The study focuses on graduate students who conduct research in the engineering lab. The research laboratories in the university are places for both research and education. Graduate students in the lab are students who are going through transition from students to professional researchers and engineers. Learning that occurs in the research lab is closely intertwined with enculturation to these specific communities. To provide detailed and enriched descriptions of such learning, a cognitive-ethnographic approach has been used in this study. The feasibility of this approach has been demonstrated by a significant body of related work in cognitive ethnography (Hutchins, 1995; Williams, 2006), situated learning (Lave 1988; Lave & Wenger 1991), laboratory studies (Latour & Woolgar, 1979; Galison, 1987; Knorr Cetina, 1995, 1999; Newstetter et al., 2002; Newstetter et al., 2004; Nersessian & Newstetter, 2013), and related approaches (Engeström 2005, 2008).

Methodology

Cognitive Ethnography

Cognitive ethnography aims to understand human cognitive processes. While traditional ethnography mostly focuses on cognitive products (belief systems, artifacts) created by the observed culture or group, cognitive ethnography focuses on the cognitive processes (learning, problem solving, decision-making) that create those products (Nersessian, 2019; Williams, 2006). Cognitive ethnography shares many data collection methods with traditional ethnography, including participant observation, interviews, use of field notes, photos, and video-recordings. In addition to traditional ethnographic methods, cognitive ethnography uses analytic frameworks from cognitive science, which enables fine-grained, micro-scale, and holistic analysis of cognitive activities that consist of discourses, non-verbal expressions, artifacts, and environment (Grohman, et al., 2020; Lee et al, 2015, 2017, 2020; Alac and Hutchins, 2004; Hutchins and Palen, 1997; Williams, 2006).

Field Sites

MHR Lab[2]

Our primary field site has been a mechanical engineering research lab at a research university in Texas. This lab is of moderate size and at the time of observation consisted of seven regular members: the lab director who was a faculty member at the university, a post-doctoral researcher who recently joined the lab, and five graduate students. The lab members' research focuses on human-robot sensory interactions during medical intervention. During the observational period, the MHR Lab underwent a few changes. Due to the COVID-19 pandemic, the lab was closed for a few months, then re-opened with limited capacity. The lab members had to work remotely and take shifts in working at the lab. In addition, the lab director moved from one university to another one in a different city, where they reestablished the lab with all of the previous members. During the course of observation, one graduate student obtained her PhD and became a post-doc researcher. Since moving to the new location, the MHR Lab has been recruiting new members.

[2] The name of the lab is a pseudonym and not the acronym of the lab name.

AP Lab[3]

The AP Lab is a material science and engineering lab that focuses on advanced polymer research at the same university as the original MHR Lab. We have added this lab as a secondary field site to collect additional data when the COVID-19 pandemic prevented in-person data collection at our original field site. When the MHR Lab moved to another location, the AP Lab became our primary field site. The AP Lab is bigger than MHR Lab. there are eleven regular members in the lab who attend the online lab meetings – a post-doc and ten graduate students. The other members of the lab, such as a faculty member who has directed the entire lab, a post-doc researcher, and a few graduate students who also work as interns at the local companies, have requested not to be included in our study. Following the COVID-19 pandemic guidelines, the AP Lab has also been in the lockdown, permitting remote work and shifts in the lab with limited capacity.

Data Collection

Participant Observation

In a cognitive ethnographic study, the primary method of data collection is participant observation. The participant observer was embedded in the field site, the MHR Lab, in January 2020. The MHR Lab had a large space that was used as a main laboratory, a supplementary laboratory shared with another lab, and a cubical-style office space shared with other engineering research groups. Most of the experimental activities were conducted in the main laboratory. The participant observer obtained access to the main and the supplementary laboratories and had a desk in the main lab. The participant observer spent regular hours in the lab, observed the lab activities, took field notes, and conducted informal interviews when

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[3] The name of the lab is a pseudonym and not the acronym of the lab name.

necessary. She also participated in a few lab activities. For example, she volunteered to be one of the subjects to test a surgery robot system and performed a few tasks using the robotic arms. The participant observer collected data in the filed site for approximately two months until the COVID-19 pandemic stopped all the in-person data collection.

Online Lab Meeting Observation

When the pandemic hit, and all in-person activities on campus were suspended, the MHR Lab and AP Lab began holding online lab meetings. These online lab meetings became an important group activity for the lab members in both labs, during which they exchanged their research updates, presented their results, and discussed issues pertaining to their research. In terms of online observation, the virtual lab meeting became the only accessible lab activity for us during the pandemic. The participant observer attended and observed lab meetings in our two field sites. The participant observer took fieldnotes, video-recorded when possible, and communicated with the lab members at the lab meeting.

Short Stories based on Collaborative Autoethnography

During the COVID-19 pandemic, we collected online data through observation of accessible virtual activities. It was impossible, however, to maintain the full merits of participant observation as obtained through interaction with the lab members at the field site. To address this challenge, we adapted our study procedure by asking the lab members to write short personal stories about the ways they coped with the impact of the COVID-19 pandemic on their research. This new study procedure was based on the idea of Collaborative Autoethnography (CAE), which is "(…) a qualitative research method that is simultaneously collaborative, autobiographical, and ethnographic (Chang et al., 2012)." As an autoethnographic approach, this methodology is based on self-reflection about an individual's experiences related to cultural, social, or physical circumstances. CAE also includes collaboration, allowing individuals to share and co-analyze their autoethnographic data to find meanings. Therefore, the participant observer shared her story with the lab members, too. Then, follow-up questions or interviews have been conducted individually as needed.

Data Analysis

At the time of preparing this report, the data collection and analysis is ongoing. Our preliminary analysis is based on the data included in the participant observer's fieldnotes gathered during observed events both onsite and online. These observed events included various types of interactions among the lab members that we have been examining to identify learning activities. In particular, we focused on learning activities that involved interactions between the lab members, such as peer discussions, teaching and learning, and collective problem-solving. Then we examined the emerging learning goals, the type of learning activity, and the roles of involved people. After the initial analysis of the fieldnotes, follow-up interviews were arranged with the lab members.

Video recordings of online lab meetings and interviews are being examined according to the results of the initial analysis of the fieldnotes. To analyze short stories written by the participants, we developed an analytic framework based on Levine et al.'s (2021) study report that examined the impact of the COVID-19 pandemic on early career scholars and doctoral students in the education area. Considering the circumstances and background of graduate students in engineering, we used an analytic framework that includes six themes: background, impacts on research, continuing research work, learning, connections/community/communication, and work-life balance. Four members from the MHR Lab and seven members from the AP Lab provided us their stories. Each story was analyzed based on these themes and the general profile for each theme was extracted.

Preliminary Findings

Self-Regulated Learning: A Default Learning Strategy in the Lab

Based on our observations, learning in the engineering research labs operated as self-regulated learning. Self-regulated learning indicates that the learners take control of their own learning to conceptualize, design, and execute (Zimmerman, 1990). Self-regulation is essential to advance in any academic field, and cultivating self-regulated learners is one of the central goals in higher education (Hodges, 2015). Each member of our field site lab had his/her own research project to conduct. They might seek guidance or help from their advising faculty or more experienced peers to choose the topic, to plan the research procedure, and to solve the problems they encountered, but the decisions were their own to make. Figure 1 shows the cultural model of MHR and AP lab members' self-regulated learning. The lab members chose what they wanted to learn and made plans about how to proceed. They controlled the procedure and revised or altered it as they needed. These self-regulated learning processes were closely related to the research projects they conducted and were still clearly observable when the unexpected COVID-19 pandemic crisis occurred. To adjust, the lab members found alternative ways to continue their research: some switched their research topic to a topic that they could do at home; if possible, they took all the devices and resources home and continued to work; or they participated in a project to fight against the pandemic using their expertise.

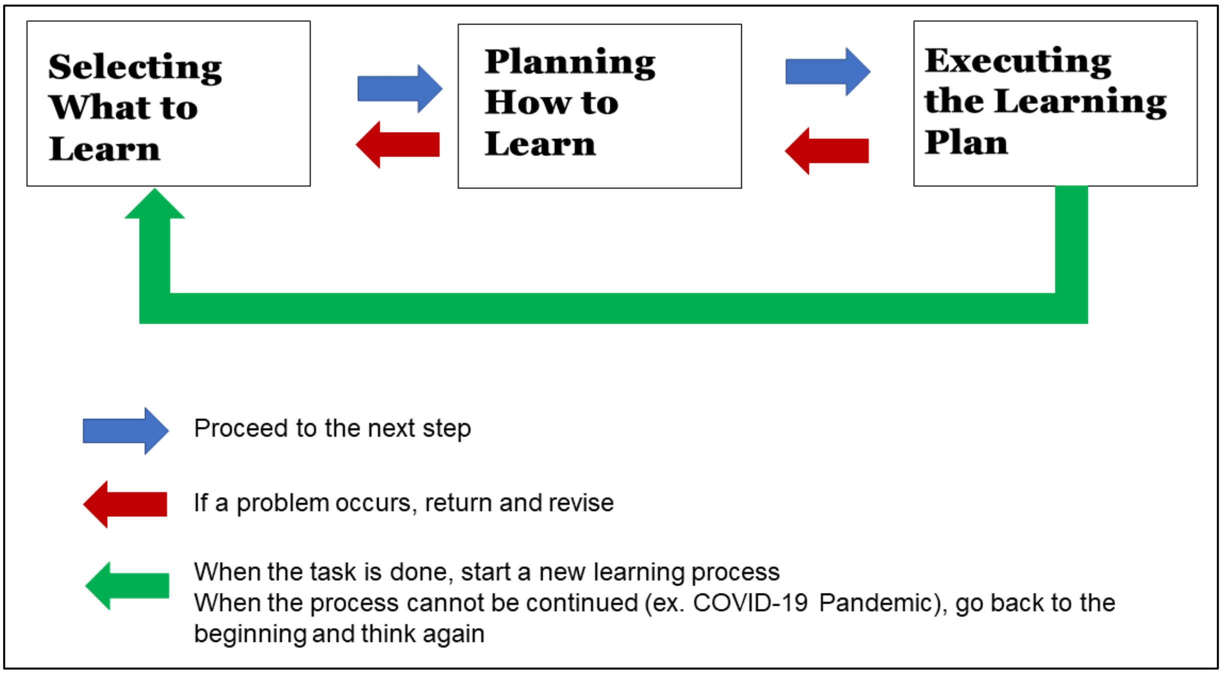

Figure 1. The cultural model of self-regulated learning process that occurs in the engineering lab

Scaffolding: An Organic Instructional Strategy

Self-regulated learners actively seek feedback from external sources such as teachers' comments and peers' contribution in collaborative groups and this external feedback helps make self-regulated learning effective (Butler & Winne, 1995). During the observation of the MHR Lab, we noticed that the feedback from the lab director who was also an advising faculty to the graduate students in the lab, worked like a scaffolding strategy. The lab director differentiated her feedback according to the current level of skills and abilities of the student presenting at the lab meeting. When the presenter was experienced and familiar with the topic, the lab director asked questions or made comments that tend to trigger more discussion about the content such as "Have you tried …….?" and "One of my idea about this is ……." The exchanges resemble discussions at an academic conference. When the presenter was less experienced or the topic was not familiar, the lab director often provided additional explanations—"Let me explain…"—or brought up related knowledge—"Do you remember

…….?” These exchanges resemble interactive teaching approaches in the classroom. Providing different feedback based on the learner’s ability and situation to help the learner complete the task reminded us of the pedagogical strategy known as “scaffolding.” In general, scaffolding is a strategy in which an expert provides the necessary support for a learner to accomplish the specific task, differentiated according to the learner’s ability and situation. As the learner obtains more independence, the expert’s support is gradually diminished (Malero, Hernandez-Leo, & Blat, 2012; Sharma & Hannafin, 2007; Wood, Bruner, & Ross, 1976). We observed that such scaffolding was occurring quite frequently in the MHR Lab.

