



From the Editor

It is with great pleasure that we publish the first issue (Vol. 1, No. 1, Sep-Dec 2020) of the *Southeast Asian Journal of STEM Education*. Discussions about starting a STEM Education journal began several months ago with Dr. Pornpun Waitayangkoon, the Director of the Regional STEM Education Centre of the Southeast Asian Ministers of Education Organization (SEAMEO) headquartered in Bangkok. Dr. Pornpun's vision of the new center included an online peer-reviewed journal that would showcase research and "what works" in STEM education, focusing on STEM education in the region while also publishing studies and successful projects from other locations around the world. The goal is to inform educators, administrators, policy makers and STEM-based industries in Southeast Asia of what STEM education is, why it is needed, and how it is linked to issues in local schools, communities and businesses, as well as to the world at large.

While STEM education is well developed and integrated in the school curricula of many countries around the world, it is still a relatively new idea in the curricula of many Southeast Asian countries. Indeed, while some countries have integrated STEM teaching and learning, others in the region are just now learning about the concept of STEM education and its potential. It is in this light that the SEAMEO STEM Ed Centre provides professional leadership, joining with corporate and education partners to develop curricula, projects, teaching modules, student and teacher academies, professional learning communities, and other resources for STEM education in the region. The *Southeast Asian Journal of STEM Education* is proud to be part of this effort.

We have assembled a review board whose members are experienced STEM educators and STEM education researchers from countries around the world. In addition, we are advised by our Associate Editors, a group of highly respected educators whose support and suggestions are invaluable. The in-house journal team has worked hard to screen manuscripts, determine needed revisions, and communicate with authors and reviewers to ensure a quality publication. My deep appreciation and thanks go to Managing Editor Jirayu (Pete) Arayaprayoon, copyeditor and proofreader Sarit Sanguanwongse, Senior advisors Tom Corcoran and Ed Reeve, and Advisor Sattiya Langkapin. Their assistance has been crucial to the success of the journal.

In this inaugural issue, we are pleased to have authors from four countries contributing to the knowledge base in STEM Education. **Ophelia Kee and Tan Aik-Ling** of Singapore write about a study that strives to answer the question *What are students' challenges and perspectives when generating a STEM solution to a real-world problem?*; **Cladys M. Falcunaya, Marvin J. Rosales, and Apple Kaye C. Vera** discuss the impact of student misconceptions of heat and temperature on STEM studies in a Philippine high school; **Fred N. Finley**, a science educator from the U.S. reports on the need for culture-based STEM education, focusing especially in Southeast Asia; **June Alexis Razonable** gives an in-depth look at how using computer simulations in a Philippine high school to solve problems in chemistry helped promote conceptual change to correct misconceptions; and **Tomohiro Takebayashi and Yoshisuke Kumano** from Japan discuss how the study of local geological materials can be used in integrated STEM teaching and learning.

--John Stiles, Editor in Chief



Generating STEM Solutions to a Real-World Problem: Challenges and Promises

Ophelia Kee and Tan Aik-Ling*

National Institute of Education
Nanyang Technological University, Singapore
*Corresponding author: aikling.tan@nie.edu.sg

Abstract

Global education systems have placed an increasing emphasis on the teaching of science, technology, engineering and mathematics (STEM) in a more integrated and contextualised manner. However, there are many critics who challenge the advantages of integrated STEM education. Hence, instead of taking a dichotomous perspective of integrated STEM or non-STEM, the focus is placed on the quality of integrated STEM activities that students are presented with and their impact on students' learning experiences. In this article, an integrated STEM lesson with conceptual knowledge from chemistry as the lead discipline was designed and carried out in a Grade 8 classroom. Students had to undergo the process of analysing background information followed by problem identification. Subsequently, they were presented with scientific experiments and relevant cases studies to strengthen their content knowledge. Lastly, the students engaged in group discussions to propose solutions and present information related to an interdisciplinary problem. Through this activity we sought to answer the research question: *What are students' challenges and perspectives when generating a STEM solution to a real-world problem?* After analysing the students' artifacts, video recordings of the lesson, and students' formative assessments, we were able to identify some of the struggles that the students and teachers faced in an integrated STEM classroom, together with the improvements that are needed for a more beneficial learning experience.

Keywords: integrated STEM, rusting, chemical reactions, problem solving

This article describes an integrated STEM activity based on the phenomenon of rusting. Rather than teaching rusting purely as a chemical reaction between iron and oxygen during chemistry lessons, we aimed to engage students with a real-world problem related to rusting of bridges and through the activity, learn to apply chemical concepts to slow down rusting. Beyond the science of rusting, the activity required students to appreciate the design of bridges and understand the economic implications related to rusting of bridges. Through presenting scientific knowledge in the context of a problem, we hoped to develop students' ability to connect scientific knowledge, engineering concepts, technological capabilities and problem-solving abilities in their learning. The research question, "*What are students' challenges and perspectives when generating a STEM solution to a real-world problem?*" forms the focus of this study.

Curriculum integration through meaningful application of subject matter knowledge to solve real-world problems is touted to provide learners with more holistic learning experiences.



For instance, Venville et al. (1998) described a technology project that engaged students with investigating traction, types of materials, power transmission systems (technology), friction, gears, pulleys, torque (science), and changing variables on standard Lego™ models (mathematics) as the students build the model (engineering). Through working on these real-world integrated STEM activities, students drew on their science, technology and mathematics knowledge and their problem-solving skills to generate solutions.

Integration of STEM

Integration of different disciplinary knowledge can be carried out by bringing together conceptual knowledge, identifying common epistemic practices and social norms to achieve synergy in practices to enable problem solving. An integrated curriculum requires teachers to renegotiate traditional subject boundaries, practices and outcomes. Furner and Kumar (2007, p. 186) argue that integrating disciplinary knowledge to facilitate learning makes learning “more relevant, less fragmented, and more stimulating experiences for learners.” While there are many people supporting the benefits of the integrated STEM learning experiences, there are also critics, from STEM as well as non-STEM faculty members, who challenge its advantages and even highlight implications that an overemphasis on STEM education may be detrimental to the learning of other disciplines (Breiner et al., 2012) as well the how some STEM implementation has trivialized the social, cultural and moral implication of STEM in the larger society. The scholars who have taken a more critical view of STEM are worried that the economic rationale for STEM in K-12 increasingly tends to exclude social, cultural, and environmental implications of STEM beyond content mastery. However, all scholars support the idea of integration as an effective method of teaching and learning various content areas, STEM or non-STEM, for a well-rounded education.

Rather than taking a dichotomous perspective of integrated STEM vs non-STEM, we argue that what matters in integrated STEM learning experiences is the quality of integrated STEM activities that students are presented with. Here we present an example of an integrated STEM activity with conceptual knowledge from chemistry as the lead discipline.

To provide a meaningful real-world context for students to understand the connections between rusting as a chemical reaction involving iron, water, and oxygen, and the commercial implication of rusting in infrastructures, students were presented with a complex, persistent and extended problem (Tan et al., 2019). Rusting of physical infrastructure is a complex problem because in order to reduce the rate of rusting, one needs to apply knowledge from more than two of the four STEM disciplines (mainly science, mathematics, and engineering). Rust is a persistent problem for people around the world despite the availability of various solutions. Finally, the issue of rusting demands that the students engage with the activity for a sustained period of time to understand related issues and to generate plausible solutions. Using the three characteristics of “complex, persistent and extended,” we designed an activity requiring students to determine ways to reduce or prevent rusting of a bridge that was built in a place with high humidity (such as Singapore) and to use their knowledge to predict the rate of rusting in different climatic zones.



Key STEM Concepts Used in the Activity

Rusting has led to several infrastructural damages such as the destruction of bridges, oil pipelines, military jets, ships and nuclear power plants. It has also resulted in some deaths. In many industrial countries, hefty budgets are allocated for managing the rate of rusting and corrosion of infrastructures. The average budget for preventing rust and corrosion is between 3.4% to 4.5% of the Gross Domestic Product (GDP) (Jacobson, 2016). The reason for the substantial sum is because rust can deem parts of a building unusable in the blink of an eye and repair costs are high. As such, effective rust prevention methods should be adopted to reduce these unnecessary accidents and expenditure.

The chemistry behind rusting and its associated problems can be found in curricular documents in many parts of the world, from America to Australia to Asia. The inclusion of the process of rusting as a chemical change, regardless of the social or cultural context, is indicative of its importance (Australian Curriculum, Assessing and Reporting Authority, [2020] National Resource Council, [2012]). This core idea of a chemical reaction is mirrored in the GCE "O" level chemistry syllabus in Singapore. Specifically, students are required to be able to (a) Describe the essential conditions for the corrosion (rusting) of iron as the presence of oxygen and water; prevention of rusting can be achieved by placing a barrier around the metal, e.g., painting, greasing, plastic coating, and galvanizing, and (b) Describe the sacrificial protection of iron by a more reactive metal in terms of the reactivity series where the more reactive metal corrodes preferentially, e.g., underwater pipes have a piece of magnesium attached to them (Singapore Examinations and Assessment Board, 2020, p. 18). Table 1 details the key concepts of the integrated STEM activity.

Table 1

Key Concepts

<u>Lead STEM discipline</u>	<u>Chemical sciences</u>
Grade level	8 or equivalent
Big idea	Using the chemistry of rusting to reduce/prevent rusting in infrastructures and to predict the rate of rusting in different climatic zones
Essential pre-existing knowledge	<ul style="list-style-type: none"> • Balancing of chemical equations • Oxidation and reduction (redox reactions) • Simple graphing techniques
Possible learning outcomes	<ul style="list-style-type: none"> • Describe the essential conditions for the corrosion (rusting) of iron as the presence of oxygen and water; prevention of rusting can



be achieved by placing a barrier around the metal, e.g. painting; greasing; plastic coating; galvanizing.

- Describe the sacrificial protection of iron by a more reactive metal in terms of the reactivity series where the more reactive metal corrodes preferentially, e.g. underwater pipes have a piece of magnesium attached to them.
- Chemical change involves substances reacting to form new substances.
- Identify questions and problems that can be investigated scientifically and make predictions based on scientific knowledge.
- Construct and use a range of representations including graphs, keys and models to present and analyse patterns or relationships in data using digital technologies as appropriate.

Designing a Real-World Activity

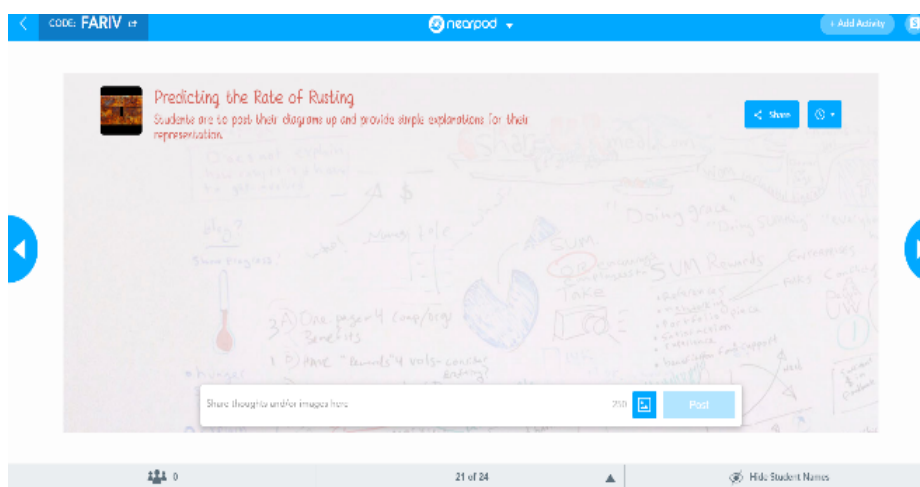
In designing the activity, both the disciplinary paradigm and the integrated paradigm (Venville et al., 2002) were considered: the conceptual subject matter knowledge of individual disciplines and the connections of epistemic practices, conceptual knowledge and social norms across different disciplines are taken together with problem-solving to generate solutions.

From a disciplinary perspective, science was integrated into students' learning as students were required to describe the essential conditions for the corrosion (rusting) of iron and to identify the different types of rust prevention methods with confidence in order to complete the activity. For mathematics, students analysed data and applied their graphing techniques to present their predictions on the rate of rusting in different climatic zones. For engineering, students were challenged to generate possible solutions to prevent a bridge from rusting in an area with high humidity. They designed, illustrated, and explained their prototype as part of the engineering aspect of the lesson. The lesson, however, did not progress to allow students to build, test and refine their design. While we recognise that the design process requires students to build and test the prototype, this was not carried out during the lesson as there was insufficient time to bring the whole process to fruition. The experience that we are sharing here serves to inform the learning experiences that students often are given limited time and the potential of a more holistic learning experience is possible only when more time is made available. Technological outcomes, such as programming and computational thinking, did not feature prominently in this activity. Rather, technology was applied as a teaching and learning tool to facilitate the access of videos, slides, online quizzes, and poll throughout the lessons. The specific technological tool used during the lesson was Nearpod™, which is an

award-winning online platform that allows for students' engagement with a ready-to-run interactive lesson for K-12 teachers. Figure 1 illustrates a Nearpod function that allowed students to present their answers in front of the entire class. Students were also allowed to conduct research online. Thus, technology was heavily adopted as a facilitation and research tool for the students rather than for students to learn technological knowledge such as computational thinking. Figure 2 illustrates the connections between the disciplines and the relative depth to which each was applied in the learning.