Interestingly, the lab director was not aware that she was using scaffolding as an instructional strategy, as shown in the following excerpt from her email correspondence:

I’m not aware that I’m doing it, but I do try to make sure that if a student brings something up that only the two of us are familiar with, I try to give that context to the group. Also, as students get more experienced, I try to encourage them to act more independently since that is my long-term goal for their education (Dr. Mac[4], the director of the MHR Lab).

As can be seen in the excerpt, scaffolding used in the MHR Lab occurs without formal planning or instructional design. We call this type of instructional strategy an organically-occurring scaffolding. We discuss more details about scaffolding in the engineering lab in a separate publication.

The Role of the Lab Meeting

During the COVID-19 pandemic, a new role for the lab meeting was established in both the MHR and AP Labs. These labs have regular lab meetings in which students present their research updates and obtain feedback from the faculty and peers. When the COVID-19

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[4] All the names appeared in this paper are pseudonyms to protect the anonymity of the participants.

pandemic caused the complete lock down of the research labs in the university, lab meetings were also suspended. Within a month after the COVID-19 related lockdown, our two field sites, the MHR Lab and the AP Lab, resumed their regular lab meetings, holding them online. The online lab meetings have continued, even though the labs resumed their research activities at limited capacity and gradually restored them to full capacity. When observing the MHR and AP Labs, we noticed differences in the meeting style. The MHR Lab meetings had a friendly and free atmosphere, and the members of the lab always had their videos on and saw each other's faces. The topics discussed in the meeting were varied, from selecting new furniture for the lab, to a mentoring session about how to write a research paper for the professional journal, to collaborate in writing a review paper, and to research update presentations. On the contrary, the AP Lab held typical lab meetings. They followed a fixed protocol including announcements and updates about the lab, discussions of lab safety issues, and student presentations. Also, the lab members did not choose to have their cameras on except for the post-doc mentor who led the meeting and the member presenting their research. Considering this discrepancy between the two labs' meeting styles, it is worth noting that the members of both labs mentioned that the lab meetings became a good opportunity to engage with one another not only professionally but also socially. When the labs re-opened with limited capacity, meaning the lab members had to alternate the shifts and could not share the physical lab space with other people, the lab meetings remained the only occasion to virtually meet all of the lab members at the same time. The lab members admitted that attending the lab meeting gave them the sense of security that they still belonged to the lab. Apparently, a new role of the regular lab meeting as an anchor to hold the lab members together has emerged under the COVID-19 crisis.

Table 1. Comparison of online lab meetings in two field sites

Lab Name	MHR Lab	AP Lab
Frequency & Duration	Weekly, 1 hour	Weekly, 1 – 1.5 hour
Organizer	Lab Director (Faculty)	Post-Doc Mentor
Participants	2 post-docs, 4 graduate students	10 graduate students
Video Conference	Lab Director: on video All participants on video	Post-Doc Mentor: on video Participants: off video Presenter: on video
Topic to discuss	Various topics Decided what to discuss next at the end of the meeting	Fixed topics: Lab updates; Lab safety issues; Student Research Update Presentation
Procedure	Varied according to the topic	1) Lab announcement and updates 2) Lab safety discussion 3) Student Presentation (1 or 2)

COVID-19 Impacts and Responses

According to the short stories the lab members wrote, the members in our participating labs were trying their best to continue research under the COVID-19 pandemic. Table 2 shows the key terms that the lab members mentioned in their short personal narratives about how they coped with the COVID-19 crisis. Those key terms have been sorted according to the following categories: background, impacts on research, continuing research work, learning, connect-community-communication, and work-life balance. The "Background" category indicated what they were doing when the lockdown occurred. The lab members were mostly planning or preparing for a new project, graduation, or internship. As seen in Table 2, the COVID-19 pandemic had many negative associations for the lab members. Key terms such as delayed, slowed, suffered in efficiency indicated the difficulties they encountered. Nevertheless, all lab members tried to continue their research and learning or used those times to do something useful such as joining an expert group to help health workers.

Table 2. Key terms mentioned in the lab members' short personal narratives

Lab Name	MHR Lab	AP Lab
Background	start, prepare	plan, graduate, prepare
Impacts on Research	difficult to manage, suffered in efficiency, no human studies	affected my (plan, graduation, work pace), delayed, slowed
Continuing research work	shifting, revisiting, reevaluating	Joined (expertise group to help, a new group to continue), get back to lab (with special permission, with limited capacity)
Learning	learning, practicing	learning (a new way, software etc.), reading & reviewing papers
Connection-Community-Communication	same communication in professional life	keep us accountable, keep in touch
Work-Life Balance	challenges in home environment, use the commuting time for something else	not working very well (with two small kids), not that bad (used time for personal growth)

A small difference was noticed between the two labs, perhaps based on their areas of expertise. For example, the MHR Lab focuses on human-robot interaction. As in-person data collection was not allowed during the pandemic, they shifted the research focus to non-human subject studies such as virtual simulation or used their time to revisit and reevaluate their previous data analyses. All of the MHR lab members continued to work remotely. In contrast, the AP Lab studies material science; therefore, many lab members tried to go back to the lab either with special permission or with limited capacity. The lab members continued their research in the lab, but they took turns working solo and kept social distancing. For example, one member took the night shift and worked during the night in the lab; he could not see any of the fellow lab members for months. In addition, many members in the AP Lab joined a local expert group to develop innovative personal protective equipment (PPE), such as masks, to help frontline healthcare workers. They made contributions using their expertise in material science. An additional difference among lab members was also noticed, which was not based on expertise but rather based on each member's personal circumstances. For example, two members in the same AP Lab expressed different feelings about balancing professional and personal life during the pandemic. A member who was a parent with two small kids mentioned "not working well" and "exhausted," while another member who lived alone mentioned, "not that bad" because he could use the time for personal growth.

Discussion

Our preliminary findings fell under two headings: 1) learning in the research lab and 2) the impact of COVID-19 on the research lab. During observations, we noticed that learning in the research lab was largely self-regulated. That is a good sign for higher education, because undergraduate education aims to cultivate self-regulated learning for students (Hodge, 2015).

Apparently, graduate students who conduct research in the lab achieved a certain level of self-regulated learning. What looked interesting to us was the relationship between two types of learning we identified in the lab, scaffolding and self-regulated learning, and the implication that relationship suggested. Self-regulated learning is facilitated by effective feedback (Butler & Winne, 1995). Organically occurring scaffolding that we observed in the research lab contained various types of feedback. We assume that organically occurring scaffolding enhances self-regulated learning in the lab, and that is how learning continues while conducting research in the research lab. This mechanism also provided a clue about the pedagogical value of joining research labs. Scaffolding happened through social interaction between lab members. In scaffolding, a type of social interaction enhanced self-regulated learning. Students may not be able to obtain such support when they study a subject and conduct research in solitary manner. They can experience this type of learning through a social experience when they belong to the research lab.

Another topic of interest is the impact of the COVID-19 pandemic. The impact of COVID-19 was serious, starting with the sudden lockdown, and it caused a lot of difficulties for the lab members' research and their professional plans. However, we found that the lab members, most of whom were graduate students, were resilient, and they found ways to continue their learning and research. How they proceeded varied based on their expertise and circumstances. While the MHR Lab members remotely worked with alternative topics and methods, the AP Lab members worked in the lab keeping social distance. The MHR Lab members worked on human-robot interaction research and could not continue with human subjects under the pandemic. That is why the MHR Lab members tried to find alternative topics and methods. The AP Lab members' research was mostly not related to human subjects. The majority of the AP Lab members did their best to work in the lab, even though that meant to work alone in the lab during the specific time slot. While individual members worked their best to cope with the difficulty, the lab leadership also contributed to continue the research and learning. In the MHR Lab, the director launched a new project to collaboratively write a review paper. This project gave an opportunity to the lab members to study and accomplish something while their human subject studies were not allowed. In the AP Lab, the post-doc organized volunteers and led them to join a local expert group to develop innovative personal protection equipment to help health workers who fought against the virus. This project made members realize that they could contribute for the public good using their expertise.

Conclusion

At this point, research labs in universities are returning to their full capacity, and the members in our two field sites are adapting to the return to (relatively) normal operations. Our study, which used qualitative methods of cognitive ethnography to discover rich details about how learning occurs through research in the engineering lab, had to adapt due to the unexpected COVID-19 circumstances. Nevertheless, we observed a couple of interesting and important types of learning that happen in the research lab: self-regulated learning and organically-occurring scaffolding. Considering the importance of self-regulated learning in higher education and considering the effectiveness of scaffolding as an instructional strategy, these findings indicate that there are more points to ponder and explore, and our study should continue to pursue them. Also, the unexpected crisis created an unusual situation, and we could observe how this COVID-19 pandemic affected graduate students' professional and social life and how they cope with such crisis. In conclusion, what we observed and witnessed was these young researchers' perseverance, resilience, and determination to continue their research.

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12. GAS Students' Attitudes and Career Interests towards STEM

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) education has been identified as a roadmap towards global competitiveness and innovation. Unfortunately, the Philippines is lagging behind its Southeast Asian counterparts in human capital in the STEM fields. Hence, there is a need to fix the leaky Philippine STEM pipeline. One way to do this is to have science teachers develop a more positive attitude and career interest towards STEM among the students, including non-STEM, through differentiated and research-based teaching strategies. In this study, the researchers present a quantitative survey study that examines General Academic Strand (GAS) students' attitudes and career interests towards STEM in terms of gender, grade level, intent to go to college, and relationship with a Science and Technology (S&T) professional. Using the Student Attitudes towards STEM (S-STEM) tool, 58 GAS students from Grade 11 and Grade 12 were surveyed. In terms of the students' attitude towards STEM, it was found out that there is no significant difference between their scores across variables except for the attitude of Grade 12 students towards engineering and technology, which is significantly more positive than Grade 11 students. On the other hand, in terms of their career interests, on average, male students showed more interest in CoreSTEM subjects than females. Ultimately, insights about these findings concerning pedagogical and practical implications that could address the issues raised were discussed.

Keywords: STEM Education, Attitudes towards STEM, S-STEM, Career Interests towards STEM, GAS Students

Introduction

As the strengthening of Science, Technology, Engineering, and Mathematics (STEM) education being recognized as one of the key elements towards innovation and international competence, the Philippines was found behind its Southeast Asian counterparts when we talk about human talent pool development in the field (Padolina, 2014). In 2013, Singapore and Malaysia have 6,618 and 2,826 research and science specialists, respectively. On the other hand, the Philippines only had 270 in the same year, which is way below the United Nations Educational, Scientific, and Cultural Organization (UNESCO) standard of 380 (Dadios et al., 2018). It has been argued that the pool of Science and Technology (S&T) experts in the country could be increased by reinforcing STEM education and curricula in all grade levels.