Figure 1

Nearpod's "Collaborate!" Tool



Implementing the Real-World Activity

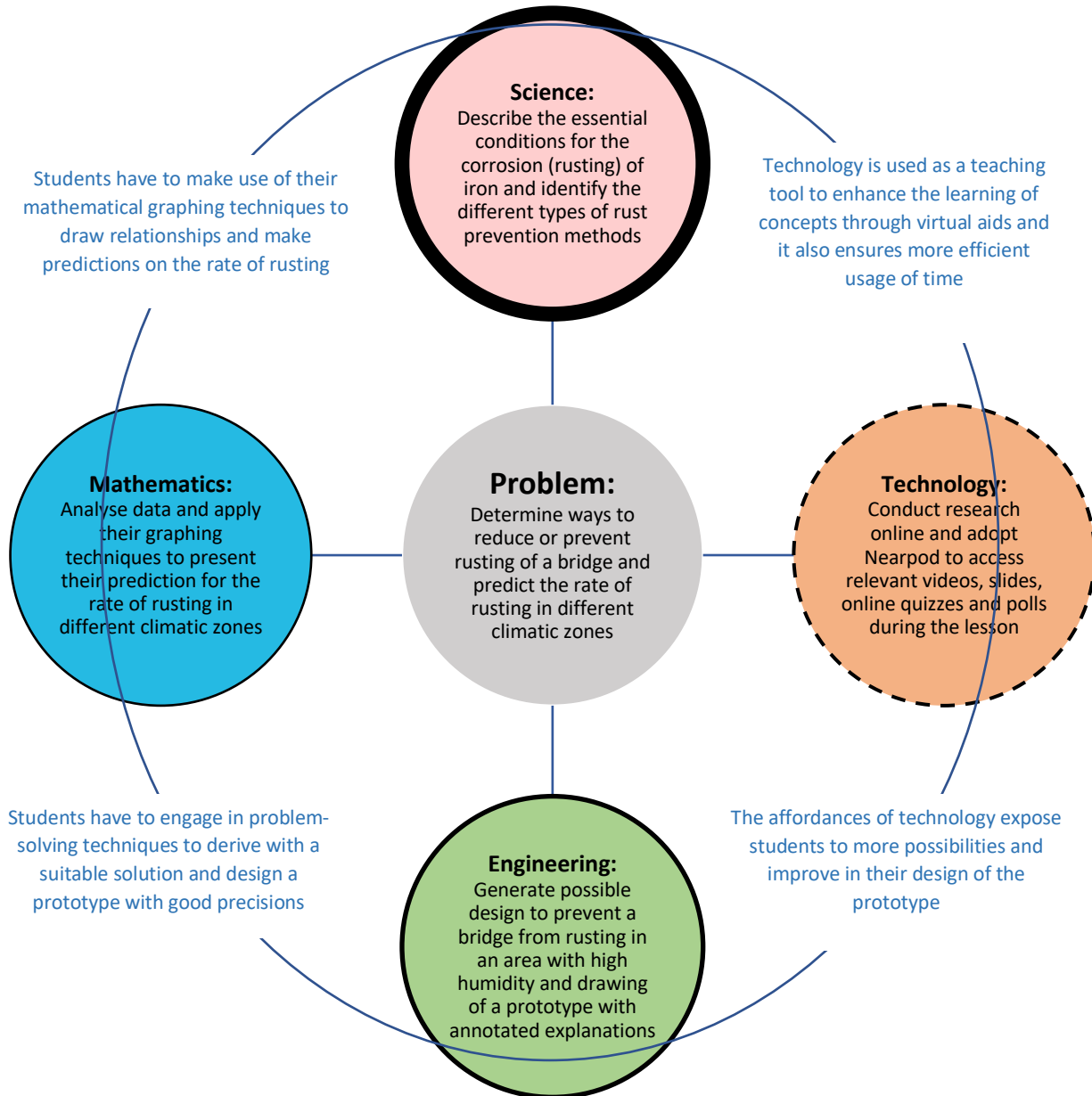
In a "traditional" teaching classroom setting, students may not fully comprehend the negative impacts of rust and thus fail to appreciate the importance of learning the chemistry behind rust formation. This activity is planned and implemented in a manner to enable students to use their knowledge of rusting to propose solutions to prevent it from happening.

Identifying the Problem

The class described here was a class of students with average ability in science. Students were given activity worksheets consisting of the background information on rusting and the impact of rusting in infrastructures. Upon entering the Nearpod online portal, students were given access to all of the learning slides and relevant resources on their mobile devices. Students spent about 10 minutes answering questions based on what they had learned from the background information on the topic of rusting. These questions varied with increasing difficulty; an example can be seen in Figure 3. Subsequently, students' performances were discussed, and misconceptions were corrected by the teacher.

Figure 2

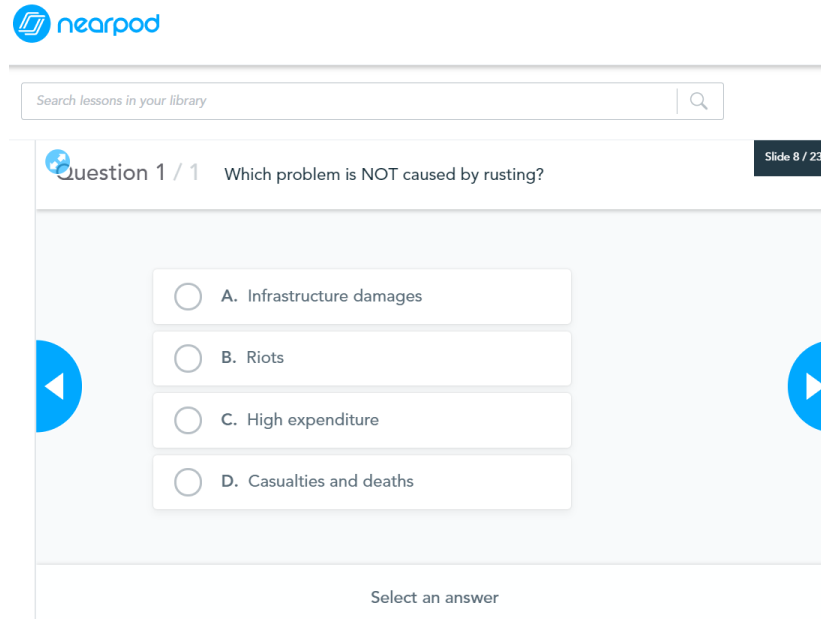
Mapping the Disciplinary Knowledge and Connections Between Disciplines to the Problem. The Intensity of the Line Indicates the Relative Depth with Which each Disciplinary Knowledge is Addressed.



Graphic © by the authors.

Figure 3.

Students used Mobile Phones to Answer Questions on Nearpod.



Deciding on the Nature of the Problem

Afterwards, students spent about 25 minutes brainstorming and identifying the problems related to the phenomenon of rusting. After the brainstorming session, students were presented with case studies on *The Golden Gate Bridge in San Francisco* and *Lowe's Motor Speedway in North Carolina*. They also watched related videos at their own pace as the links were available on the Nearpod portal as seen in Figure 4. Even though these cases are based in the U.S., the cases supported students' understanding of how rusting influences structures in different climatic conditions (zones). Additionally these cases provided links to how knowledge from different disciplines within and outside of STEM provided the nature of the problem, causes of it, potential solutions, and impact on larger social lives (tourism, sports, social life, etc.).

After watching the video, students viewed a virtual scientific demonstration on the portal as seen in Figure 5. The nail rusting demonstration was a scientific investigation activity that aimed to teach students the conditions for rusting (Building of scientific content knowledge).

Figure 4.

Student Access to Videos on Various Case Studies Related to the Rusting of Bridges and its Problems.

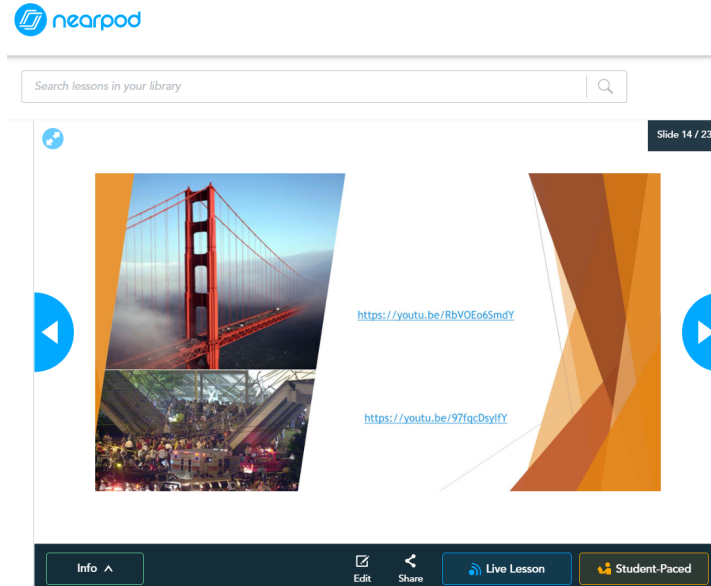
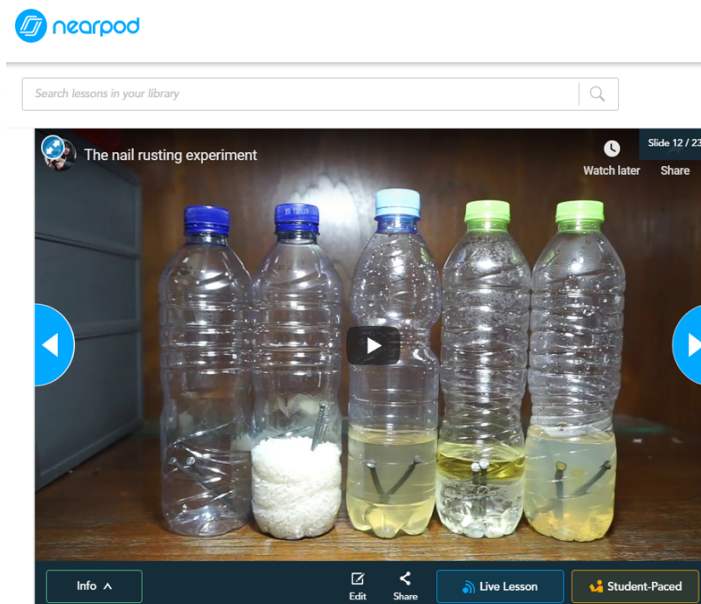


Figure 5.

Student View of an Online Scientific Investigation Allowing Close Proximity

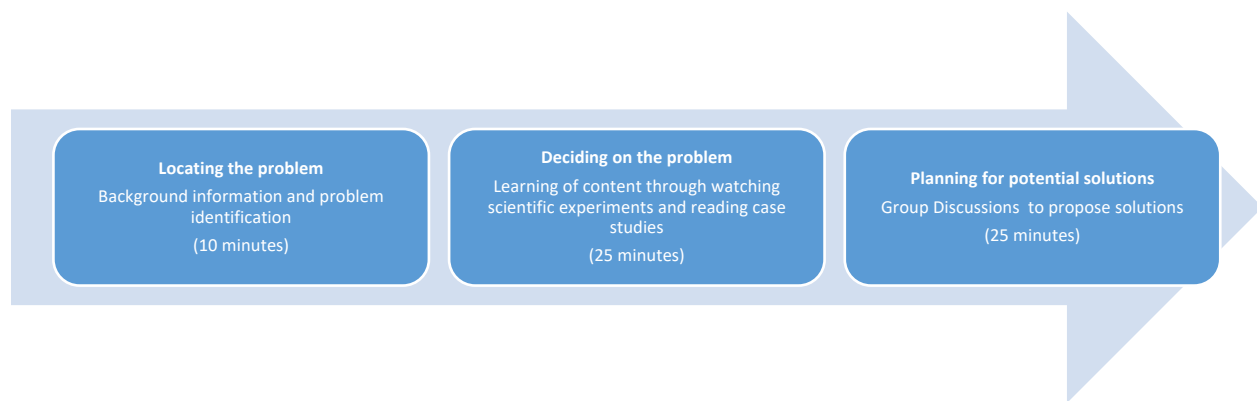


Planning for Potential Solutions

With an improved understanding of the conditions for rusting and rust prevention, students worked together in groups of four to propose solutions to prevent rusting of bridges (Problem solving). Students drafted their ideas on an activity sheet and eventually uploaded their ideas onto Nearpod. This phase of the lesson took about 25 minutes. At the end of the lesson, the students plotted a graph to predict the rate of rusting (mathematical skills) in the different climatic zones (geology). The entire implementation process is simplified in Figure 6.

Figure 6.

Outline of the Implementation Process



The time taken for each phase of the lesson (shown above) is dependent on the readiness and profile of learners. The time reflected here is the duration recorded during the actual lesson.