To do this, science educators must redirect their pedagogy towards improving students' attitudes and interest towards science. DeWitt and Archer (2015) emphasize that such pedagogy cannot guarantee that they would pursue a science or science-related field. It can only serve as an indicator of students considering choosing this field later as a possibility. They argued that if one does not have any aspirations in science, it is unlikely to pursue a career in this area.

In Senior High School (SHS), the most vulnerable to career shifts are students under the General Academic Strand (GAS) of the Academic Track. Most schools prescribe this track for Grade 10 completers who are still undecided about their career path. Here, they will be equipped with the necessary skills and knowledge to help them in whatever specialization they want to pursue. This is why, after STEM students, GAS students must be considered the next prospects for the STEM talent pool.

In this paper, the Student Attitudes towards STEM Survey (S-STEM) for Middle School and High School (Grade 6 to Grade 12) was used to gauge GAS students': (i) attitudes towards mathematics, science, engineering, and technology, and 21st century skills; and (ii) interests towards twelve STEM career pathways, clustered as Core STEM and Biology-Medicine. Comparisons were made based on their demographic profiles, in particular, by (a) grade level, (b) gender, (c) intent in pursuing higher education, and (d) relation to an S&T professional.

The results of this study allow us to assess the potential of GAS students in pursuing a career in the STEM field in the future. These can inform interventions and strategical frameworks to realign students' future career paths towards STEM. Furthermore, in hindsight, this also gives us an idea of how these students viewed STEM throughout their basic education years. Learners tend to have a more positive attitude towards STEM disciplines if they deem their classes fun yet meaningful, or a bad image towards these subjects if they experienced the opposite. Aside from this, studies concerning SHS students, specifically GAS, are scarce. Hence, this study is a necessary addition to the literature in this area of inquiry.

This paper includes a literature review on students' attitudes and career interests towards STEM with an elaboration of the study's theoretical orientation. The methods are discussed next, including the samples studied, the instrument used, and the procedures. And finally, the results section will show the findings from statistical treatment implemented on the data, discussion towards curricular implications, limitations, and recommendations for future directions.

Literature Review

Attitudes and Career Interests

Eccles and Wigfield (2002) argued that self-efficacy (beliefs in one's own ability to accomplish a task) and expectancy-value (one's beliefs on whether he or she can execute an action to produce a specific outcome) comprise student attitudes towards an academic discipline, in this case, STEM. Lent and Brown (2006) proposed the Social Cognitive Career Theory, which states that the aforementioned factors, together with career interest, can predict a student's intent to join the STEM talent pool.

Luo et al. (2019) posit that student attitudes toward STEM are deeply anchored on two motivation theories: expectancy-value theory and self-efficacy theory. Eccles and Wigfield (2002) discuss that Bandura, the proponent of social cognitive theory, emphasized the difference between the two expectancy beliefs borne out of these two theories. Efficacy expectation refers to one's beliefs on whether they can execute an action to produce a specific outcome. Say a student athlete believes that they can win a competition, they are more likely to be more committed in training to prepare themselves for the contest. On the other hand, outcome expectancy refers to a belief that a particular behavior can create a particular outcome. For instance, when a student studied hard for an exam, they are more likely to ace it. These theoretical perspectives are reflected in the S-STEM survey, which was implemented in this study.

Meanwhile, several researchers determined that demographic factors like gender, grade level, intent to pursue college, and relationship with an S&T professional also affect student attitudes and career interests towards STEM.

Klopfer (1971, in Osborne et al., 2003) elaborates that 'attitudes towards science' can be described as: (a) exhibiting positive attitude towards the discipline and scientists; (b) using inquiry as a thought process mechanism; (c) imbibing scientific attitudes; (d) enjoying experiences in learning science; (e) having interests towards activities concerning science; and (f) having interests in pursuing science as a career path. Gardner (1975) and Osborne et al. (2003) argue that scientific attitudes and attitudes towards science are two different constructs. The former pertains to the traits that scientists are expected to manifest during a scientific endeavor. On the other hand, the latter requires an object of attitude to which one is asked to react, either positively or otherwise; and this was the definition used in this study.

According to Huyer (2015), gender parity among researchers, especially in doctorate level, is not yet around the corner. However, some countries like the Philippines have achieved this. In 2007, the percentages of women in the field were 59.5% in the natural sciences, 39.9% in engineering and technology, 70.2% in medical sciences, and 51.3% in agricultural sciences (UNESCO, 2015).

Several studies have shown that males have more positive attitudes and aspirations towards science than females (Denessen et al., 2015; DeWitt & Archer, 2015; Hacıeminoğlu et al., 2015); while in Toma et al. (2019), the difference is much lower than the other reported studies. To elaborate, males were found to have stronger aspirations (DeWitt & Archer, 2015) and have a significantly higher enjoyment level (Denessen et al., 2015). Also, female teachers' enjoyment in teaching science and their perceived competence were significantly lower vis-a-vis their male counterparts (Denessen et al., 2015). On the contrary, in the study of Said et al. (2016), gender was found not to affect attitudes towards science. They argued that it could have been superseded by cultural values, which is highly plausible for countries with developing knowledge economies.

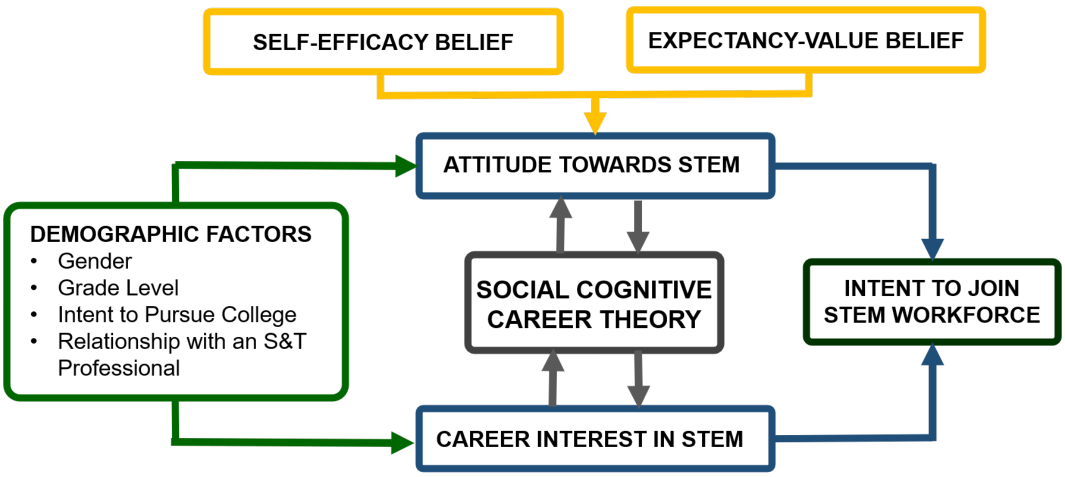
Unfortunately, a negative trend has been found in the attitudes towards science as a student's education level increases (Denessen et al., 2015; DeWitt & Archer, 2015; Said et al., 2016; Toma et al., 2019). Said et al. (2016) emphasize that interests, perceived ability, and beliefs in the utility of science decrease as learners' age increases. This shows disengagement in science classrooms gets stronger as the learner advances in age. Toma et al. (2019) attribute this disengagement to learners' dissatisfaction with pedagogies and learning activities in science.

Role models are efficient resources in improving students' ideas of STEM (O'Brien et al., 2017). Several researches looked into whether having connections with a female STEM role model can improve students' perception of science (González-Pérez et al., 2020; O'Brien et al., 2017; Van Camp et al., 2019). All three studies found that engaging learners with a role model induce a favorable outcome. This also includes an increase in their performance, self-efficacy, and view of STEM as a career. However, Shin et al. (2016) noted the lack of literature on role modeling outside gender boundaries. Hence, they investigated the effect of role model exposure to both STEM and non-STEM students' interest and perceived compatibility in the discipline. It was found that role model exposure positively impacted their perception of academic belongingness for both groups and self-efficacy for STEM students.

The theoretical orientation of this research posits the effect of demographic factors (i.e., gender, grade level, intent to pursue college, and relationship with an S&T professional) on student attitudes, anchored in their self-efficacy and expectancy-value beliefs, and career interests towards STEM. The social cognitive theory, which situates learning in the middle of a dynamic interaction between the learners and their environment, integrates these two variables to predict students' intent to join the STEM workforce.

Figure 1

The Theoretical Framework of the Study



Unfried et al. (2015) identified attitudes towards STEM and career interests are good predictors of whether students intend to join the STEM workforce in the contemporary world. Understanding these two variables allows us to look for feasible instructional innovations and curricular improvement. Hence, assessing students' attitudes and career interests towards STEM leverages the most conducive learning conditions that allow learners to achieve learning competencies more efficiently and effectively (Luo et al., 2019).

Methods

Context of the Study

One of the significant reforms in Philippine education in the last ten years is the enacting of Republic Act 10533, otherwise known as the "Enhanced Basic Education Act of 2013." This was borne out of comparisons of the Philippine educational system among its Southeast Asian counterparts. The primary significant change it brought was expanding the duration of basic education from ten years to twelve years, with a mandatory year in the kindergarten level, thus the name K-to-12 Curriculum. This was designed with the following features in mind: decongested, seamless, relevant, responsive, enriched, and learner-centered (Southeast Asian Ministers of Education Organization - Regional Center for Educational Innovation and Technology [SEAMEO INNOTECH], 2012).

The additional two years in high school, termed as Senior High School (SHS), was established to prepare the learners to be of age (eighteen years old) when they have to decide whether to either proceed to employment or pursue a degree program relevant to their chosen career path. They can choose among the three tracks: Academic Track, Technical-Vocational-Livelihood (TVL) Track, and Sports and Arts Track. Academic Track is divided into four strands: General Academic Strand (GAS), Science, Technology, Engineering, and Mathematics (STEM) Strand, Accountancy, Business, and Management (ABM), and

Humanities and Social Sciences (HumSS) ("The K to 12 Basic Education Program," n.d.). Unfortunately, the Department of Education (DepEd) has yet to release a primer or descriptions for the strands and tracks, aside from the list of subjects offered in SHS. Most released memoranda and information materials are about the voucher program and the positive effects of having them undergo SHS.

As mentioned, this study was conducted to know GAS students' attitudes and career interests towards STEM in relation to their gender, grade level, intent to pursue college, and relationship with S&T specialists. Since there is a problem in the Philippine STEM pipeline, there is a need to increase the pool of S&T talent and human resources (Dadios et al., 2018; Padolina, 2014). One possible solution is attracting students from other strands like GAS to switch to STEM, which can improve their attitudes and interests towards STEM. The results of this study would give us baseline information intended to be used for educational innovations and interventions that can increase learners' attitudes towards STEM. The research questions are as follows:

- Does gender, grade level, intent to pursue college, and relationship with S&T specialists affect GAS students' attitudes towards STEM?
    a. Does gender, grade level, intent to pursue college, and relationship with S&T specialists affect GAS students' career interest towards STEM?

Sample

The sample consisted of 58 GAS students, 51.5% of which are males, in a public school in Valenzuela City. In terms of their grade levels, 46.6% of the participants are Grade 11, and the remaining are Grade 12. Surprisingly, Figure 2 shows that no student answered no to the question, "Do you plan to go to college?" Those who answered yes overwhelmingly outnumber ($N = 50$) those who are still not sure ($N = 8$).

Figure 2

Distribution of the Participants Intending to Pursue College

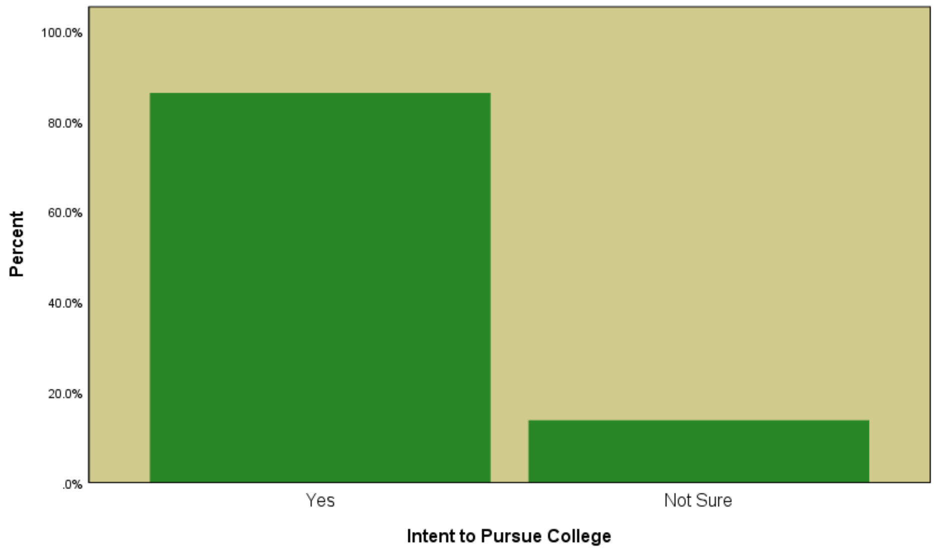


Table 1 shows whether the participants know S&T Specialists, specifically (a) scientists, (b) engineers, (c) mathematicians, and (d) technologists. First, only 12% of the participants personally know someone working as a scientist, while half of them declared that they do not know anyone working in the pure science field. On the contrary, a little more than half (51.7%) of them know an engineer. Then, 43.1% of the respondents said that they do not know anyone who works as a mathematician. Lastly, 48.3% of the respondents confidently stated that they know someone who works as a technologist (e.g., information technologist, medical technologist, and computer specialists).

Table 1

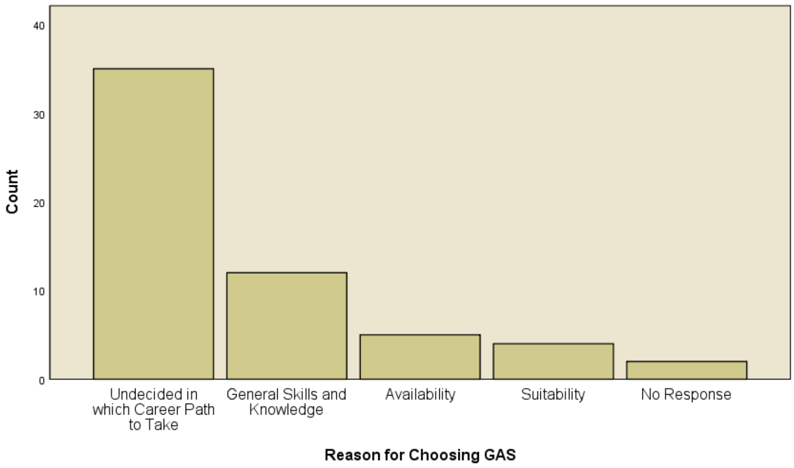
Distribution of Frequencies and Percentages of the Participants Knowing a STEM Specialist

	No		Not Sure		Yes	
	Frequency	Row Valid N %	Frequency	Row Valid N %	Frequency	Row Valid N %
Do you know any adults who work as a/an…						
scientist	29	50.0%	17	29.3%	12	20.7%
engineer	20	34.5%	8	13.8%	30	51.7%
mathematician	25	43.1%	12	20.7%	21	36.2%
technologist	18	31.0%	12	20.7%	28	48.3%

Figure 3 shows the reasons why the respondents chose GAS as their strand in SHS. The primary reason for students choosing GAS is that they were still unsure about their future career paths. The next reason in rank was to gain general skills and knowledge to use in whatever direction they want. Third, since not all SHS schools offer all strands, they chose the one available in the nearest school to their residence. The last reason they gave was that it suits them, or this is aligned with their future career paths (e.g., teacher education).

Figure 3

Frequency of the Respondents and their Reasons for Choosing GAS



Instrument

The instrument used for this study is the Student Attitudes towards Science (S-STEM) Survey for Middle and High School Students. This was developed by Friday Institute for Educational Innovation (2012). Table 2 shows the psychometric constructs, which comprise the first part of the survey, with corresponding items, Cronbach's alpha for reliability, and sample item. The four constructs are as follows: (a) Attitudes towards Mathematics, (b) Attitudes towards Science, (c) Attitudes towards Engineering and Technology, and (d) Attitudes towards 21st Century Learning. For the first three, the survey measures students' self-efficacy and expectations in the discipline. In comparison, the last construct measures one's confidence in terms of self-directed learning, as well as their communication and collaborative skills. These constructs are five-point Likert scales with the following responses: *strongly disagree, disagree, neither agree nor disagree, agree,* and *strongly agree*, which were given weights from 1 to 5 for analysis.

Based on Table 2, it can be noted that all constructs have high-reliability indices that range from 0.89 to 0.91, which is equivalent to good to excellent. This signifies that the instrument has high internal consistency.

Table 2

Operationalization of S-STEM Survey for Middle and High School

Construct	Number of Items	Cronbach's Alpha (for Middle and High School)	Sample Item
Attitudes towards Mathematics	8	0.90	I can get good grades in math.
Attitudes towards Science	9	0.89	I am sure I could do advanced work in science.
Attitudes towards Engineering and Technology	9	0.89	I like to imagine creating new products.
Attitudes towards 21st Century Learning	11	0.91	I am confident I can set my own learning goals.

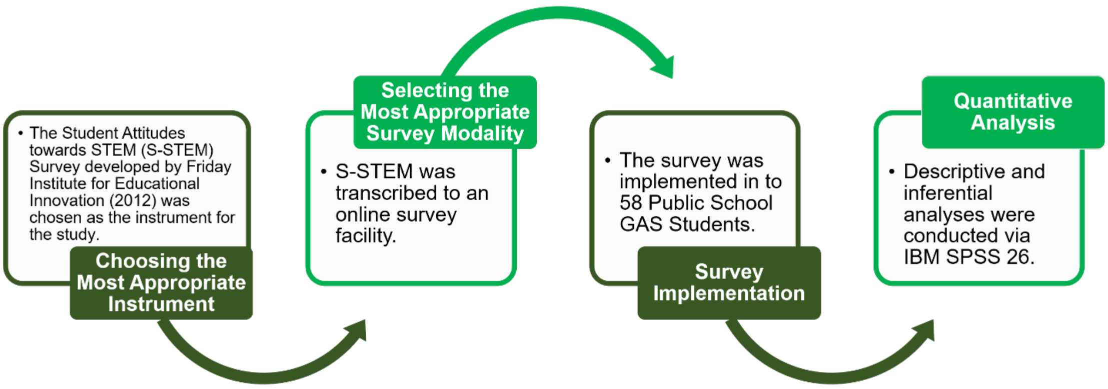
The next section of the questionnaire asks the participants about their attitudes towards twelve (12) STEM career areas. The items here are four-alternative forced choice with the following choices: *not at all interested, not so interested, interested*, and *very interested*. Wiebe et al. (2018) made a cluster analysis to group these career areas using the Spearman correlation matrix. These two clusters represent how students tend to segregate STEM disciplines. The Bio-Medicine Cluster includes Biology and Zoology, Veterinary Work, Medicine, and Medical Science. All others are clustered as Core STEM fields (i.e., Physics, Environmental Work, Mathematics, Earth Science, Computer Science, Chemistry, Energy, and Engineering).

Procedure

The participants were invited to answer the survey via Google Forms voluntarily. They were asked for their consent, especially those who are below eighteen years old. Aside from this, they were provided the notice of confidentiality to ensure data privacy. It took about ten to fifteen minutes to answer the survey. The results were then collected and processed using IBM SPSS 26.

Figure 5

Flowchart of the Research Procedures



The statistical analyses that were employed in this study followed these steps. First, descriptive analyses (i.e., mean, median, and standard deviation) of both the four attitude constructs and career interests per demographic category (i.e., gender, grade level, intent to pursue college, and relationship with an S&T professional) were generated. Then, the Kolmogorov-Smirnov test for normality ($N \geq 50$) was conducted on the four constructs to know if the assumption of normality was violated. All attitude constructs across all the demographic factors showed $p > 0.05$, with a 95% confidence level. This means that the null hypothesis will be accepted. Hence, the distribution of data is normal in all variables. Thus, for the last step, parametric tests were used to test whether a significant difference lies between demographic groups in each attitude construct.

Results

Attitude towards STEM

Gender

In gender comparison (see Table 3), it can be noticed that there are approximately point percentage differences between males and females, with respect to the means for the four attitude constructs measured. Analyzing gender effects, the scores of both genders did not differ with statistical significance ($p > 0.05$) in all constructs.

Table 3

Comparison by Gender of Means per Attitude Construct

	Gender						
	Males			Females			
	n	M	SD	n	M	SD	*p*
Attitudes towards Mathematics	30	2.92	0.52	28	2.82	0.35	.401
Attitudes towards Science	30	3.19	0.56	28	3.20	0.66	.934

Attitude towards Engineering and Technology	30	3.60	0.75	28	3.19	0.83	.057
Attitude towards 21st Century Learning	30	3.58	0.71	28	3.53	0.95	.789

Grade Level

Comparing the attitude scores based on grade level, on average, Grade 12 students got higher scores than Grade 11 students. This holds for all constructs.

Table 4

Comparison by Grade Level of Means per Attitude Construct

	Grade Level						
	Grade 11			Grade 12			
	n	M	SD	n	M	SD	*p*
Attitudes towards Mathematics	27	2.77	0.41	31	2.96	0.46	.097
Attitudes towards Science	27	3.18	0.55	31	3.21	0.66	.869

Attitude towards Engineering and Technology	27	3.15	0.76	31	3.62	0.79	.024
Attitude towards 21st Century Learning	27	3.52	0.85	31	3.59	0.82	.748

Based on Table 4, there is a significant difference in the mean scores for attitudes towards engineering and mathematics of Grade 11 (*M* = 3.15, *SD* = 0.76) and Grade 12 (*M* = 3.62, *SD* = 0.79), with *t* (56) = -2.32, *p* = 0.024. This suggests that Grade 12 students have a more significantly positive attitude towards engineering and technology than Grade 11 students. Other than this, these results suggest that the mean scores of Grade 12 and Grade 11 students are not significantly different.

Intent to Pursue College

This demographic variable produced interesting results. For mathematics (*M* = 2.89) and science (*M* = 3.21), those who intend to pursue college had a more positive attitude than those who are unsure. However, the opposite holds for engineering and technology (*M* = 3.69) and 21st century learning (*M* = 3.70). Essentially, across the four constructs in Table 5, these results suggest that the means scores of students intending to pursue college and those still undecided are not significantly different.