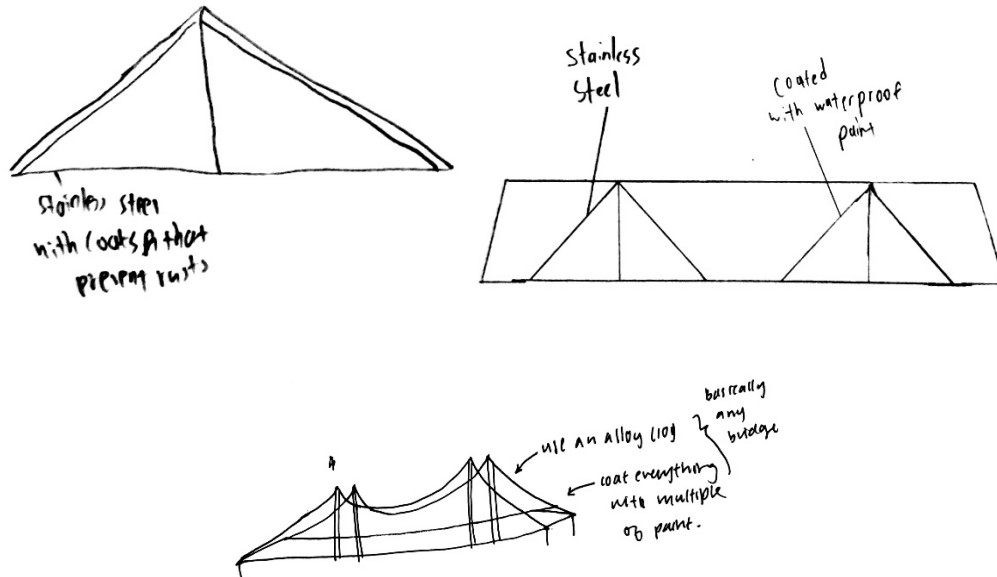
Evaluating the Activity

Four main observations were made from this particular integrated STEM activity after analysing the video recording of the entire lesson and the students' artefacts. Here we highlight some of the challenges that the students faced, the potential learning problems, and the benefits resulting from such an integrated learning framework. Furthermore, we also hope to provide insights on how we can improve the quality of the integrated STEM activity.

The first observation obtained is that most of the students struggled to devise creative and innovative strategies on their own to reduce rusting of bridges built in warm and humid environments, as seen in Figure 7. Many of them simply suggested existing designs that adopt the use of stainless steel and paint-coating to prevent rusting. Some of them even pointed out that their solution was "basically any bridge." Based on their proposed solutions, the majority of the students could be given more exposure and practice to real-world integrated STEM activities to develop their creativity and innovation, particularly their abilities to pay attention to details, and problem-solving skills.

Figure 7

Solutions Lacking Creativity and Details



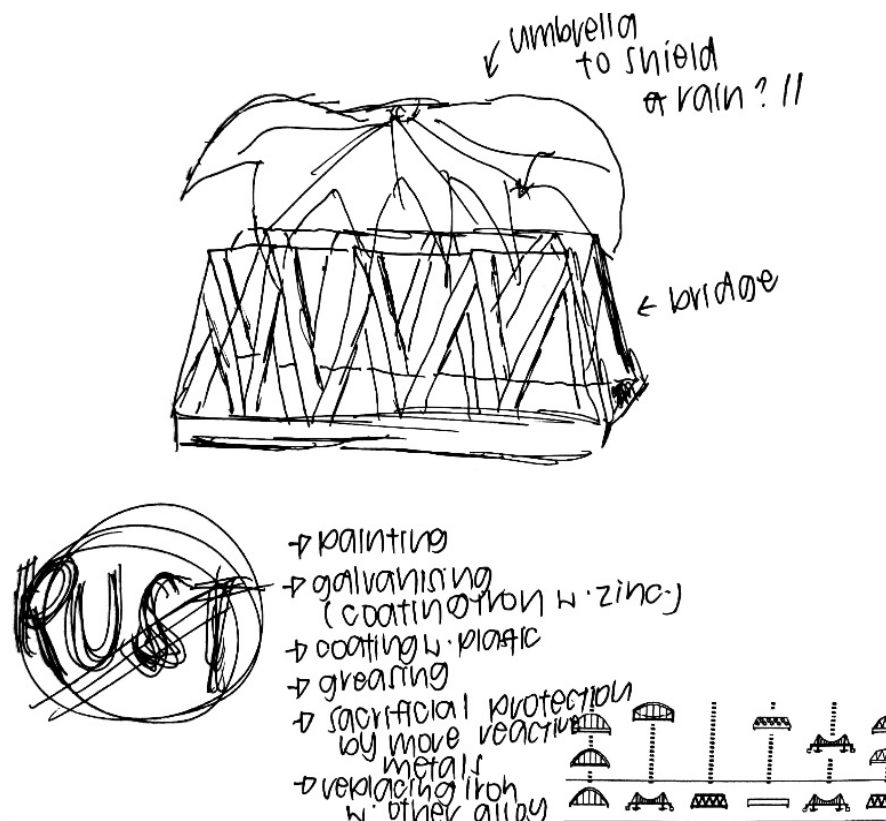
Two possible reasons could explain the lack of students' creativity in generating solutions: (1) the time allocated for brainstorming was too short, and (2) this was the students' first encounter with engineering and the newly taught concept of rusting. Thus it is understandable that many students found it challenging to derive creative yet plausible solutions for a complex, persistent, and extended problem at the start. As such, we advise that teachers who intend to adopt an integrated STEM lesson should apportion a longer period of time for discussions and also to provide several samples of innovative designs for students to consider. This could help students move from a situation of "idea scarcity" to "idea fluency" (Crismond & Adams, 2012). Teachers may also consider providing different perspectives on the multi-faceted problem to emphasise the endless possibilities of solutions and also enable students to weigh in on the trade-off of each proposed solution. The discussion of the trade-off included cost and availability of jobs as well as waste accumulation. This discussion clearly demonstrated that understanding a problem and solution requires knowledge from different fields, both STEM and non-STEM, including cultural, social, and budgetary concerns.

The second observation was that students exhibited uncertainty with the problem at hand and their lack of knowledge in science and engineering resulted in many of them relying on online search engines to facilitate their idea generation. Such dependence on the Internet to generate solutions can potentially cause many students to lose sight of the process of problem-solving itself. This is a major downfall of the ease of access to technology in an integrated STEM

lesson. From another perspective, teachers need to be able to guide students to think and learn from existing work that is out there, borrow ideas, and apply these ideas to devise their own solutions. For example, Figure 8 shows a student's proposed solution involving a large umbrella over the bridge, but she expressed doubt in her work as she could not find it on the Internet.

Figure 8

A Student Wrote a "Question Mark" on Her Proposed Design, Expressing Doubt in Her Work as it was not Supported by Ideas Found on the Web.



In such cases, teachers could scaffold students' searches for ideas on the Internet with suggested keywords and encourage more student-generated ideas instead. An overreliance on the world wide web may be detrimental to students' creativity and problem-solving skills.

The third observation was that many of the students appeared to be confused and even clueless when asked to draw links to other subjects such as geography and mathematics. In this interdisciplinary activity, students had to analyse information about the four unique climatic zones in the world and predict the rate of rusting in the different countries in these zones. They

were tasked to present their predictions in the form of a graph with the correct labels and axes. Only one-third of the students provided justifiable predictions based on the given information. Moreover, many of the students, who understood the information correctly, failed to provide appropriate axes and labels, as seen in Figures 9 and 10. The failure of students to represent the correct trend and pattern points to the need to focus on both content of rusting as well as the epistemic norm of graphical representation. As such, it is evident that many students struggled in an integrated learning framework that involves content and skills from more than one discipline.

Figure 9

Failure to Label the X and Y Axes Despite Making the Correct Prediction

4a. Identify the climatic zones for these countries.

- (i) Greenland (75° N): Polar and sub polar zone
- (ii) Malaysia (0°): tropical zone
- (iii) New Zealand (45° S): temperate zone
- (iv) Saudi Arabia (30° N): Sub tropic Zone

4b. Analyse the piece of information given and plot a graph to represent the different rates of rusting in the four different countries based on your speculations. Include axes and labels if applicable.

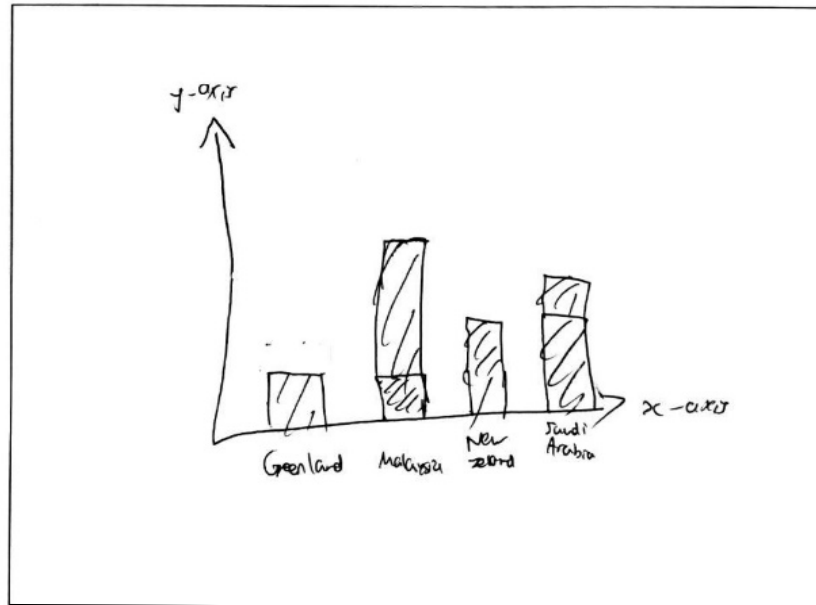
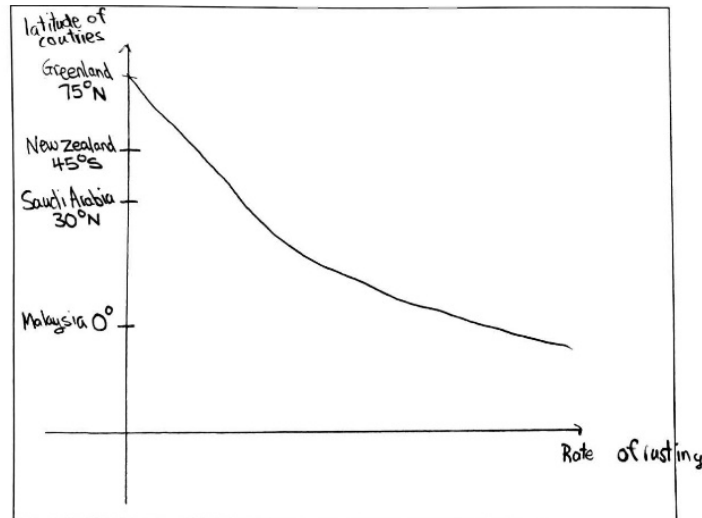


Figure 10

Incorrect Placing of the Independent Variable (Latitude of Countries) on the Y Axis and the Dependent Variable (Rate of Rusting) on the X Axis



This example indicates to us that teachers need to scaffold new ideas and expectations early on in the lesson. Additionally, students have differing levels of competency in different content areas (math, science, geography, history, etc.). Therefore, teachers need to provide supports to aid students to learn how different content ideas can help them in finding a solution to a real-world problem. One way to provide support for students is that teachers provide a review section consisting of all the relevant pre-requisite knowledge required from other subjects before students embark on an inter-disciplinary activity.

The fourth and final observation showed that most students were able to see the connections between the topic of rusting and real-world scenarios. Some of their responses are noted below.

S1: *“With a high rate of rusting, more things will break easily, that will cause higher money for renewal.”*

S2: *“If we know the rate of rusting, we can learn more about how to prevent it.”*

S3: *“(Issue of rusting is relevant in Singapore) because Singapore has many planes that protect SG’s air force.”*

These students were able to identify the consequences of rusting, the importance of understanding it, and its relevance in Singapore’s context. As such, through an integrated STEM activity, the majority of the students were able to articulate the relevance of their learning in the real world.



Conclusion, Limitations, and Challenges

By engaging students in designing a way to reduce the rate of rusting, we hoped that students would learn the science behind rusting, how to engineer a bridge so that it will rust at a slower rate, and also to appreciate the economic, social and cultural implication of rusting. The problem served as the integrative mechanism for this learning to take place. Our observations of students during the lesson indicate that more time is needed for students to engage with discussion so that the focus can shift from only focusing on the correctness of the conceptual knowledge to a more holistic manner to also understand the relevance of the scientific knowledge.

We recognise that creativity takes time and continuous effort to hone but with the right guidance and support, students were able to become familiar with engineering practices through an integrated STEM lesson. While the identification of a problem for an integrated STEM lesson is important, the success of an integrated STEM experience also relies on the implementation of the lesson. Our experiences concurred with aspects of facilitating design processes (Crismond and Adams, 2012) and showed the importance of (1) allocating sufficient time to allow students to engage in generative idea brainstorming to develop idea fluency, (2) allowing group discussion to weigh the benefits and trade-off of ideas so as to increase confidence of solution generated, and (3) decreasing students' reliance of the world wide web for ideas and confidence.

Based on the observations of the lesson, one important revision that can be made to the lesson is to schedule a longer period of time for students to engage in the design process and to engage in refinements of their prototype. Secondly, teachers can arrange for just-in-time (need-related) learning for students who are unfamiliar with any aspects of the activity (for example, mathematical concepts and representations).

In summary, students' lack of familiarity with breaking a problem into its component parts and applying relevant subject matter knowledge to solve problems highlight the need for greater alignment between the learning context and the students' knowledge and learning capacity (Nadelson & Seifert, 2017). Our observations during the lessons showed that while some students were able to see greater relevance in their learning and provide more holistic solutions, others required more time and scaffolding. Therefore, integrated STEM activities that are centred around real-world problems with solutions requiring the application of subject matter knowledge would require more instructional time for benefits to be deemed significant.



Ophelia Kee is a fourth-year undergraduate student who is training to become a science teacher. Her teaching specializations are secondary school chemistry and mathematics. Ms. Kee participated in the prestigious URECA (Undergraduate Research Experience on Campus) programme under the supervision of A/P Tan Aik Ling and has presented her work at the annual Australasian Science Education Research Association (ASERA) Conference.