Table 5

Comparison by Intent to Pursue College of Means per Attitude Construct

	Intent to Pursue College						
	Yes			Not Sure			
	n	M	SD	n	M	SD	*p*
Attitudes towards Mathematics	8	2.89	0.44	50	2.80	0.51	.608
Attitudes towards Science	8	3.21	0.63	50	3.13	0.47	.728
Attitude towards Engineering and Technology	8	3.36	0.83	50	3.69	0.61	.274
Attitude towards 21st Century Learning	8	3.53	0.86	50	3.70	0.62	.590

Relationship with an S&T Professional

For the last demographic variable, the comparison of means of those who know an S&T specialist (i.e., scientist, mathematician, engineer, and technologist) and those who do not show a rather peculiar result on the average. For instance, those who are not sure whether they know a scientist had a more positive attitude towards science (M = 2.95), mathematics (M = 3.33), engineering, and technology (M = 3.56) than those who actually know one.

Table 6

Means and Standard Deviations among the Four Constructs Across the Demographic Variables

		Attitude towards Mathematics		Attitude towards Science		Attitude towards Engineering and Technology		Attitude towards 21st Century Learning	
		M	SD	M	SD	M	SD	M	SD
knows a scientist	Yes	2.81	0.40	2.82	0.69	3.12	1.06	3.13	0.88
	No	2.85	0.49	3.27	0.60	3.43	0.74	3.70	0.74
	Not Sure	2.95	0.40	3.33	0.47	3.56	0.71	3.62	0.87
knows an engineer	Yes	2.78	0.49	3.21	0.64	3.43	0.83	3.60	0.87
	No	3.01	0.31	3.16	0.61	3.33	0.75	3.56	0.85
	Not Sure	2.88	0.52	3.22	0.57	3.49	0.96	3.39	0.63
knows a mathematician	Yes	2.88	0.42	3.06	0.59	3.46	0.85	3.52	0.72
	No	2.82	0.50	3.21	0.69	3.30	0.82	3.52	1.00
	Not Sure	2.99	0.37	3.41	0.38	3.52	0.75	3.70	0.61
knows a technologists	Yes	3.00	0.36	3.15	0.75	3.38	0.92	3.48	1.05
	No	2.76	0.56	3.13	0.50	3.40	0.72	3.64	0.54
	Not Sure	2.74	0.40	3.41	0.29	3.44	0.70	3.60	0.62

To answer the research question, "Are there significant differences between the mean scores of the students who know an S&T professional, those who are not sure, and those who do not?", for all particular categories of professions, no significant difference was found using the One-Way ANOVA for all the constructs.

Career Interests in STEM

Table 8 shows the descriptive statistics of the two STEM clusters (i.e., Core STEM and Bio-Medicine) across the demographic variables. It can be seen that both males and females got the same mean for Bio-Medicine Cluster (M = 2.50), but males (M = 2.64) got a higher score than females in the Core STEM Cluster. In terms of grade level, Grade 12 students have higher STEM interests in both clusters than Grade 11. This also holds for those who intend to go to college compared to those who are still undecided.

On average, students are unsure if they know a scientist showed more interest in both clusters as career paths. In comparison, this also holds for those who personally know an engineer. Those who know a mathematician and a technologist have shown more interest in the Bio-Medicine Cluster than those who are not sure if they know one. This is the reciprocal case for their interest in Core STEM career paths.

Table 7

Means and Standard Deviations among the Two STEM Career Clusters Across the Demographic Variables

		Core STEM Cluster		Bio-Medicine Cluster	
		M	SD	M	SD
Gender	Male	2.64	0.62	2.50	0.73
	Female	2.38	0.55	2.50	0.54
Grade Level	11	2.38	0.56	2.49	0.62
	12	2.63	0.62	2.51	0.67
Intent in Pursuing College	Yes	2.52	0.61	2.54	0.64
	Not Sure	2.45	0.51	2.25	0.63
knows a scientist	Yes	2.49	0.74	2.46	0.76
	No	2.41	0.51	2.47	0.61
	Not Sure	2.71	0.61	2.57	0.64
knows an engineer	Yes	2.62	0.65	2.62	0.64
	No	2.35	0.54	2.36	0.70
	Not Sure	2.52	0.49	2.41	0.42
knows a mathematician	Yes	2.63	0.65	2.60	0.58
	No	2.34	0.55	2.43	0.72
	Not Sure	2.68	0.53	2.48	0.58
knows a technologist	Yes	2.52	0.65	2.61	0.67
	No	2.35	0.46	2.44	0.58
	Not Sure	2.74	0.62	2.33	0.66

Discussion

This paper reports on students' attitudes and career interests towards STEM according to gender, grade level, intent in pursuing college, and personal relation to an S&T professional. Taken together, except for attitudes towards engineering and technology of Grade 11 and Grade 12, it was found out that these demographic groupings did have an impact on the attitudes of GAS students towards STEM.

In terms of gender, the means of attitude scores towards STEM of males were slightly higher than females, consistent with the reports of some studies (Caleon & Subramaniam, 2008; Denessen et al., 2015; DeWitt & Archer, 2015; Hacıeminoğlu et al., 2015). However, in this present study, the difference is not statistically significant, and this resonates with the findings of Toma et al. (2019) and Said et al. (2016). Both argued that the absence of gender effect on attitudes towards STEM could be attributed to the students' socio-cultural context. The "expected" result could have been overridden by cultural values upheld in developing countries. This also calls to mind the relevance of students' socioeconomic factor, which was not included in this study, that may have motivated them to seek economically-sound opportunities in the field of STEM (Said et al., 2016).

Meanwhile, in terms of career interests, the results are the same with Wiebe et al. (2018). Males, generally, had higher scores in Core STEM than females. On the other hand, in the Bio-Medicine cluster, the means are the same, but females had lower standard deviation than females. This resonates with the argument of Wiebe et al. (2018), where males prefer physical sciences (including engineering) while females prefer biological sciences (including medicine).

Based on their grade level, on average, Grade 12 students were observed to see STEM in a more positive light than Grade 11 students. This is most seen in their attitudes towards engineering and technology. Surprisingly, this is contrary to the results of previous studies (Denessen et al., 2015; DeWitt & Archer, 2015; Said et al., 2016; Toma et al., 2019), which showed a decline of interest in STEM as the learner progresses in terms of grade level. This result, however, is similar to Erdogan (2017). The result, though, must be interpreted with caution since the reason for this must be studied further. However, we offer different possible explanations and perspectives for these results. From a curricular standpoint, Grade 12 GAS students have taken more core subjects in STEM (e.g., Statistics and Probability and Physical Science) than their Grade 11 counterparts. Also, it must be noted that none of these subjects directly requires them to do tasks related to engineering. Another possible reason for this could have been their strand. As described earlier, majority of them took GAS as their strand because they were still undecided on which path to take. It could have been possible that during their stay in SHS, they have slowly realized that they could possibly go to STEM fields. This resonates with the findings on career interests which shows that Grade 12 students are more likely to switch to STEM fields, both in Core STEM and Bio-Medicine Clusters, than Grade 11 students.

On average, those who are sure to pursue further studies see Science and Mathematics more positively in terms of students' intent to go to college. On the other hand, those who are not sure have a more positive attitude towards engineering and technology and 21st century learning. Nonetheless, in terms of career interests, those who intend to continue their studies have a higher interest in STEM fields in both clusters.

González-Pérez et al. (2020) and Shin et al. (2016) emphasized the significant influence of having role-models in attracting learners to choose STEM fields. However, based on the results of this study, it was found that knowing an S&T professional does not impact students' attitudes and career interests towards STEM. This is dissimilar to the results of González-Pérez et al. (2020). This surprising result could be due to factors affecting the efficacy of influence that a role model can provide, identified by Lockwood and Kunda (1997). These are (a) domain self-relevance and (b) perceived attainability of the model's success. In relation to the former, it could have been that the students do not necessarily imagine themselves as S&T professionals. On the other hand, the latter focuses on whether the students believe that they could also achieve what the role model has achieved. The consequence of seeing the role model's achievements as unattainable can induce discouragement and demoralization.

Some limitations were observed in this study. First, the sample was relatively small compared to those in the literature. Larger sample size is preferable to yield a more reliable result. Aside from this, since this study was limited to self-administered questionnaires, the respondents were not interviewed further about their STEM views and interests. Doing so would have allowed us to probe the opposing results on Grade 11 and Grade 12 students' differing attitudes towards STEM. This was due to the constraints brought by pandemic restrictions implemented by the school administrators.

Despite these limitations, this study has practical implications for the field of STEM education in the Philippines. First, we contributed to the literature that shows a measurement of student attitudes and career interests towards STEM. Again, this can be used as a rationale for future instructional innovations and improvements in teaching STEM, specifically in SHS. Aside from this, the increase in attitudes from Grade 11 to Grade 12 towards engineering and technology opens a new discussion on which aspect of the curriculum design allowed this increase to happen.

Secondly, as gender parity in STEM research is achieved in the Philippines, it becomes more apparent how the views of males and females do not differ statistically (Huyer, 2015). Employing more science pedagogies to continue reducing gender effects and gaps in students' attitudes and career interests towards STEM must be considered by teachers. Equal opportunities and support for every learner, regardless of gender must always be provided (Toma et al., 2019). Performance tasks such as laboratory activities and rich-context authentic tasks allow both males and females to develop 21st century skills (e.g., collaboration, cooperation, and communication). With this, the realization of 'Science for All' or an inclusive science curriculum may be realized sooner than expected.

Furthermore, their perception of self-compatibility with STEM must be reinforced through various strategies such as immersing them more with science practice, even non-STEM students, and exposing them with role models through videos and actual conversations and discussions (González-Pérez et al., 2020).

Finally, measuring attitude constructs towards STEM has significantly been emphasized to help fix the Philippine STEM pipeline by encouraging students to see STEM in a more positive light, if not an economically viable option.

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13. Gamified Drills in Senior High School Chemistry: A Study on its Impact on Students' Conceptual Understanding and Motivation in Learning Ionic Bonding

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Abstract

One of the key topics in chemistry that students find confusing is the concept of ionic bonding. If students struggle to understand core chemistry concepts, it will even be more challenging for them to relate those ideas to their daily lives. Students' difficulties in conceptual understanding may be related to issues of motivation to learn (Purba et al., 2019) and this has become a practical concern for teachers, particularly during the current remote learning context. Several studies suggest that gamification increases students' motivation to learn and conceptual understanding (Maul, 2012; Hanus & Fox, 2015). Gamification is the utilization, in a non-game setting, of multiple game features, such as points, leader boards, challenges, levels, or even storylines (Zichermann & Cunningham, 2011). In this study, we measured the impact of gamified drills, used during an instructional unit on ionic bonding, on conceptual understanding and motivation of 50 Grade 11 Science Technology Engineering and Mathematics (STEM) students who are currently enrolled in an online General Chemistry course at a college institution. The gamified drills used throughout the study consisted of different gamifying features such as leaderboards, rankings, and competition. A non-randomized sampling technique was used to classify students into a comparison group ($n = 19$) and a treatment group ($n = 20$), with the latter experiencing gamified drills during instruction. Before and after the instructional unit, students' conceptual understanding was measured using ionic bonding achievement test (IBAT) while motivation with chemistry motivation questionnaire (CMQ; Glynn & Koballa, 2006). The results suggest that both groups experienced gains in conceptual understanding and motivation. Comparing between the groups, students who were exposed to gamified drills demonstrated increases in both measures, but with low effect size. Implications of these findings will be discussed in relation to design of online learning environment to improve chemistry teaching and learning.

This research is an initial investigation that explores how gamification affects student's academic achievement and motivation in learning ionic bonding. In this section, we attempt to discuss four key ideas that inform this study: the 1) nature of gamification; 2) outcomes of gamification in science education; 3) problems faced by students when studying the concepts of ionic bonding; and 4) relevance of the issue being investigated.

Nature of Gamification

Gamification is the utilization, in a non-game setting, of multiple game features, such as points, badges, leader boards, avatars, levels, or even storylines (Zichermann & Cunningham, 2011). Recent research into the applications and implications of gamification has been the subject of several scholars' inquiry in various educational fields. Gamification, however, has often been used interchangeably with the notion of serious games, game-based learning, and learning by design, not until a critical analysis of their differentiation is undertaken. Serious games have a context for enhancing and fostering one's lifestyles and raising social awareness, whereas game-based learning (GBL) is a game form that provides some predetermined educational outcomes which can be achieved by adding all the features of game elements (Chia & Hung, 2017). Additionally, learning by design encourages learners to develop and incorporate their own game design to improve their way of learning (Chia & Hung, 2017). Gamification shares with all these forms the element of learning in a fun and engaging manner (Schaffhauser, 2013).

Outcomes of Gamification in Science Education

The gamification context facilitates positive learning for students in different subject areas, as reported in studies where students' self-efficacy, motivation, academic achievement, engagement, and attention have been examined (Dichev & Dicheva, 2017). Gamification can be used in a variety of contexts, both with and without using digital technology, since the main purpose of games is to motivate students in learning to solve problems through creative thinking (Ketola, 2019). It is worthwhile to implement this approach in science education, because of its compelling effect on achieving certain educational objectives. Previous studies that demonstrated the feasibility of using gamification techniques in the science classroom has been critically reviewed (Maul, 2016). Incorporating gamification principles into science education will reinforce learners' scientific and ICT literacy, promoting lifelong learning and meeting the need for 21st century skills.

Students Difficulties in Learning the Concept of Ionic Bonding

The Science, Technology, Engineering and Mathematics (STEM) education program is a science and mathematics-oriented curriculum devised for high school students in the Philippines. It is an academic strand within the senior high school curriculum and includes a specialized subject called General Chemistry that tackles the concept of ionic bonding as one of its major topics.

Difficulties in learning the concept of ionic bonding is one of the many reasons for students developing low scientific literacy. According to a case study by Ali (2012), the traditional way of teaching science in some schools is solely dependent on textbooks, with most teachers expecting students to memorize scientific facts, especially in the field of chemistry. Students consider most of the concepts in chemistry confusing and abstract. In particular, they find it challenging to grasp the topics of chemical bonding, nature of atoms and molecules, and chemical reactions (Ali, 2012). To comprehend a more complex chemistry concept, the topic of chemical bonding, especially the nature and nomenclature of ionic bonding, is regarded as fundamental and pre-requisite knowledge. Providing interactive drills and activities will promote learning mastery and positive attitude of learners while learning (Rathakrishnan, 2017).

Knowing the potential of gamification as a tool for learning and increasing learners' engagement, we intended to measure the effects of gamification in this present study. Though gamification is now a trend in education, studies exploring its effect in teaching different chemistry topics is limited (Muntean, 2011; McGonigal, 2011; Gonzalez & Area, 2012; Hellwege & Robertson, 2012; Brunsell & Horejsi, 2013). This research would also address one of the methodological issues identified by Hamari et al. (2014) in their investigation of gamification in education, which is the absence of a comparison group. Hanus and Fox (2015) reported that students in a gamified course demonstrated more motivation, satisfaction and empowerment over time than those in a non-gamified class. Furthermore, the use of gamification in this study is limited to its use in drills or activities rather than in whole class discussions.

This study contributes to ongoing discussion related to gaming and education. First, researchers are interested in the value of using innovative games to promote learning in various disciplines other than science. Second, researchers are also exploring effective ways to enhance the program of teaching chemistry. Gamification is a potentially beneficial approach for enhancing students' performance and motivation during the learning process. It could be added to our repertoire of instructional approaches. Non-game educators might consider integrating gamification into their teaching. Aside from promoting scientific literacy, incorporating gamification components into online chemistry instruction will improve students' information and communication technology (ICT) literacy skills.

Methods

Sample

In this study, we measured the impact of gamified drills, used during an instructional unit on ionic bonding, on conceptual understanding and motivation of 50 Grade 11 STEM students. The students were enrolled in an online General Chemistry course at a college institution. The institution offers a variety of academic tracks under their senior high school program, such as Accountancy, Business and Management (ABM), General Academic Strand (GAS), Humanities and Social Science (HUMSS) and STEM, which is the target strand of this study.

Since not all students can afford to attend a synchronous class and are not always readily available to participate in synchronous online sessions, convenience sampling was used to select the participants (25 students were introduced to a traditional approach to learning ionic bonding, while the other 25 were exposed to a gamified intervention). In cases where participants in a target population have satisfied the set practical requirements, such as availability and accessibility to participate in the study, a convenience sampling was considered (Etikan, 2016).

Measures

Ionic Bonding Achievement Test (IBAT)

To evaluate student’s knowledge before and after synchronous class discussions of both groups, the Ionic Bonding Achievement Test (IBAT) was developed (see Appendix B & C). The items found in IBAT are constructed based on the Most Essential Learning Competencies (MELC) that the students must develop in order to learn the topic. MELCs were produced to facilitate schooling during the COVID-19 pandemic. They are used to build and track learners' target skills as they advance through each grade level, according to the Department of

Education in the Philippines. Additionally, the IBAT used in this study consists of 20 multiple-choice questions. We (the researchers) content-validated the instrument, drawing on our training and experiences as chemistry educators, and then submitted it to the partner-teacher who taught the class under study for further validation purposes. Necessary adjustments were then made based on the comments of the teacher and the researchers.

Chemistry Motivation Questionnaire (CMQ)

The validated "Science Motivation Questionnaire (SMQ)" designed by Glynn et al., (2009) was used in this research to measure students' motivation before and after chemistry instruction (see Appendix A). SMQ is an instrument designed to provide researchers and science educators information on how well students are motivated when learning science in general. Moreover, in order to determine students' desire to study science, researchers must investigate why students struggle, how exactly are they doing, and what values, thoughts, and emotions they have during the learning process. SMQ is a 30- item Likert-type questionnaire with a 5-point scale (5 = strongly agree, …, 1 = strongly disagree). With the permission granted by the original authors of the instrument, modifications were made in the questions and scale's name, such as changing the word "science" into "chemistry". Hence, we called the modified questionnaire Chemistry Motivation Questionnaire (CMQ). While it was modified, CMQ still measures the same dimensions as SMQ.

Research Design

This study employed a pre- and post-test, quasi-experimental research design. Following non-randomized sampling technique, 25 students from class A were randomly chosen as a treatment group, while 25 students from Class B were chosen as a comparison group. Both groups took the Ionic Bonding Achievement Test (IBAT) and Chemistry

Motivation Questionnaire (CMQ), but only the students in the treatment group experienced gamified drills during instruction.

Experimental Procedure

Development of gamified drills

We developed gamified drills using web-based applications, such as kahoot, quia and science greek, on topics included in their module during the target week of the study.

Validation

The development of materials, including content and gamifying elements, were validated by researchers who have experienced developing a game as a requirement for a graduate course, as well as by the teacher who handled the class under study.

Implementation

Fifty students from treatment and comparison group took the IBAT and CMQ pre-test prior to the start of the synchronous classroom discussion via Zoom. The pre-test was set in Google Forms with a link sent to students ahead of shortly before the start of the class session. The teacher then continued to teach the class about the concept of ionic bonding. Only the experimental group was exposed to gamified drills. Before they ended their synchronous session, students were asked to answer again the Ionic Bonding Achievement Test (IBAT) and Chemistry Motivation Questionnaire (CMQ). However, a minimal change was made to the post IBAT, such as changing the given compound, to ensure that the students did understand the topic.

Evaluation

Using IBM SPSS Statistics 25, the collected data were prepared for statistical analysis.

Statistical Analysis

To identify whether there is a significant change in students' academic achievement, pre- and post-IBAT results were analyzed using paired-samples t-test. t-test is typically conducted to determine the difference of the resulting means between groups. It is commonly used in hypothesis testing to identify if a treatment actually affects the population of interest or how the two independent groups differ from one another (Bevans, 2020). Similarly, t-test was conducted on pre-test and post-test scores for the CMQ in order to check if there was a significant change in students' motivation due to the instruction (with and without gamification). Pearson coefficient for the correlation among samples was used to evaluate if the data within the group significantly differed from each other. The independent samples t test was also performed to assess if the data between the experimental and control group significantly differ in mean scores for the pre- and post-test s.

Results and Discussion

Profile of the Respondents

Out of 39 students in the treatment and comparison group, 55% were male. All the respondents were in the age bracket of 16-18 years old. Specifically, 48% were 16 years old, 40% were 17 while 12% were 18. The age range is what we expected for this grade level.

Students' Learning Achievement in Ionic Bonding

The Pearson coefficient for the results of pre- and post-test scores for IBAT shows a correlation of 0.601, indicating moderate to high correlation for the comparison group. The IBAT mean scores of students who experienced the traditional synchronous discussion indicate some gain, with pre-test (M = 7.32, SD = 3.45) and post IBAT (M = 11.9, SD = 3.37) results. To determine if the conceptual gains is statistically significant, a paired-samples t-test was performed. The result in Table 1 indicates that there is a statistically significant difference between pre- and post-test scores, suggesting that studying the concept of ionic bonding using traditional synchronous discussion increases the IBAT scores of students.

Table 1

Paired-Samples t Test of Comparison Group

		Paired Differences							
					95% Confidence Interval of the Difference				
		M	*SD*	*SEM*	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1	Pre-test comparison group (IBAT)-Posttest comparison group (IBAT)	-4.579	3.043	.698	-6.045	-3.112	-6.560	18	.000

Pre- and post-IBAT scores of the treatment group have a Pearson coefficient for correlation of 0.757, signifying that the average scores in the two variables are strongly correlated. A paired-samples *t*-test was used to determine if students in the treatment group experienced conceptual gains. Table 2 indicates that there is a significant difference in the IBAT scores before ($M = 10.1$, $SD = 3.64$) and after ($M = 13.8$, $SD = 2.97$); $t\ (19) = -6.83$, $p < 0.001$. This finding suggests that the use of various gamified drills increases students' conceptual understanding about the concept of ionic bonding.

Table 2

Paired Samples Test of Treatment Group

		Paired Differences							
					95% Confidence Interval of the Difference				
		M	*SD*	*SEM*	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1	Pre-test treatment group (IBAT) - Post-test treatment group (IBAT)	-3.650	2.390	.534	-4.769	-2.531	-6.829	19	.000

Although, both treatment and comparison groups show gains in conceptual understanding, it can be noted that the treatment group's pre and post IBAT scores have a higher mean and lower standard deviation than the comparison group. This seems to suggest that the gains for the treatment group are greater than that for the control group.