Tan Aik Ling is an associate professor and Deputy Head (Teaching and Curriculum Matters) at the Natural Sciences and Science Education academic group at the National Institute of Education, Nanyang Technological University, Singapore. Dr. Tan is one of the founding members of meriSTEM@NIE, a centre that focuses on research, development and outreach in STEM education in Singapore and Asia. Her current research interests are in the area of science classroom interaction, science teacher professional development as well as STEM curriculum development. She has published more than 45 peer refereed journal articles, 22 book chapters and co-edited three books in the area of science and STEM education.

References

- Australian Curriculum, Assessing and Reporting Authority (ACARA). (2020). *Year 8 science content*. Downloaded on Jul 5, 2020 <https://www.australiancurriculum.edu.au/f-10-curriculum/science/>
- Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, 101(2), 738-797.
- Furner, J., & Kumar, D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology*, 3(3), 185-189. <https://doi.org/10.12973/ejmste/75397>



Jacobson, G. (Ed.) (2016). *NACE impact report: International measures of prevention, application, and economics of corrosion technologies study*. Houston, Texas: NACE International.

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, 110(3), 221-223. DOI:

<https://doi.org/10.1080/00220671.2017.1289775>.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

<https://doi.org/10.17226/13165>.

Singapore Examinations and Assessment Board (SEAB). 2020. *Chemistry Singapore-Cambridge general certificate of education ordinary level 2020 syllabus 6092*: 18.

https://www.seab.gov.sg/docs/default-source/national-examinations/syllabus/olevel/2020syllabus/6092_y20_sy.pdf

Tan, A.-L., Teo, T. W., Choy, B. H., & Ong, Y. S. (2019). The S-T-E-M quartet. *Innovation and Education*, 1, 3. <https://doi.org/10.1186/s42862-019-0005-x>

Venville, G. J., Wallace, J., Rennie, I. J., & Malone, J. A. (1998). The integration of science, mathematics and technology in a discipline-based culture. *School Science and Mathematics*, 98(6): 294-302.

Venville, G. J., Wallace, J., Rennie, L. J., & Malone, J. A. (2002). Curriculum integration: Eroding the high ground of science as a school subject? *Studies in Science Education*, 37, 43-84.



Appraisal of STEM Students' Misconceptions of Heat and Temperature

Cladys M. Falcunaya^{1,2*}, Marvin J. Rosales^{1,3}, and Apple Kaye C. Vera^{1,4}

¹Philippine Normal University, Manila, Philippines

²Philippine Science High School, Calabarzon Region Campus, Batangas City,
Batangas, Philippines

³Department of Education, Luis Palad Integrated High School, Tayabas City, Philippines

⁴Southern Luzon State University, Lucena Campus, Lucena City, Philippines

*Corresponding author: cmfalcunaya@cbzrc.pshs.edu.ph

Abstract

This study was designed to determine the common misconceptions about heat and temperature among one hundred fifty-one (151) Grade 12 STEM students of Luis Palad Integrated High School in the Philippines. In the research process, an adapted 30-item multiple-choice Heat and Temperature Concepts Questionnaire (HTCQ) was administered to appraise the misconceptions among the student-respondents. It was followed by an in-depth interview with 20 students who had the most incorrect responses. This was done in order to determine the factors that affect the formation of misconceptions. Findings showed that the majority of these students have alternative concepts of heat and temperature that were greatly affected by experiences, prior learning, and, their attitude towards the subject. As an implication, it is suggested that these misconceptions must be immediately addressed by relating them to contexts that are understandable to the learners at their level.

Keywords: science education, misconceptions, heat and temperature, STEM students

Conceptual change is a gradual process that takes place as learners embed fresh data into their present constructs. Evaluating learning throughout this process needs action to diagnose misconceptions and fully grasp how information is changing. The conception of learners is grounded on their real-world experiences, which do not always align with scientific principles, however, these ideas may change as they mature. A student's embedded knowledge may be inaccurate or misunderstood. Misunderstandings of a concept are called misconceptions. Students' significant structural adjustment of concepts without the development of delusions depends on individual differences such as intellectual level, motivation difference, perception preference (Kuzgan & Deryakulu, 2004), and the teaching-learning environments (Sen & Yilmaz, 2012).

All teachers, not only as teacher-researchers, have the responsibility to determine the existing ideas of the students in order to structure in-depth lessons through the administration of diagnostic tests. This also serves as a reference for the teachers to ascertain the most



appropriate, high-quality instructions that will elicit the best understanding of the students of the key science concepts that the students are expected to learn (Alwan, 2011).

On a personal note as a teacher, when trying to solve a complex problem in physics, it has been observed that students often over-generalize a particular principle in an attempt to solve the problem. Teachers of physics subjects share concepts with their students and those students who have previous knowledge of the topic can more easily relate to the subject.

Physics has intricate topics and students often digest it one step at a time, learning the basics then going to more complex topics, but if a single process is missed it can make the correct explanation ambiguous. It is surprising to teachers when students tend to have a narrow understanding of a physics lesson and frustrating when helping their students learn the basic concept of the lesson. Although students may be able to provide a correct response to physics-related queries, they implicitly show their understanding of the underlying physics theories based from deep-seated rote memory or worse, grasp onto a concept which they believe to be scientifically accurate but is not.

Concepts of Misconceptions

Misconceptions are ideas of individuals based on their comprehension and appreciation that are not scientifically accurate. Some people embrace a misconception because they do not fully understand the notion.

Misconceptions, misunderstandings, or incomplete ideas about a process or concept in a subject (Scheuermann & van Garderen, 2008), erroneous conception or a mistaken notion (Meyers, 2007), that differ from what is known to be scientifically correct, are common and can arise in any discipline. However, many researchers have emphasized that teachers should be focused on developing knowledge structures (Mesutoğlu & Birgili, 2017) instead of focusing on avoidable mistakes; equally important is correcting the misunderstanding and knowing what techniques can be used to work with them. Hence, students can have the opportunity to unlearn the misconception and learn the correct one.

Misconceptions should not be mistaken for preconceptions, alternate conceptions, naive ideas, and common sense conceptions for the reason that they do not specifically involve student understanding before instruction (Halim et al., 2019). These alternative concepts should be scrutinized and corrected after being exposed to formal instruction (Dolgos, 2006), with the discrepancy of students' ideas arising out of a confusion of informal thinking that is currently being welcomed by the scientific community. The risk in those misconceptions is when students have difficulty correcting their misconceptions because such preconceptions cannot be released or corrected as it is difficult for them to process new material properly.



Background of the Study

Early 21st century science teachers are facing multiple problems. Surprisingly, in science accomplishment, learners in the United States still fall behind learners in other nations, especially from many European and Asian countries (National Center for Education Statistics, 2007). Relatively, the results of the Programme for International Student Assessment (Pisa) by the Organization for Economic Cooperation and Development (OECD) in 2019 revealed that Filipinos fared worst among 79 countries in reading literacy and second lowest in both mathematical and scientific literacy (Reysio-Cruz, 2019).

Access to appropriate textbooks and classroom resources are just some of the complex problems in the field of science education (including pre-service and professional growth); other issues include political and religious objections to state-of-the-art science education, the need to satisfy norms and prepare learners for evaluation criteria, and the use of the Internet as a data source.

Anderman and Sinatra (2017) point out that science, engineering, and technology enable graduates to engage in open discussions on science-related topics, be responsible citizens of modern society and deal with a great deal of information in the scientific and technical areas, as they hold the key to meet current and future challenges. However, although for example, most U.S. employees have a certain degree of background on basic science concepts, not all do. This problem has led to a widespread call for a new approach to K-12 science education in the United States.

Based on a survey, the number of Overseas Filipino Workers (OFWs) who worked abroad at any time during the period April to September 2019 was estimated at 2.2 million (Philippine Statistics Authority | Republic of the Philippines, 2020), economically contributing to both GNP of the Philippines and GDP of the countries where they are situated. However, some of the Filipino professionals who have worked overseas have found it difficult to get a good opportunity based on the degree they have finished because the educational institution in the Philippines is different from abroad (Ednave et al., 2018). Since the implementation of the K-12 curriculum in 2013, the educational system of the Philippines is still in the process of renewing in order to correct some factors that have been identified. People in the education sector are making every effort to address the needs of the people and to provide the Philippines with a quality education program that offers an adequate time frame for mastering concepts and skills, cultivating lifelong learners and training graduates for tertiary education, middle-level skills development, jobs, and entrepreneurship. Though the goal is not to send Filipinos abroad, it is a reality that there are greater job opportunities for them in many foreign countries where they can improve their standard of living.

The curriculum is an essential aspect of the academe and Filipino learners are adjusting to the academic arena to suit the K-12 curriculum's current layout since its conception in 2013. The K-12 curriculum is the consequence of the education sector's three-year mediation by



Philippine policy implementers and was subjected to tedious and complex processes before it was implemented (Cabili & Capilitan, 2015). However, the transition from the Basic Education Curriculum (BEC) to K-12 Curriculum in the education system in the Philippines drew negative reactions from different groups of society. Grageda (2016) stated that the Philippines is not yet ready with this significant shift in the whole education system. Despite the calls to suspend this, the government remains firm on this new transition, believing that the additional years in education will enable the nation, especially the learners, to meet the standards of the global market. Meanwhile, the Science framework for Philippine Basic Education contains three curriculum components: (1) inquiry skills, which explain and discover physical phenomena; (2) scientific attitudes, which refers to the values and habits of mind; and (3) content and connections, which give meaning to the context of the subject matter that is under exploration (Gonzales, 2019).

Under the K-12 curriculum of the Department of Education, senior high school students have to select a track as they enter grade 11. They can choose among three tracks: Academic; Technical-Vocational-Livelihood; and Sports and Arts. The Academic track includes three strands: Accountancy, Business, and Management (ABM); Humanities and Social Sciences (HUMSS); and Science, Technology, Engineering, Mathematics (STEM). Each strand is unique as they offer subjects relevant to each strand as they move up to the tertiary level.

Luis Palad Integrated High School (LPIHS) is one of the five high schools in the Division of Tayabas located at Brgy. Ipilan, Tayabas Quezon. It has recently become the first ISO 9001:2015 certified public high school in Quezon Province, and the third in Calabarzon. For the school year 2019-2020, it had nine hundred sixty-two (962) senior high school enrollees. The school offers academic tracks that include STEM, HUMSS, ABM, and GAS. Currently, the Senior High School Department of LPIHS is in its second year of offering STEM. With this, the students and the faculty are still refining their understanding and navigating the course offerings, particularly in the sciences.

As a central focus of the study, students enrolled in the STEM strand are required to take additional science and math subjects, which include pre-calculus, basic calculus, general chemistry 1 and 2, general biology 1 and 2, and general physics 1 and 2. Looking at the performance of STEM students in these subjects, it is evident that learning gaps are present based on their mean percentage score (MPS) for the past two years. In particular, the MPS for general physics 2 is lowest in 2018 (64.18) and in 2019 (58.15). This value is far below the passing rate of 75 set forth by the education department.

Being considered by many as the most essential and over-arching with other sciences, physics has had a significant effect on all other scientific advancements. In addition, students in many fields try to learn physics because it plays a basic role in all other phenomena. True enough, it corresponds to what used to be called natural philosophy, from which most modern sciences emerged (Gottlieb & Pfeiffer, 2013). With this in mind, there is a need to look at how well students in the Philippines have really understood concepts in physics, as they have low

test performance in the subject, in the hope of identifying misconceptions they may still possess despite being grade 12 students in the STEM strand.

Student misunderstandings are omnipresent across the fields of science, technology, engineering, and math (STEM). Introductory core subjects such as physics is a good venue to determine and remediate students' misconceptions since it is a prerequisite to various STEM-related courses such as engineering and technology, however it is confirmed that there are several identified misconceptions, particularly in the introductory level (Neidorf et al., 2020). Because STEM classes tend to build on each other, it can be particularly detrimental to student learning to transfer misconceptions. These misunderstandings are often recognized through interviews, inventories of concepts, or analysis of a text. However, misconceptions of learners become particularly apparent in student-generated writing (Halim et al., 2019) because it offers more data about knowledge of learners than multiple-choice issues or other forced-response evaluations.

Misconceptions have long-term consequences but practicing science in the classroom helps to correct misunderstandings and fosters enthusiasm for the scientific sector (Meyers, 2007). Student misconceptions are a hindrance to science, technology, engineering, and math courses and unless the students do well, the misconceptions will continue to cause learning difficulties as the students make progress in their studies (Halim et al., 2019).

To further provide quality education to the youth, it is of utmost importance that student learning should be based on how well they can apply concepts learned in the classroom to real-life situations. This would be possible if they would be free from misconceptions as they finish their senior year. Thus, appraising how well STEM students understood scientific concepts from grades 7 to 12 would aid in determining possible misconceptions they may have formed to help them and the school realize ways to address this issue.

Statement of the Problem

STEM students have been performing poorly in their physics classes, particularly on the concept of heat and temperature, for the past two years. In order to determine the learning gap of the students, this study is concerned with the appraisal of their misconceptions on heat and temperature.

Specifically, it sought to answer the following questions:

1. What are the misconceptions of STEM students regarding heat and temperature based on the Heat and Temperature Concepts Questionnaire (HTCQ)?
2. How did STEM students come up with their answer for each test item?
3. What are the possible factors that affected the conceptions of the STEM students towards heat and temperature concepts?

Significance of the Study

The findings of this study are deemed significant for various stakeholders such as students, science educators, teachers, administrators, educational researchers, and the researchers themselves.

Students. This study will help learners to correct their heat and temperature misconceptions. A previous understanding of the student can be used as a construction block to acquire fresh understanding. They are now free to ask about those thoughts with this understanding that provide incorrect views. This makes the learners more engaged in the process of teaching-learning where they can participate actively. Students have previous misunderstandings about content that make it even more difficult to understand the larger image, hence a scheme needs to be developed to make use of the preconceptions for a better understanding of the material.

Science educators. The results will provide links between the previous understanding of the student and the introduction of fresh science ideas. Essentially, when both students and teachers have a chance to actively participate in learning science, students recognize the fallacy of their misunderstandings, and conceptually clarify the freshly obtained data. The significance and persistence of these obstacles to real comprehension should not be underestimated by a science teacher.

Teachers. The teacher becomes a co-learner and facilitator. The results of this study may provide some direction for teachers on how to prepare their lesson plans and generate new teaching techniques to understand learners for a more efficient teaching-learning process. Identified misconceptions will be the springboard of the educators on which tactic will be the best means to correct the confusion among their future scientists, which has a great potential to cause confusion with new learning. Also, it can be a guide in helping the students to construct or reconstruct a correct framework for their new knowledge.

Administrators. This research study will give an idea to the university administrators to initiate a seminar related to the new strategies that will present materials that can aid in correcting students' misconceptions. It would be greatly beneficial to support the teachers to develop their pretest misconception material for their course, such as instructor's manuals, textbook material, and their knowledge of the field. It also benefits school administrators who are involved in educational system reforms in the country thru the continuous improvement of the K-12 curriculum.

Educational researchers. Researchers can use the data of this study to conduct more extensive research that may lead to the development of new materials or processes that may enhance the facilitation of learning.

Limitations of the Study

The investigation was limited to Grade 12 students taking the Science, Technology, Engineering, and Mathematics (STEM) Strand at Luis Palad Integrated High School. The program consisted of 151 students during the first semester of the school year 2019-2020.

The questionnaire was simultaneously administered among the student-participants during the first quarter wherein the topics were not yet discussed in their General Physics subject, consequently, the conceptions that students may currently have had are solely based on their schema acquired during their grade 11 and junior high school years.

The focused subject matter in this study are topics that were included in the Department of Education Science Curriculum under the K to 12 Program. The instrument deals only with limited topics on heat and temperature. The questionnaire encompassed the subtopics, namely concepts of heat and temperature, heat transfer and temperature change, and thermal properties of materials.

The results of the study were used to determine the alternative concepts of the students about heat and temperature where the teachers utilized the results to correct the misconceptions through the course of the lesson by applying the various conceptual change models suitable for the factors causing the alternate concepts of the students.

Methodology

Research Design

This research study involved a methodology for conducting an investigation that encompassed collecting and analyzing information and integrating mixed methods of quantitative and qualitative research.

The objective for the researchers was to understand the identified misconceptions about heat and temperature of the senior high school STEM students, which were obtained through the quantitative analysis of their responses through the Heat and Temperature Concepts Questionnaire (HTCQ).

Furthermore, qualitative research was utilized to corroborate their responses to better understand and explain the causal processes involved, hence, an interview was conducted. It was for the students to express how they come up with their answers for each item.



Respondents

A total of 151 Grade 12 students, who are enrolled in the Science, Technology, Engineering, and Mathematics (STEM) Strand in Luis Palad Integrated High School (LPIHS), Division of Tayabas City, Quezon, were given consent by their parents to participate in this study. The participants were purposely chosen for the reason that these students had finished Grades 7-11 at LPIHS and were anticipated to have a strengthened and profound knowledge about the topic. Furthermore, they were expected to pursue science and engineering-related courses upon entering the tertiary level. In addition to this, twenty (20) students who got the lowest scores in the HTCQ were identified and subjected for an oral interview. This number of interviewees was selected so that saturation of interview responses may be minimized (Saunders, et.al., 2018).

Research Instrument

Heat and Temperature Concepts Questionnaire (HTCQ)

To determine the alternative concepts of the STEM student, the Heat and Temperature Concepts Questionnaire (HTCQ) was adapted (Alwan, 2011). Originally, it was constructed through the suggested steps by Robbins (1998) on the constructional course of the multiple-choice questionnaires. The adapted HTCQ consisted of thirty multiple-choice questions, which are situated in everyday circumstances. Questions 1 to 26, 28 and 29, 27, and 30 were originally from Yeo and Zadnik (2001), Driver (1989), and Elwan and Almahdi (2007), respectively.

The test items were adapted from the HTCQ and grouped into four sub-topics that they fall into, namely; (1) heat, (2) temperature, (3) heat transfer and temperature change, and (4) thermal properties of materials.

Heat and Temperature Alternative Concepts Interview

Twenty students from the 151 members of the study group with the lowest scores based on the HTCQ were interviewed to determine their alternative concepts about heat and temperature. They were asked to explain how they arrived with an answer to each question. They were also interviewed to gather a more complete and comprehensive understanding of the factors that might have affected their responses.

Data Gathering Procedure

The researchers directed a letter requesting permission to administer the HTCQ and conduct an interview with the intended student participants, to the schools' division superintendent of the Division of Tayabas City. The approved letter was forwarded to Luis Palad Integrated High School to formally endorse the conduct of the study.

Each student was asked to accomplish and submit a duly signed consent form by their parents, thus, allowing them to become student-participants in the study. An orientation was

held where the purpose of the research study was explained to the student respondents, before the administration of the test.

Upon evaluation of the answered instruments, twenty students who got the lowest scores in the HTCQ were interviewed to attempt to unravel the factors that might have affected their alternative understanding of the concepts. At the start of the interview, the student respondents were reminded that the questions during the interview aimed to measure their reasoning ability, not their correct response to any specific item.

Data Analysis

The students' responses in the HTCQ were scrutinized through item analysis using the ZipGrade® app. The percentage of incorrect answers were considered and analyzed to determine the students' alternative concept in each item.

The twenty students who got the lowest scores were interviewed and their responses were transcribed and analyzed to determine the possible factors that affected the conceptions of the STEM students towards heat and temperature concepts. To determine how the alternative conceptions (Table 1) of students formed, their explanations for the provided response in each item were analyzed.

Results

All of the student-respondents answered the HTCQ simultaneously; their knowledge about the topics were based on their learning from their previous grade level from the spiral progression of lessons in science, hence students received formal learning before the study was conducted. Item analysis showed the percentage of incorrect responses in each item opposite their alternative conceptions.

The results show that only about 36% of the students had the correct concept of heat especially in the relationship between "cold" and "heat" with the highest percentage of alternative response (*Students' Conceptions of Heat*). Correspondingly, data in *Students' Conceptions of Temperature* presents that only an average of 39% of the students had accurate ideas of temperature, specifically item no. 21 shows only 10% of students having correct concepts. In terms of *Students' Conceptions about Heat Transfer and Temperature Change*, only 35% of the students comprehended it correctly. Lastly, the results of *Students' Conceptions on the Thermal Properties of Substances* show that there were only 37% of students who had correct ideas about the topic.

After the evaluation of the students' conceptions about heat and temperature, the students who scored as the lowest twenty (20) were interviewed, thus the percentage shown in Table 2 represents the interviewed students per se. The students were asked to explain how they came up with an answer in each item (see Table 2). Commonly, some students simply



guessed from the provided selection of possible answers, in addition to those who expressed that they knew little about the topic: either they forgot that it was taught or they did not fully understand the essence of the concepts in real-life application. A majority of the students also explained that their responses were based on their personal experiences and that is how they comprehended the ideas as applied and observed in their daily encounters, but were not correctly aligned to the scientific principles behind the experiences.

Based on the responses of the STEM students regarding the factors that have affected their conceptions about heat and temperature, they find the topic difficult to understand mainly because they have forgotten what their teachers taught them from the previous grade levels. The respondents also claimed they had not yet encountered some of the topics asked from the questionnaire, which confused them as they answered it. These instances are, one way or another, factual especially since there are several reasons for classes to possibly be interrupted, e.g., natural catastrophes and non-academic activities, yet the curriculum is ideally designed to consume the prescribed number of school days without interruption. Furthermore, they added that they did not analyze each item thoroughly, thus resulting in misinterpretation of questions. Some also recalled that they disliked the way the topic was taught back then, which led them to become bored and uninterested. Finally, many lacked the confidence and self-esteem to explain the heat and temperature concept because they relied mostly on their stock knowledge.

Table 1

Students' Conceptions of Heat, Temperature, and Thermal Properties

Students' Conceptions of Heat		
<i>Alternative Concept</i>	<i>Item Numbers</i>	<i>Incorrect Response, %</i>
Heat is a substance and not a form of energy.	10, 22	70, 47
Heat and cold are different, rather than opposite ends of a continuum.	10, 13, 18, 23, 24	70, 73, 49, 90, 91
Heat and temperature are similar.	15, 18, 27, 30	66, 49, 79, 51
Heat is proportional to temperature and cannot be quantified.	7, 11, 15	51, 45, 66
<i>Average</i>		<i>64.07%</i>



Students' Conceptions of Temperature

<i>Alternative Concept</i>	<i>Item Numbers</i>	<i>Incorrect Response, %</i>
Temperature is not an interval data	15	66
Sense of touch can determine the temperature of an object.	16	50
Cold is a quantity that can be held by an object	10, 18, 21, 22	70, 49, 90, 47
Continues heating of boiling water gives rise to its temperature	5	59
Boiling point is the highest temperature a material can reach.	19	84
Cold bodies do not contain heat.	7,10, 11, 22, 26	51, 70, 45, 47, 60
Size of an object affects its temperature, hence it is an extrinsic property	1, 9, 14	61, 67, 49
The lowest temperature has no limit.	25	72
<i>Average</i>		<i>61.00%</i>

Students' Conceptions about Heat Transfer and Temperature Change

<i>Alternative Concept</i>	<i>Item Numbers</i>	<i>Incorrect Response, %</i>
An increase in temperature is always due to heating	3, 4, 5	79, 67, 59
Heat only travels upward making it rise	20	59
Heat and cold flow from one material to another	10, 13	70, 73
Temperature adds up if two objects were combined together	7, 13	51, 73
When objects of different temperature became in contact, will cause warm temperature to become cold and vice versa, but they do not possess similar temperature. The students are unfamiliar with the thermal equilibrium concept.	1, 2, 3, 6, 9, 10	61, 73, 79, 69, 67, 70
A hot object readily cools down and a cold object readily warms up.	17, 24	43, 91
Temperature can be transferred through materials	3, 13	79, 73
Heat transfer is not explained through the kinetic theory	25	72
Energy transfer has nothing to do with hotness or coldness of an object	18, 20, 21	49, 59, 90
<i>Average</i>		<i>65.27%</i>

Students' Conceptions about Thermal Properties of Materials

<i>Alternative Concept</i>	<i>Item Numbers</i>	<i>Incorrect Response, %</i>
Temperature is a particular property of an object	9, 14, 16, 24	67, 49, 50, 91
<i>Alternative Concept</i>	<i>Item Numbers</i>	<i>Incorrect Response, %</i>
Heat and cold can be absorbed and held by metals for a longer period of time, hence the metal feels cold.	9, 14, 16, 20	67, 49, 50, 59
When an object can instantly become warm, it doesn't instantly become cold.	25	72
Colder objects has more heat to lose	11	45
The water will only boil at 100°C	4, 8, 12, 19, 28	67, 82, 45, 84, 60
Ice is always at 0°C and its temperature depends on its size	1	61
Water melts the ice which makes the ice warmer, thus it cannot be at 0°C.	2, 11	73, 45
Steam is colder than the boiling water.	6, 19	69, 84
Materials like wool have the ability to generate heat on its own.	17, 23	50, 90
There are materials that are resistant to heating, some are easily heated some are not	26	60
Heating separates the hydrogen and oxygen atoms of water	12	45
When heated object has constant temperature, heat is added.	29	61
<i>Average</i>		63.00%

Table 2

Explanations of Student Responses for Each Item

Item Number	Respondents' Conceptions
1	When asked about the temperature of ice cubes in a refrigerator, 40% of the interviewed students thought that the size of the ice cubes will affect their temperature. As they had already perceived, the freezing point of water is 0°C, thus the ice cubes maintained that temperature.



Item Number	Respondents' Conceptions
2	Seventy percent of the interviewed respondents only guessed their answer when asked about the most likely temperature of water when the ice cubes added to it stopped melting. They believe that adding water to the glass will result in a higher temperature. They further believed that when ice cubes are put in water, their temperature is transferred to the water.
3	Ice cubes which have nearly melted totally and are resting in a pool of water on the counter most probably have a temperature of 5°C, according to the students. Sixty-five percent also answered that if ice melts, the temperature will be higher. These answers were just assumed by the respondents and they find it hard to explain their responses with confidence.
4	When asked about the most likely temperature of water as it started to rapidly boil, 40% responded that the initial temperature is 100°C. The same percentage of respondents also believed that the highest boiling point of water is 110°C.
5	In answering this question, 55% of the respondents said they only guessed their answer on the temperature of water, which is continuously boiling. They hold the conception that the highest boiling point of water is 110°C and that the temperature of water rises because it has been left in a hot temperature.
6	When asked about the temperature of steam above boiling water, 40% reasoned that steam has a lower temperature than boiling water. They also added that their response to the question was simply a guess.
7	45% of the students only assumed their response to the temperature of a mixture of two cups of water wherein the first is at 40°C and the second cup of water is at 10°C. To determine their answer, 20% of them added the two values of temperature, which resulted in a higher temperature value. They said honestly that they did not fully analyze the question.
8	In answering the effect of high altitude on the boiling point of water, 60% said that they only guessed their responses. They thought that the boiling point of water is inversely proportional to the altitude where it is being boiled.
9	In comparing the temperatures of the plastic bottle and the cola inside, 40% of the students thought that it relies on the volume of cola and size of the bottle. They also believed that when placed in the refrigerator, the cola in the can would cool faster compared to the cola in the plastic bottle.
10	When asked why the countertop in the given situation feels colder than other areas of the counter when a cola can was placed on it, 35% of them thought that the temperature of the cola can is transferred to the countertop.
11	Thirty-five percent of the interviewed students thought that ice will lose more heat than water because it is colder than the latter. In addition, they also believed that the lower temperature of ice caused it to lose more heat.