Students' Motivation

A paired sample *t*-test was conducted to compare the motivation of students in the comparison group before and after the synchronous classroom discussion. Table 3 shows that there is no significant difference in the students' motivation before (M = 3.85, SD = 0.37) and after (M = 3.92, SD = 0.50) they experienced a traditional synchronous classroom discussion; t (18) = -1.38, p = 0.184. This result suggests that studying the concept of ionic bonding using a traditional synchronous discussion has no significant influence on students' motivation.

Table 3

Paired Samples Test for the Difference of Pre-test and Post-CMQ Scores of the Comparison Group

		Paired Differences							
					95% Confidence Interval of the Difference				
		M	*SD*	*SEM*	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1	Pre-test comparison group (CMQ) - Post-test comparison group (CMQ)	.06667	.21053	.04830	-.16814	-.03840	-1.380	18	.184

Table 4 shows the result of the paired sample *t*-test that was conducted to analyze the students' motivation in the treatment group. These results indicate that there is a significant difference in students' motivation before ($M = 3.88$, $SD = 0.40$) and after ($M = 4.10$, $SD = 0.42$) they have been exposed to gamified drills or activities while learning the concept of ionic bonding; t (19) = -2.24, p = 0.037. Thus, this result suggests that gamifying chemistry instruction can positively influence students' motivation in learning the concept of ionic bonding.

Table 4

Paired Samples Test of the Difference of Pre-test and Post-CMQ Scores of the of the Treatment Group

		Paired Differences							
					95% Confidence Interval of the Difference				
		M	*SD*	*SEM*	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1	Pretest treatment group (CMQ) - Posttest treatment group (CMQ)	-.216	.433	.0967	-.419	-.0142	-2.240	19	.037

Even though the comparison group showed motivation scores with higher mean and lower standard deviation, only the treatment group demonstrated a statistically significant improvement. Perhaps students in the comparison group experienced the typically high level of motivation during the synchronous discussion. Whereas students in the treatment group, because they experienced a new mode of instruction, became even more motivated to experience a novel approach.

Conclusion

Using a modified Chemistry Motivation Questionnaire (CMQ) designed by Glynn and Koballa (2016) and the Ionic Bonding Achievement Test (IBAT) that we developed and content-validated, the study investigated the impact of the gamified drills on senior high school students' conceptual understanding about ionic bonding. The results of the study indicate that students in both comparison and treatment groups demonstrated an increase in conceptual understanding and motivation. However, in terms of conceptual understanding, the treatment group obtained higher mean differences relative to comparison group, suggesting that gamifying chemistry instruction, the use of gamified drills specifically, has a positive influence. These results are comparable with the findings of Tolentino (2018), which reported that gamifying physics instructions resulted in increase of students' motivation and conceptual understanding to study a specific physics lesson.

Our study however has its limitations. Firstly, this study is a purely quantitative research and no qualitative data was collected in order to triangulate the results of the study. Secondly, because of the limited time to prepare, only three gamified activities were made and used in the intervention process. Lastly, the paper only explored the impact of using gamified drills on students' achievement in a specific chemistry topic. Therefore, one cannot generally conclude that this approach can be the optimum strategy to enhance students' academic performance in Chemistry.

Taking into consideration the limitations of this study, the researchers recommend having no delayed post-tests since an immediate post-test would yield a better measure of conceptual gains about the topic. Moreover, it is also suggested that future research test other gamified activities aside from the drills used in the study. Likewise, exploring other topics in General Chemistry is also highly encouraged for there are still limited studies that investigate the application of game elements in a chemistry classroom, particularly in a full online set-up. Further studies may also conduct semi-structured interviews to further interrogate students' experiences of learning Chemistry topics in a fun and engaging manner.

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Appendices

Appendix A

Instrument : Chemistry Motivation Questionnaire

Adapted from: Science Motivation Questionnaire: Construct Validation with Nonscience Majors (Glynn & Koballa, 2006).

Direction: In order to better understand what you think and how you feel about your chemistry course, please respond to each of the following statements from the perspective of: ‘‘When I am in a senior high school chemistry course. . .’’

1 - Strongly Disagree 2 - Disagree 3 - Neutral

4 - Agree 5 - Strongly Agree

		1	2	3	4	5
1	I enjoy learning chemistry					
2	The chemistry I learn relates to my personal goals					
3	I like to do better than the other students on the chemistry tests.					
4	I am nervous about how I will do on the chemistry tests					
5	If I am having trouble learning chemistry, I try to figure out why.					
6	I become anxious when it is time to take a chemistry test.					
7	Earning a good chemistry grade is important to me.					
8	I put enough effort into learning chemistry					
9	I use strategies that ensure I learn chemistry well					
10	I think about how learning chemistry can help me get a good job					

11	I think about how the chemistry I learn will be helpful to me					
12	I expect to do as well as or better than other students in the chemistry course.					
13	I worry about failing the chemistry tests.					
14	I am concerned that the other students are better in chemistry.					
15	I think about how my chemistry grade will affect my overall grade point average.					
16	The chemistry I learn is more important to me than the grade I receive.					
17	I think about how learning chemistry can help my career.					
18	I hate taking chemistry tests.					
19	I think about how I will use the chemistry I learn.					
20	It is my fault if I do not understand the chemistry.					
21	I am confident I will do well on the science labs and projects.					
22	I find learning chemistry interesting.					
23	The chemistry I learn is relevant to my life					

Appendix B

Instrument: Pre-test for Ionic Bonding Achievement Test (IBAT)

MULTIPLE CHOICE: Choose the letter of the BEST answer in the following questions.

1. How many valence electrons should sulfur (S=16) atom have in its Lewis dot model?

A. 5
B. 6
C. 7
D. 8

2. Which of the following atoms given their atomic numbers BEST represents the given illustration of Lewis dot structure?

A. nitrogen (N=7)
B. carbon (C=6)
C. oxygen (O=8)
D. fluorine (F=9)

3. When combined with chlorine (Cl=17) atom, which element given their atomic masses would NOT form an ionic compound?

A. neon (Ne=10)
B. silver (Ag=47)
C. copper (Cu=29)
D. sodium (Na=11)

4. How many atoms of iodine (I=53) is required to form an ionic compound with magnesium (Mg=12)?

A. 1
B. 2
C. 3
D. 4

5. Which of the following is NOT an anion?

A. sulfite ion
C. mercurous ion
B. nitride ion
D. perchlorate ion

6. In naming a metal ion which belongs to transition elements that can have more than one typical ionic charge, how is the numerical value of the charge indicated?

A. by prefix
B. by suffix
C. by superscript after the name
D. by Roman numeral following the name

7. Which of the following statements is TRUE about the properties of ionic compounds?

A. They are solid at room temperature.
B. They are liquid at room temperature.
C. They have low melting point and boiling point.
D. They are not a good conductor of heat and electricity.

8. What is the charge of group 6A elements when they form ions?

A. +2
C. +6
B. -2
D. -6

9. What is the formula and total charge of carbonate ion?

A. CO_2, -1
C. CO_3, -2
B. CO_2, -1
D. CO_3, +2

10. What is the name of the chemical formula CuSO4?

A. copper (I) sulfite
C. copper (II) sulfite
B. copper (I) sulfate
D. copper (II) sulfate

11. What will be the formula of the compound formed by aluminum and hydroxide?

A. AlOH
C. Al(OH)3
B. Al_3OH
D. Al_2(OH)3

12. How many electrons does bromine atom (Br=35) require to form an ion compound with lithium (Li=3)?

A. 1
C. 3
B. 2
D. 4

13. Which of the following correctly provides the name and symbol of the ion?

A. HNO_2, nitric acid
C. H_2SO_3, sulfuric acid
B. HClO, chloric acid
D. H_2CO_3, carbonic acid

14. Which of the following atoms is BEST described in the statement: element X reacts with oxygen to form an ionic compound with formula X_2O_3, the X-ion has 3 valence electrons?

A. carbon
C. aluminum
B. hydrogen
D. potassium

15. What is the valence and charge of the electron configuration of $1s^22s^22p^63s^23p^3$?

A. 3, +3
C. 5, -3
B. 3, -3
D. 5, +3

16. What is the electron configuration for argon atom (Ar=18)?

A. $1s^22s^22p^63s^23p^4$
C. $1s^22s^22p^63s^23p^6$
B. $1s^22s^22p^63s^23p^5$
D. $1s^22s^22p^63s^23p^64s^1$

17. What is the chemical name and formula when one phosphorus atom and 3 oxygen atoms formed a polyatomic ion?

A. PO_3, phosphite ion
C. $(PO_3)^{3-}$, phosphite ion
B. PO_3, phosphate ion
D. $(PO_3)^{3-}$, phosphate ion

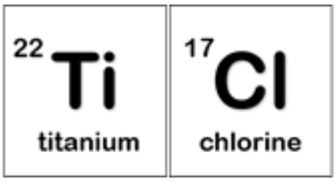
18. Which among the following atoms will form an ion having a -2 charge?

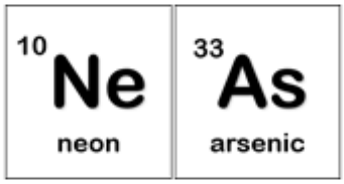
A. sulfur,16
C. iron,26

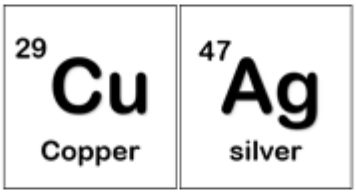
B. magnesium,12

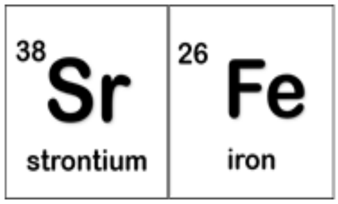
D. arsenic,33

19. Which pair of atoms will most likely form an ionic compound?

A. 

C. 

B. 

D. 

20. As Au3+ ion and O2- ion react to form a compound, what is the chemical name and formula?

A. Au_3O_2, aurous oxide

C. Au_2O_3, gold (III) oxide

B. Au_3O_2, auric oxide

D. Au_2O_3, gold (II) oxide

Appendix C

Instrument: Post-test for Ionic Bonding Achievement Test (IBAT)

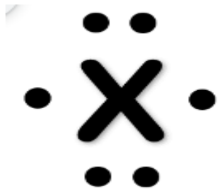
MULTIPLE CHOICE: Choose the letter of the BEST answer in the following questions.

1. How many valence electrons should silicon (Si=14) atom have in its Lewis dot model?

A. 5 C. 7

B. 6 D. 8

2. Which of the following atoms given their atomic numbers BEST represents the given illustration of Lewis dot structure?



A. nitrogen (N=7) C. oxygen (O=8)

B. carbon (C=6) D. fluorine (F=9)

3. When combined with chlorine (P=15) atoms, which element would NOT form binary ions?

A. iron (Fe=26) C. copper (Cu=29)

B. argon (Ar=18) D. calcium (Ca=20)

4. How many atoms of bromine (Br=35) is required to form an ionic compound with magnesium (Na=11)?

A. 1 C. 3

B. 2 D. 4

5. Which of the following is NOT an anion?

A. sulfate ion
B. nitride ion
C. auric ion
D. hypochlorous ion

6. In naming metal ions which belong to a transition element and can have more than one typical ionic charge, how is the numerical value of the charge indicated?