Item Number	Respondents' Conceptions
12	In explaining what is inside the bubbles that form in boiling water, 25% of the respondents believed that it is simply air. In addition, they also believed that it is the heat rising up. This question also raised confusion among the students.
13	When asked to explain the cooling process of a hot egg placed in cold water, the respondents were able to describe what happens to the egg and the water. But on a deeper note, 75% were not able to reason out how this process happened.
14	The students were confused when asked why metal chairs are colder than the plastic ones. 45% of them explained that it is simply because metals are conductors and have higher heat capacity, which is why they are colder than plastic materials.
15	When asked which statement is correct when a radio announcer said that "tonight it will be a chilly 5°C colder than the 10°C it was last night," 55% answered that it will be twice as cold tonight as it was last night. They believed that the numerical difference in temperature will result in a doubling of effect in the temperature scale.
16	In explaining why the metal ruler felt colder than the wooden one, 45% of the students said that metal is a great conductor; that's why it absorbed more coldness than wood. They also pointed out that wood is naturally warmer than metal and it does not conduct much heat or cold.
17	In determining the most likely room temperature in the given situation, 45% of the interviewed students found it hard to analyze the question and said that they did not actually know this concept. They tried answering that the dry cloth has absorbed heat but were not able to solve for the actual room temperature.
18	When asked to compare the warm carton with the cold carton, 40% reasoned out that the refrigerator uses more cold, thus, making the carton cold as well unlike in the countertop which is hot.
19	When asked to explain how food is cooked faster in a pressure cooker than a typical saucepan, 65% of the interviewed students answered that it is due to the sealed lid which distributes heat evenly. They added that the high pressure cooks the food faster since the higher the pressure, the higher temperature.
20	In explaining why cakes are cooked at the top shelf inside the electric oven, 55% the students answered that the temperature of an electric oven at the top and at the bottom are the same. They added that metal trays are conductors of heat.
21	When asked to explain how sweating cools down the body, 70% of the students only guessed their answer. They answered that it is due to the temperature change and that the body releases heat through the sweat to cope with the temperature of the environment. They added that because sweat is cold, the skin becomes cold as well.



Item Number	Respondents' Conceptions
22	In explaining why the metal pump becomes hot when pumping up bike tires, 70% of the students responded that metals are conductors of heat and the pumping generates friction which in turn generates heat.
23	In explaining why we wear sweaters in cold weather, 70% of the interviewed students explained that it keeps the cold out and it generates heat so heat loss can be reduced. They added that without a sweater, heat will be removed from the body.
24	When asked to explain why the wooden sticks of a popsicle from the freezer have a higher temperature than the ice part, the students answered that wooden sticks contain more heat compared to the icy part. Accordingly, they said that wood attracts more heat. Seventy percent of them also added that they only guessed their answer.
25	When asked about making super-conductor magnets at -260°C , 30% answered that super conductors cannot be cooled at this temperature and that it's colder than the average freezing point.
26	Based on the response of the students, 45% were confused by the question. They added that the blanket used was a poor insulator and did not carry heat energy.
27	When asked to define what temperature is, the students answered that it is the scale value of heat. 35% of them also point out that temperature depends on heat.
28	In reading the temperature between two cans with varying amounts of boiling water, 50% responded that the can with the lesser amount of water will have higher temperature than the other can as both come to a boil.
29	When asked why the temperature readings have several 420°C , the 70% answered that the records were added to get that value. They also added that they find it hard to analyze the question.
30	When asked what heat is, 40% of the interviewed students stated that it comes from the body or transferred from one to another. Their answer to this question is simply based on their experience.

Discussion

As we construed from the findings, the results show that the students' misconceptions can be categorized into various conceptual change models. It is evident that the learners possess alternative concepts of heat and temperature, which may partly be because of how the terms "heat" and "temperature" are used in daily semantics (Limon, 2001). Since heat and temperature concepts are quite complicated to understand, students find it difficult to understand how they are applied in actuality making it hard for them to explain the occurrence



of related phenomena. Hence, more than half of the student respondents could not distinguish heat from temperature and thought they can be used interchangeably, which is consistent with findings in other similar studies (Ericson & Tiberghien, 1985; McDermott, 2003). Additionally, several students thought that cold is another quantity independent of heat instead of thinking that the transfer of heat goes from the hot object to the cold object. Likewise, students thought of temperature as an extrinsic property of an object that it is a function of the amount of matter, where they erroneously assume that a bigger object is hotter than a small one. These results coincide with Vosniadou and Skopeliti's (2013) claim that students construct a naive understanding of physics as a product of their daily encounters in the context of lay culture to form a coherent conceptual system, which they use as a basis for the explanation of their experience, however, a misconception occurs in the combination of learned scientific facts with the prevailing—however, mismatched naive--physics frameworks.

One of the rudimentary topics under heat and temperature that students have difficulty telling apart is the concept of specific heat and heat capacity, specifically in item 7, in which the students had difficulty analyzing due to the mathematical nature of the question, thus grounding their answers by performing basic arithmetic instead of using the formula $Q=mc\Delta t$, wherein the amount of heat energy lost or gained (Q) is equal to the mass of the substance (m) multiplied by its specific heat (c), and the change in its temperature (Δt). Though half of them got it correct, the interview group cannot explain how they came up with the correct answer other than by intuition. It also shows that even if the question was a common daily encounter such as mixing tap water to boiling water in preparing warm enough chocolate drinks, still they cannot relate the physics concepts to experience. Additionally, the phase change is one of the processes that is incorporated in heat and temperature and students commonly thought that an increase in temperature is always due to heating; also, their misconceptions can be due to the integrity of their basic knowledge in evaporation and condensation, which were taught in the previous science subjects in junior high and elementary school, which is conclusive of either their weak foundation or poor retention, similar to the study conducted on the first-year high school students (Ayas & Costu, 2001) that temperature increases when a material continues to get heat from an external source, thus the concept of thermal equilibrium is not acknowledged. The students can confront these conceptual challenges in thermodynamics through the use of self-generated analogies (Haglund & Jeppsson, 2013) reinforced by the laboratory model of conceptual change (Ohlsson & Cosejo, 2013). Through these models, the students will be able to become familiar with the new topic through recategorization experimentation, which has the potential to give thorough information of the sequential dynamics of learning, revealing how initial conceptions are eventually transformed.

In terms of heat transfer, students have the notion that heat and cold are particular properties of materials, thus objects are normally warm and cold. They also hold onto the idea that cold moves from one material to another rather than heat moves from warmer to a cooler object, which only a little less than 30% of the students knew. Students also perceived that using the sense of touch one can quantify both heat and temperature mainly because we have this common practice of measuring someone's body temperature by feeling their forehead.

Similar misconceptions are also found in several studies when performed in classes of preservice teachers (Gönen & Akgün, 2005) and K to 12 teachers (Quan et al., 2011). Nonetheless, several students had a correct understanding of conductors and insulators, however, they could not point out the mechanism of heat transfer in these objects. They also misused the term heat capacity indicating it as the heat carried by an object. This result models Thagard's (2014) study on explanatory identities of ordinary things with scientific ones, since the students barely define the meaning of heat capacity, they are not able to explain its concept in heat transfer hence, that to gain conceptual change students need to examine and experience it to gain insights and justification about the scientific concept.

Looking at the statements about the factors that have affected the students' conceptions about heat and temperature, they can be attributed to the teacher, the topic, and the learner (Potvin, 2013). The way their teacher taught the topic during their junior and senior high school years has an impact on how well the students have understood these concepts. It should not be disregarded that one factor to such a misunderstanding by students is the failure of the teacher (Kartal et al., 2011) that can lead to various kinds of students' misconceptions.

Thus, even adults, including teachers, can occasionally have misconceptions (Burgoon et al., 2010). Several pieces of research (Wandersee et al., 1994; Astolfi et al., 2006) indicate that misconceptions still exist despite the formal instruction the students received, for the reason that there was no check and balance between the taught concept of the teachers and how the students grasp the context. However, this alternative conception can be improved if the teachers have properly described the information processing task and the cognitive mechanisms responsible for those activities that will correct misconceptions through Rusanen's (2013) mechanistic alternative model.

Finally, the students themselves contributed to their conception of heat and temperature because their behavior towards the topic and their study habits as well were not constructive based on their responses to the interview questions. They neglected to deeply process given information and simply aimed to finish the task at hand without realizing and reflecting about whether their responses were correct or not. Thus, as Erman (2016) recommended, the teacher should identify misconceptions about prior knowledge or concepts prior to teaching the basics, identify reference book learning, and facilitate effective communication so that information received by the students is complete and correct.

Conclusion and Its Implication to Teaching and Learning

From the outcomes of the study, the researchers have determined and classified three propositions that could address issues that arose from the findings. These implications are anchored on the students' misconceptions about heat and temperature, the underlying reasons for their alternative conceptions, and the factors which could have affected them.

Revealing the misconceptions of STEM students in heat and temperature gave a different perspective on the depth and breadth of their conceptual understanding of the topic

when compared to the currently mandated spiral progression curriculum. This study has further shown gaps in the curriculum which may be solved at earlier stages before they become detrimental to student learning as they progress educationally, such as lack of vertical interconnectedness in a certain discipline and horizontally with other fields.

Additionally, it is recommended that educators should demonstrate heat and temperature concepts by using the prior experiences of students to be able to provide correct settings and effective strategies as well. Since the learners already possess ideas regarding heat and temperature before entering the classroom, the teacher must provide pedagogical approaches that place more focus on assisting learners to construct scientific knowledge and analysis. This idea is similar to the work by Ali Alwan (2011) that shows providing appropriate situations and effective pedagogies such as multi-contexts should be used to introduce and explain heat and temperature concepts, so students can better understand the concept and see how the concepts are transferred and applied. Also, constructivism can be used to take students' misconceptions into account when designing instruction. The method of dealing with misconceptions was to use strategies of conceptual change designed to promote the acquisition of new concepts as a consequence of the exchange and differentiation of the existing concepts and the integration of new concepts with existing ones (Baser, 2006). Incorporating inquiry-based activities can also significantly improve students' conceptual understanding of heat transfer as measured by questions closely related to the instructional activities (Nottis et al., 2018).

Even though the STEM students were able to provide some theoretical knowledge and explanations regarding heat and temperature, some of them do not fully comprehend the underlying concepts about the subject, which is critical when they pursue science-related courses in the future. Hence, teaching must focus on:

- 1) Conceptual understanding of physics or theoretical and mathematical problems that challenge students' initial common sense framework.
- 2) Guiding students in the construction of new systems of concepts for understanding these concepts. Teachers must know what techniques, representational tools, and conceptual resources to draw upon to make new concepts intelligible to students, and also how to build these constructions in a sequenced manner.
- 3) Classroom discourse that encourages students to identify, represent, contrast, and debate the adequacy of competing explanatory conceptual-change processes including making students aware of their initial conceptions, helping students construct an understanding of alternative frameworks, motivating students to examine their conceptions more critically, and promoting their ability to evaluate, and at times integrate.
- 4) Providing students with extended opportunities for applying new systems of concepts to a wide variety of problems. Repeated applications develop students' skill at applying new concepts, refine their understanding and help them appreciate its greater power and scope.



Cladys C. Malano – Falcunaya is a Special Science Teacher at the Philippine Science High School – CALABARZON Region Campus of the Department of Science and Technology where she also serves as the head of the Research and Integrated Science Unit. Over a decade in teaching, she mostly handled science research subjects in the secondary STEM curriculum. She is currently obtaining her doctorate at the Philippine Normal University specializing in science education.



Marvin J. Rosales is a faculty member at Luis Palad Integrated High School in the City Schools Division of Tayabas where he serves as Head Teacher III of the Science Department. He is also the coordinator of the Science-Enhanced Program for Junior High School where he leads as a consultant in the student-initiated research and development projects. He is presently earning his Ph.D. in Science Education at the Philippine Normal University.



Apple Kaye C. Vera is a college instructor at the Southern Luzon State University Dual Training and Livelihood Center - Lucena Campus teaching Physics for technical teacher education where she also acts as the Student Affairs Coordinator. She is currently finishing her Doctor of Philosophy in the Philippine Normal University major in science education.

References

- Alwan, A. A. (2011). Misconception of heat and temperature among physics students. *Procedia - Social and Behavioral Sciences*, 12, 600–614.
<https://doi.org/10.1016/j.sbspro.2011.02.074>
- Anderman, E. M., Sinatra, G. M., & Gray, D. L. (2012). The challenges of teaching and learning about science in the twenty-first century: Exploring the abilities and constraints of adolescent learners. *Studies in Science Education*, 48(1), 89–117.
<https://doi.org/10.1080/03057267.2012.655038>
- Astolfi, J.-P., Peterfalvi, B., & Vérin, A. (2006). *How children learn science*. Paris: Retz



- Ayas, A. & Costu, B. (2001). *The level of the first grade high school students' understanding of evaporation, condensation, boiling concepts*. Istanbul, Turkey: Declaration of Science and Technology Education Symposium.
- Baser, Mustafa (2006). Effect of conceptual change oriented instruction on students' understanding of heat and temperature concepts. *Journal of Maltese education research*, 4(1), 64-79. <https://eric.ed.gov/?id=ED495216>
- Burgoon, J., Heddle, M., & Duran, E. (2010). Re-examining the similarities between teacher and student conceptions about physical science. *Journal of Science Teacher Education*, 21(7), 859-872.
- Cabili, M. V., & Capilitan, D. B. (2015). A review on the issues in the implementation of K+12 science curriculum: A baseline study. *Research Gate*.
<https://doi.org/10.13140/RG.2.2.10755.30249>
- Dolgos, L. J. (2006). Targeting and attempting to correct common misconceptions in the high school chemistry classroom. Retrieved from
https://digitalcommons.brockport.edu/ehd_theses/462/
- Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education*, 11(5), 481-490. <https://doi.org/10.1080/0950069890110501>
- Ednave, R. E., Gatchalian, V. M. P., Mamisao, J. C. B., Canuto, X. O., Caugiran, M. D., Ekid, J. C. A., & Ilaog, M. J. C. (2018). Problems and challenges encountered in the implementation of the k to 12 curriculum: A synthesis. *Academia.Edu*. Retrieved from
https://www.academia.edu/39704530/problems_and_challenges_encountered_in_the_implementation_of_the_k_to_12_curriculum_a_synthesis
- Elwan, E. & Almahdi, A. (2008). Misconceptions in thermal physics and factors affecting their presence among students in the physics department at the Ajaylat High Institute for Teacher Training. *Journal of Arabization, the Arab Centre for Arabization*, Translation, Authorship and Publication, Damascus, No.33, December 2007, pp77-103.
- Erman, E. (2016). Factors contributing to students' misconceptions in learning covalent bonds. *Journal of Research in Science Teaching*, 54(4), 520-537.
<https://doi.org/10.1002/tea.21375>
- Ericson, G. & Tiberghien, A. (1985). *Heat and Temperature*. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science*. Philadelphia, PA: Open University Press.



- Grageda, H.B. (2016). Despite Opposition, K-12 Education Reform Moves Forward in the Philippines. *The Asia Foundation*. <https://asiafoundation.org/2016/08/24/despite-opposition-k-12-education-reform-moves-forward-philippines/>
- Gönen, S & Akgün, A. (2005). An analysis of the feasibility of worksheet developed as a result of the interaction between concepts of heat and temperature. *Electronic Social Science Journal*. 3(11), 92-106.
- Gonzales, N. J. (2019). Narrative experience of seasoned teachers in teaching science using spiral progression curriculum. *IOER International Multidisciplinary Research Journal*, 1(2), 59–68.
- Gottlieb, M. A. , & Pfeiffer, R. (2013). Ch. 3: The Relation of Physics to Other Sciences. In *The Feynman lectures on Physics Vol. 1*. Retrieved June 30, 2020, from shorturl.at/ekoPV
- Haglund, J., & Jeppsson, F. (2013). Confronting conceptual challenges in thermodynamics by use of self-generated analogies. *Science & Education*, 23(7), 1505–1529.
<https://doi.org/10.1007/s11191-013-9630-5>
- Halim, A. S., Finkenstaedt-Quinn, S. A., Shultz, G. V., Gere, A. R., & Olsen, L. J. (2018). Introductory biology via writing-to-learn assignments and peer review. *CBE—Life Sciences Education*, 7(2). <https://www.lifescied.org/doi/10.1187/cbe.17-10-0212>
- Kuzgun, Y., & Deryakulu, D. (2004). Bireysel farklılıklar ve eğitime yansımaları. Y. Kuzgun (Ed) ve D. Deryakulu (Ed.), *Eğitimde bireysel farklılıklar*, 95-136. Ankara: Nobel Yayın Dagitim
- Limon M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: a critical appraisal. *Learning and Instruction*, 11, 357–80.
- McDermott, L.C. (2003). Improving student learning in sciences. *Physical Science News*, 4(2), 6-10.
- Mesutoğlu, C., & Birgili, B. (2017). Awareness of misconceptions in science and mathematics education. perceptions and experiences of preservice teachers. *Ahi Evran Üniversitesi Kırşehir Eğitim Fakültesi Dergisi*, 18(2), 525–546.
https://www.researchgate.net/publication/319403020_Awareness_of_Misconceptions_in_Science_and_Mathematics_Education_Perceptions_and_Experiences_of_Pre-service_Teachers
- Meyers, K. (2007). *Examining how teaching strategies alter the misconceptions of middle school science students*. (Theses). http://digitalcommons.brockport.edu/ehd_theses/369



- National Center for Education Statistics (2007). Trends in international mathematics and science study. Washington, DC: IES Retrieved from:
http://nces.ed.gov/timss/results07_science07.asp.
- Neidorf, T., Arora, A., Erberber, E., Tsokodayi, Y., & Mai, T. (2020). *Student Misconceptions and Errors in Physics and Mathematics: Exploring Data from TIMSS and TIMSS Advanced*.
<https://doi.org/10.1007/978-3-030-30188-0>
- Nottis, Katharyn E. K.; Prince, Michael J.; and Vigeant, Margot A. (2008). *Addressing Misconceptions about Heat Transfer in Undergraduate Chemical Engineering Instruction*. Connecticut, USA: Northeastern Educational Research Association (NERA) Annual Conference. https://opencommons.uconn.edu/nera_2008/18
- Ohlsson, S., & Cosejo, D. G. (2013). What can be learned from a laboratory model of conceptual change? Descriptive findings and methodological issues. *Science & Education*, 23(7), 1485–1504. <https://doi.org/10.1007/s11191-013-9658-6>
- Philippine Statistics Authority | Republic of the Philippines. (2020). Retrieved July 22, 2020, <https://psa.gov.ph/statistics/survey/labor-and-employment/survey-overseas-filipinos>
- Potvin, P. (2013). Proposition for improving the classical models of conceptual change based on neuroeducational evidence: Conceptual prevalence. *Neuroeducation*, 2(1), 16-43.
- Quan, G., Heron, A. P., Shaffer, P., & McDermott, L. (2011). *Improvements of Student Understanding of Heat and Temperature*. (Thesis). University of Washington, Seattle, Washington, USA
- Reysio-Cruz, M. (2019, December 5). *Worst PH ranking in math, science, reading prompts DepEd review*. 1. <https://newsinfo.inquirer.net/1190208/worst-ph-ranking-in-math-science-reading-prompts-deped-review>
- Robbins, D. (1998). *Questionnaire Construction*. In G. Miller (ed.). *Handbook of Research Methods in Public Administration*. New York.
- Rusanen, A. M. (2013). Towards to an explanation for conceptual change: a mechanistic alternative. *Science & Education*, 23(7), 1413–1425. <https://doi.org/10.1007/s11191-013-9656-8>
- Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H., & Jinks, C. (2018). Saturation in qualitative research: exploring its conceptualization and operationalization. *Quality & Quantity*, 52(4), 1893–1907.
<https://doi.org/10.1007/s11135-017-0574-8>



- Scheuermann, A., van Garderen, D. (2008). Analyzing students' use of graphic representations: Determining misconceptions and error patterns for instruction. *Mathematics Teaching in the Middle School* 13(8), 471-477.
- Sen, S., & Yilmaz, A. (2012). The effect of learning styles on student's misconceptions and self-efficacy for learning and performance. *Procedia - Social and Behavioral Sciences*, 46(1990), 1482–1486. <https://doi.org/10.1016/j.sbspro.2012.05.325>
- Thagard, P. (2014). Explanatory identities and conceptual change. *Science & Education*, 23(7), 1531–1548. <https://doi.org/10.1007/s11191-014-9682-1>
- Vosniadou, S., & Skopeliti, I. (2013). Conceptual change from the framework theory side of the fence. *Science & Education*, 23(7), 1427–1445. <https://doi.org/10.1007/s11191-013-9640-3>
- Yeo, S. & Zadnik, M. (2001). Introductory thermal concept evaluation: Assessing students' understanding. *The Physics Teacher*, 39, 495-504.



Culture-Based STEM Education: Why, What, and How.

Fred N. Finley

University of Minnesota (Retired), Fulbright Fellow
New Brighton, Minnesota, U.S.
fntinley70@gmail.com

Abstract

Culture-Based STEM Education addresses local and national goals for creating STEM literate citizens who can use STEM ideas and skills in their professional, public, and personal lives. The approach includes a set of defining characteristics that require the learning of STEM subjects, interactions with local cultures, the use of national standards in conjunction with local wisdom and knowledge, and the integration of STEM subjects. Students will be engaged in critical topics such as economic, health, food, and environmental security at local, regional, and national levels. The expectation is that local communities and ultimately nations will benefit from students learning from local community members. The benefits are expected to be enhanced community and student engagement in learning STEM subjects; community applications of STEM knowledge and skills; and, most importantly, the encouragement of students to learn STEM subjects in their present and future educational endeavors and careers. Culture-Based STEM Education is expected to be practical for teachers as they apply the given characteristics and questions that guide the development of teaching units. The questions are grounded in teachers' experiences. A systematic and robust research and evaluation program on Culture-Based STEM Education will be essential to our learning about the efficacy of the approach and to provide useful modifications.

Keywords: culture-based, STEM education, STEM education research, STEM curriculum, STEM instruction, STEM characteristics.

Culture-Based STEM Education: A Point of View

The ideas presented in this paper are developing, ongoing, and evolving with the hope that others will contribute. The ideas are provided from a Western, predominately U. S., perspective but are strongly influenced by studies and many years of experiences in Thailand. The idea of Culture-Based STEM Education has been especially influenced by the work of many teachers, most notably the lead STEM teacher from Banlatwittaya School in Banlat Petchaburi (Kullat et al., 2015); a 2019 Fulbright funded project done with the University of Phayao; and published studies (Bybee, 2010; Bybee, 2013; Montri, 2013; Supot, 2013; Thawat, 2012; Marginson et al., 2013; Cogan & Dericott, 1998); the Thai Institute for the Promotion of Science and Technology, 2015); and Thai-U.S. Roundtables (Thawat, 2012; Office of Education Council & King Monkut's University of Technology, 2016). The ideas also have been influenced by the



definition of STEM education and stated goals of the new South East Asian Ministers of Education Organization (SEAMEO) STEM Education Center.

The SEAMEO STEM Education Centre's definition:

“STEM education is a teaching and learning approach, which emphasizes the connections among – or the integration of – knowledge and skills in science, technology, engineering, and mathematics to address problems facing our communities as well as larger global issues that require a skilled workforce and knowledgeable citizens who can apply these skills and knowledge to develop solutions.” (South East Asian Ministers of Education Organization, 2020)

Among the SEAMEO goals are:

- “Advocating evidence-based policy research in STEM education and providing policy recommendations;
- Developing the capacity of educational personnel and policymakers;
- Enriching regional STEM learning units by leveraging existing resources.” (South East Asian Ministers of Education Organization, 2020)

The ideas presented below support each of these goals. However, decisions about the utility of the ideas reside in the national and local cultures of the SEAMEO countries as do decisions about necessary modifications.

What is Culture-Based STEM Education?

The set of characteristics provided below has been gleaned from various national and international sources, was initially developed for the Institute for the Promotion of Teaching Science and Technology (IPST) (Finley, 2012), revised for a chapter in *Education in Thailand: An Old Elephant in Search of a New Mahout* (Promboon et al., 2018), and revised again before and after a Fulbright funded project with the University of Phayao. No claim is made that this is the only possible set of characteristics, but the claim is made that they offer a valuable starting point. These characteristics can be critiqued and improved by evidence-based research and cross-cultural experiences. The proposed characteristics of Culture-Based STEM Education are that it:

- uses at least two STEM subjects simultaneously,*
- requires applications of the domain specific, core and cross cutting concepts, and practices of the subjects,*
- relates directly to real-life activities from businesses, industries, governments, and NGOs in local, regional, national, or international communities,*
- includes substantial interactions with people from local, regional, national, or international communities,*
- engages students in studying critical topics such as health, energy resources, natural resources, environmental quality, natural hazard mitigation, the frontiers of science, technology, engineering, and mathematics (Organisation for Economic Co-operation and Development (OECD), 2006) and food resources,*

- promotes students learning with joy and benefits their present and future personal, civic, and professional lives,
- requires students to do what they will have to do as employees and citizens, that is, produce artifacts that have a counterpart in the real world,
- requires students to communicate the products of their instruction to people from their community, government agencies, businesses, teachers from the local or other schools, administrators, and students from other classrooms,
- requires and holds students accountable for being able to apply the subject matters rigorously in the planning, description, explanation, and justification of the products that result from their instruction,
- requires students to provide justified descriptions, explanations, predictions, designs, and communications related to select phenomena and societal events through the lenses of multiple relevant disciplines,
- provides opportunities for teaching about the nature of science, technology, engineering and mathematics and the interactions among those fields and society,
- provides student-centered instruction,
- requires students working and studying in cooperative groups (Johnson, D. & Johnson, R., 1999),
- uses information technologies, communications technologies, computer - based instrumentation and modeling often, and
- provides opportunities to explore many levels and types of possible STEM careers.

* (See note in the following paragraph).

A final note about the set of above characteristics is important. Using all of these characteristics in any one situation is not likely. What is more likely is that subsets of the characteristics would be used with varying degrees of emphasis depending on national and local cultures and circumstances. The creation of multiple forms of STEM units is desirable and likely (Briener et al., 2012). That said, the characteristics noted with an asterisk (*) are, at this point, considered essential to defining Culture-Based STEM Education.