A. by prefix
B. by suffix
C. by superscript after the name
D. by Roman numeral following the name

7. Which of the following statements is TRUE about the properties of ionic compounds?

A. They are solid at room temperature.
B. They are liquid at room temperature.
C. They have low melting point and boiling point.
D. They are not a good conductor of heat and electricity.

8. What is the charge of group 6A elements when they form ions?

A. +2
B. -2
C. +6
D. -6

9. What is the formula and total charge of carbonate ion?

A. CO_2, -1
B. CO_2, -1
C. CO_3, -2
D. CO_3, +2

10. What is the name of the chemical formula CuSO4?

A. copper (I) sulfite
B. copper (I) sulfate
C. copper (II) sulfite
D. copper (II) sulfate

11. What will be the formula of the compound formed by aluminum and hydroxide?

A. AlOH
C. Al(OH)3

B. Al_3OH
D. $Al_2(OH)3$

12. How many electrons does a sulfur atom (S=16) require to form an ion compound with strontium (Sr=38)?

A. 1
C. 3

B. 2
D. 4

13. Which of the following correctly provides the name and symbol of the ion?

A. HNO_2, nitric acid
C. H_2SO_3, sulfuric acid

B. HClO, chloric acid
D. H_2CO_3, carbonic acid

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A. 4, +2
C. 6, -2

B. 4, -2
D. 6, +2

16. What is the electron configuration for calcium atom (Ca=20)?

A. $1s^22s^22p^63s^23p^64s^1$
C. $1s^22s^22p^63s^23p^64s^13d^1$

B. $1s^22s^22p^63s^23p^64s^2$
D. $1s^22s^22p^63s^23p^64s^13d^2$

17. What is the chemical name and formula when one phosphorus atom and 4 oxygen atoms formed a polyatomic ion?

A. PO_4, phosphite ion
C. $(PO_4)^{3-}$, phosphite ion

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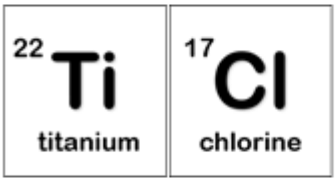
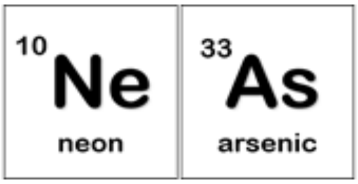
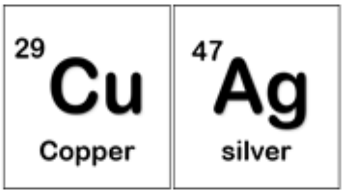
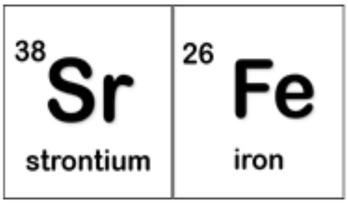
A. 

C. 

B. 

D. 

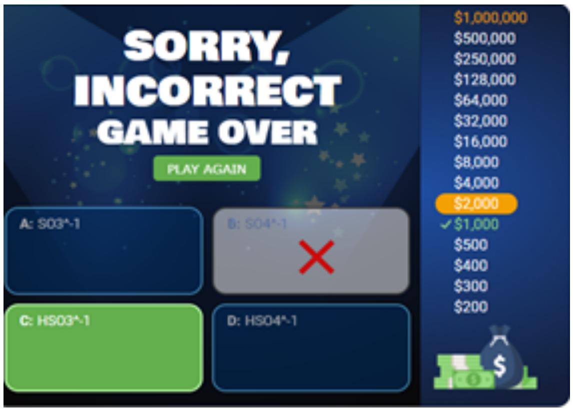
20. As Au+ ion and O^{2-} ion react to form a compound, what is the chemical name and formula?

A. Au_2O, aurous oxide C. AuO_2, gold (I) oxide

B. AuO_2, auric oxide D. Au_2O, gold (II) oxide

Appendix D

Gamified Drills for Ionic Bonding



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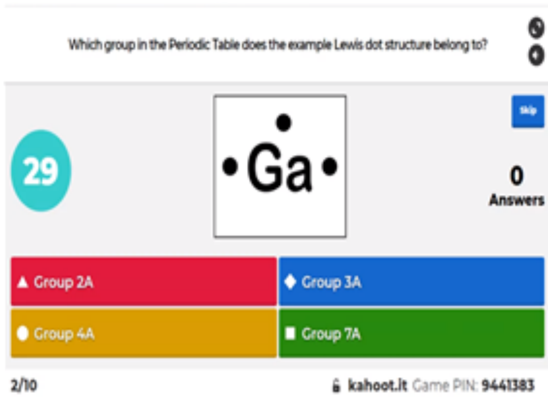

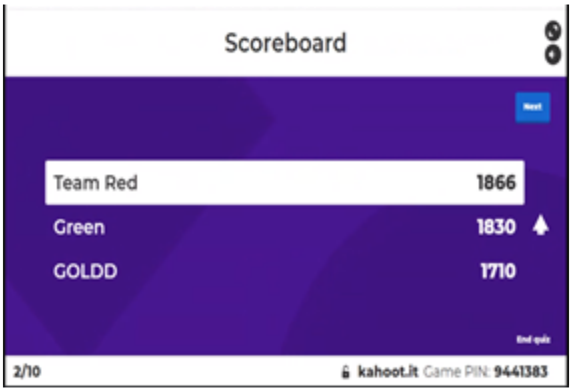

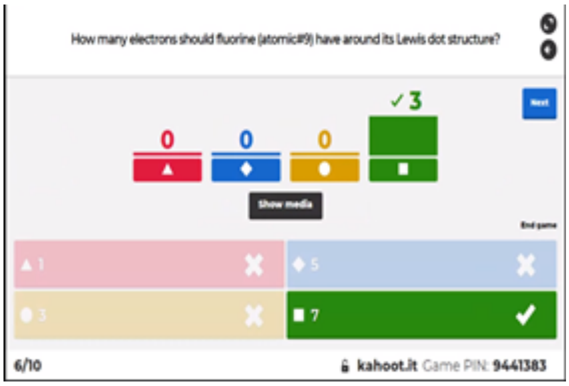

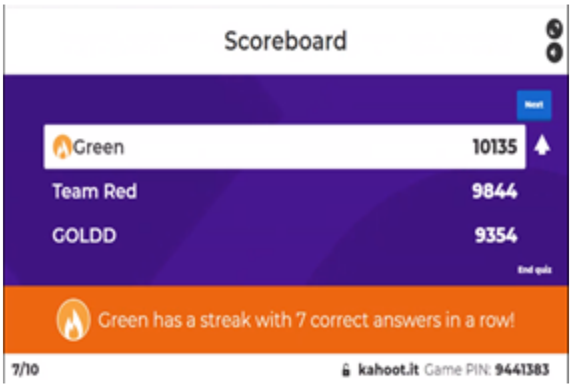

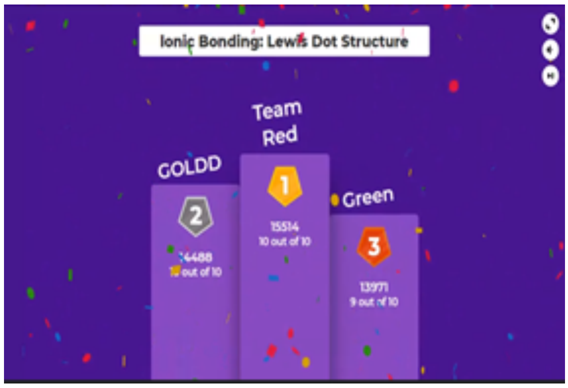

mailto:https://create.kahoot.it/share/lonic-bonding-lewis-dot-structure/05df2695-

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Appendix E

Figures

Figure 1

Profile of the Respondents According to Gender

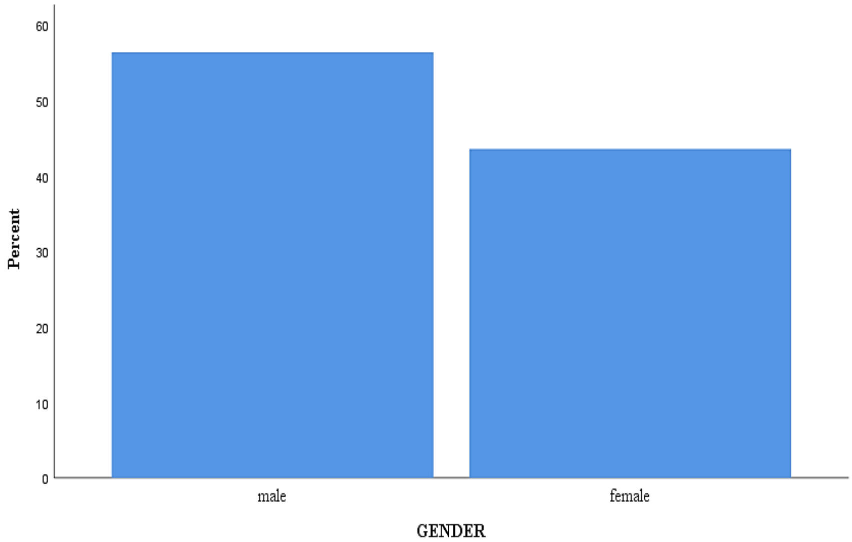
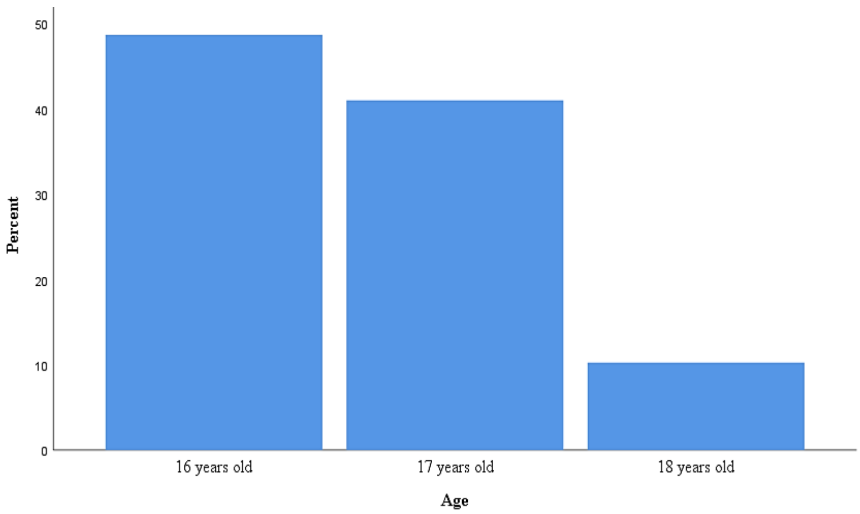


Figure 2

Profile of the Respondents According to Age



Correction

Article title: CASE STUDIES EXAMINING TEACHERS' ADAPTIVE PRACTICES IN TWO SINGAPORE SCHOOLS

Authors: Wong Hon Kit Benjamin

List of corrections done in the original article

1. Revised from IRB-2020-02-030-07 to IRB-2018-01-030-06.