Why Culture-Based?

STEM education is important because understanding STEM subjects is essential to students' present and future civic, professional, and personal lives. STEM education also is essential to national economic, health, food, and environmental securities. Unfortunately, the citizens of many communities have little direct experience with the relevance and value of understanding STEM subjects. Furthermore, their experience with STEM subjects have been highly academic, inaccessible, and unrelated to the real world (Finley, 2016). The result is a lack of cultural support for students learning STEM subjects. Too little cultural support limits students' interest and motivation in STEM education to what is required by the necessity of passing tests.



The thesis of Culture-Based STEM Education is that students need to learn STEM subjects in the context of what happens in the culture of their communities where they, along with the adults in their lives, can experience relevant and accessible applications of STEM knowledge and skills. Such experiences are likely to have lasting effects on students' interest in STEM subjects. In short, Culture-Based STEM Education is needed so that STEM knowledge and skills become a relevant, valued, accepted and a commonplace part of students' lives.

Culture-Based STEM education is supported by other reasons as well. Each of these reasons could be elaborated substantially but doing so is limited by what can be done in a single paper. For now, the following brief statements indicate additional supporting reasons:

- We need STEM experts, STEM literate politicians, media people, government officials, and administrators who support and are supported by STEM literate populations.
- Beliefs about STEM knowledge and skills – their accessibility, personal and social value, and trustworthiness - are embedded in national and local cultures and need to be considered in teaching.
- A proper understanding of STEM subjects requires that the students experience STEM subjects within their cultural contexts because science, technology engineering and mathematics are embedded in cultures.
- Always teaching STEM subjects as if they are independent of society misrepresents the nature and value of the subjects.
- Local wisdom and knowledge can be sources of new STEM knowledge.
- STEM knowledge can confirm, extend, and challenge local knowledge and wisdom.

The use of Culture-Based STEM education is not some kind of “this will fix it all tomorrow” innovation. Cultural changes require the use of well-grounded ideas in many places over many years to have large scale effects. However, enhanced STEM literacy can and must begin at local levels, with today's students within their communities. Substantial benefits can accrue to local communities and individuals as the broader cultural changes occur. Immediate enhancements of local knowledge and wisdom can be prompted by Culture-Based STEM Education. Local accomplishments can be immediate and unquestionably valuable in their own right. In fact, local accomplishments can be considered as a powerful and worthwhile goal.

How can Culture-Based STEM Education be Implemented?

Culture-Based STEM Education is a warranted and potentially impactful approach to STEM education. However, it is not the only way to approach STEM education. Problem-based learning, community-based learning, context-based learning, and place-based learning are close cousins of the approach presented here. Case studies, simulations, extended research-like investigations, and other methods also provide in-depth opportunities for students to learn. In addition, traditional methods have value, and the support of extensive instructional materials and resources. Reading text material, laboratory activities, field trips, demonstrations, problem solving, lectures, and internet search projects are teaching tools that are worthwhile and practical. In fact, it is difficult to imagine using Culture-Based STEM Education without using these tools.

Culture-Based STEM Education is a practical approach for teaching STEM subjects. It is practical because using the approach a few (2-4) times a year is recommended as is having each unit based on selected national standards. These two recommendations account for teachers reporting limited time to prepare; time needed to work with community members; and the necessity of attending to a longstanding, deeply engrained history of teaching subjects one by one; extensive national standards and national assessment requirements; government agency regulations; school schedules; and the expectations of politicians and citizens. If teachers developed one unit a year, revised that unit the next year, created one more that second year, and repeated the cycle, then, over time they would have a set of polished units to use and to share with others. What is expected from the approach is students meeting selected national standards, experiencing STEM subjects within their communities and daily lives, seeing STEM as accessible, engagement in learning, and supporting local cultures. Culture-Based STEM Education allows for in-depth relevant learning that carries into the future. The expectation is that over a few years of schooling, students will have experienced a substantial enough number of engaging and in-depth STEM units to prompt interests that are sustained for a lifetime in careers, and in their public and private lives.

Questions to Guide the Development of Culture-Based STEM Education Teaching Units.

The following is a set of questions that need to be answered to develop Culture-Based STEM teaching units. It is not an outline of what is needed in weekly or daily lesson plans. Those plans are necessary and require greater levels of detail.

The questions were derived initially from a case study of a rural school in Chachoengsao, Thailand. The situation was that the school principal, teachers, a local businessman, other community members, and students designed and developed a fish raising pond that became part of the school grounds and teaching program. The fishpond development was intended to provide a context for applying and teaching the former King Bhumibol Adulyadej's ideas of sufficiency thinking, effective business practices, career opportunities, and providing a protein source for students and community members. As the case was investigated, the teaching of STEM subjects, other subjects, and local wisdom and knowledge were evident. What was asked during the case study was, "What questions did the developers implicitly ask as they developed the project?" The case study grounded the development of the following questions in teachers' and others' actual practices. Modifications to the questions were made based on the feedback from other teachers during subsequent workshops.

Preliminaries

Project Title An example would be Designing a School and Community Fishpond.

Context Description A description of the local community, school, and students.

Unit Design Questions

- **Q1. What culturally based project or product will the students develop?** This is a 1 - 3 sentence description of the students' project or product. Having a significant student product is essential to sustaining their engagement and learning.



- **Q2. What STEM characteristics will be used?** Select the STEM characteristics that will guide the unit development.
- **Q3. What learning outcomes from National Standards (e.g., Sciences, Computer Science and Technology, Mathematics, Social Studies, Religion and Culture, National Language, Arts, English, Health, Technology and Engineering, and Physical Education) will be used?** Teachers have indicated that they could use a Culture-Based STEM Education approach only if the national standards and testing expectations were considered explicitly.
- **Q4. What community connections will be used?** List the community organizations, contact information and other community members who will participate. State what the others will do at least initially. Community members must be involved in the development of the project from the very beginning.
- **Q5. What other schoolteachers, administrators, and staff will be involved?** List the people and offices from the school and what they will do. These people can provide expertise and resources if they are part of the planning from the beginning.
- **Q6. How will the instruction be done?** Describe the key student activities of the project and the sequence of the activities as best as possible early in the planning. Changes and detailed plans will be made during the unit development process.
- **Q7. To whom will the students present their work?** This segment is essential. Teachers have reported that students stay engaged and are more concerned about the quality of their work when they know they will present to others, preferably adults.
- **Q8. What formative and summative assessments will be used?** Assessments can include information from teachers' observations, group or student activities, artistic productions, interim reports, physical models, homework assignments, semi-structured journals, project presentations, quizzes, and tests.
- **Q9. What agencies from outside the community might be needed?** The agencies listed can provide information, resources, and opportunities from regional--and perhaps national--government agencies, businesses, and institutions of higher education.
- **Q10. What budget will be needed?** List estimates of the costs for essential elements of the unit. School administrators, community members, and other participants will ask for some idea of costs and resources that will be needed as part of considering what they might be able to provide.
- **Q11. What will be the schedule of events (timeline) for the project?** State what steps will be taken with the school and community to complete the project and when they will be taken. The answer to this question provides concrete markers about what needs to be done and by when.

Questions similar to the above were used in a Fulbright funded project with the University of Phayao and area STEM teachers in September 2019. Teachers' responses resulted in modifications in the questions and several well-prepared units. The unit topics were increasing duck egg farm production and markets; improving fishing in the Maelao River; using rice straw as fuel in a locally designed cooking stove; preventing landslides; and improving corn

production. The teachers reported they would find the units usable and exhibited excitement about doing so.

Comments on SEAMEO Goals

The first SEAMEO goal is “Advocating evidence-based policy research in STEM education and providing policy recommendations.” (South East Asian Ministers of Education Organization, 2020). Research and evaluation are essential to making progress in the development of STEM education. While the above ideas are grounded in theoretical and empirical research from learning and cognition, social learning theory, the history and philosophy of science, the sociology of science, educational research and best practices, that does not mean we know the ways in which the idea of Culture-Based STEM Education will work in practice in different cultures and settings within those cultures. Evidence is needed to answer innumerable questions related to changes in students’ learning and attitudes related to STEM, community attitudes toward STEM, teachers’ knowledge and attitudes toward STEM, and the challenges and opportunities that teachers, administrators, educational planners and policy makers encounter when this idea is implemented. We, the STEM education community, need to employ a design-based strategy for the development and implementation of all STEM innovations. Design, research and evaluation, and redesign cycles are needed. Both qualitative and quantitative research and evaluation are needed within these cycles. The methods will range from practical (sometimes called action research) to rich descriptions gained from case studies to large scale quantitative assessments of innovations and eventually to experimental studies. We cannot make informed decisions with respect to Culture-Based STEM education or any other form of STEM education without in-depth and sustained studies. We cannot afford to waste time, money, and talent without learning from the efforts we make.

The second SEAMEO goal given is “Developing the capacity of educational personnel and policymakers.” (South East Asian Ministers of Education Organization, 2020). Developing and studying Culture-Based Education provides a well-grounded opportunity for meeting this goal. We can develop capabilities related how to design, teach and evaluate STEM teaching units; use local knowledge and wisdom; include all children in learning STEM subjects; have STEM be experienced as accessible and valuable; improve children’s career opportunities; and improve economic, health, food and environmental conditions at community and national levels.

The third SEAMEO goal is “Enriching regional STEM learning units by leveraging existing resources.” (South East Asian Ministers of Education Organization, 2020). Culture-Based STEM units are at the crux of the third goal. If numerous teachers plan according to the design questions given above, then the units can be entered into an open source repository for others to use, modify, and amplify as their local and national circumstances dictate. Such an open source database would be especially valuable to teachers, administrators, curriculum developers, other educators, and policy makers if accompanying research and evaluations also were posted. The posted research reports could be teachers’ own assessments of the effectiveness, usability, challenges, and suggested modifications; information gleaned from

students' in-class work and reports; more formal qualitative investigations such as case studies; and quantitative studies.

Conclusion

Culture-Based STEM Education is intended to address SEAMEO and national goals; be practical by accounting for traditional expectations and demands on teachers' time; allow teachers to be innovative; and, most of all, engage students in meaningful and inspiring STEM education. In the long run, substantial and sustained use of the idea is likely to result in meeting national goals such as improving economic, health, food, and environmental security. As the long-term goal is being met, local communities can be expected to benefit from what is learned and from enjoyable interactions with children and the local schools. Sustained research and evaluation are critical to making progress toward the goals.



Fred Finley completed a bachelor's degree in geology from Michigan State University, a master's degree in elementary school science education from the State University of New York at Cortland, a Ph.D. in curriculum and instruction, science education from Michigan State University, and an honorary Ph.D. from Rajabhat Rajanagarindra University in education: locality development. He was a faculty member in curriculum and instruction at the University of Wisconsin-Madison, the University of Maryland, and the University of Minnesota-Twin Cities. Dr. Finley retired from the University of Minnesota in 2018. His research interests have been related to Earth System Science, learning and cognition, the implications of the history and philosophy of science for science education, and curriculum design. His work and interest in

STEM education in South East Asia, primarily Thailand, began in 1991 and most recently was supported by the United States Fulbright Foundation at the University of Phayao, Thailand in September 2019. The publication most relevant to this paper is Promboon, S., Finley, F., and Kaweeijmanee, K. (2018) listed in the references.

References

- Briener, J. M., Johnson, C.C., Harkness, S.S., & Koehler, C.M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1) 16-31.

- Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher* 70(1): 30-35.
- Bybee, R. W. (2013). *A case for STEM Education: challenges and opportunities*. Arlington, Virginia: National Science Teachers Association Press.
- Cogan, J. and Dericott, R. (1998). *Citizenship for the 21st century: An international perspective on education*. London: Kogan Page.
- Finley, F. N. (2012). *A perspective on STEM education*. Paper prepared for the Institute for the Promotion of Teaching Science and Technology, and the National Science, Technology and Innovation Policy Office, Thailand.
- Finley, F. N. (2016). Solving STEM Human resource shortages: Linking Local knowledge and Wisdom to STEM literacy. In Office of Education Council and King Monkut's University of Technology, *The Seventh Thailand - US Roundtable on STEM education: Learning culture of the 21st Century Workforce*, p. 94-95.
- Institute for the Promotion of Science and Technology (IPST) (2015). *STEM network manual*. Bangkok: Institute for the Promotion of Science and Technology.
- Johnson, D., & Johnson, R. (1999). *Learning together and alone: Cooperative, competitive, and individualistic learning* (5th Ed.). Boston: Allyn & Bacon.
- Kullatat, N, Dahsah, C., Wongyounoi, S., and Mateapinitkul, P. (2015). *Context-based learning model: CBLM as a tool for promoting science communication abilities and learning achievement*. Paper presented at the annual International Conference for Science Educators and Teachers, Kasetsart University, Thailand July 17-19.
- Marginson, Simon, Tytler, Russell, Freeman, Brigid and Roberts, Kelly (2013). *STEM: country comparisons: international comparisons of science, technology, engineering and mathematics (STEM) education Final report*. Australian Council of Learned Academies, Melbourne, Vic.
- Organisation for Economic Co-operation and Development (OECD) (2014). PISA 2012 results in focus: What 15-year-olds know and what they can do with what they know? <http://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf>.
- Promboon, S. Finley, F. Kaweevijmanee, K. (2018). The Evolution and Current Status of STEM Education in Thailand: Policy Directions and Recommendations. (pp. 423 – 459). In Fry, G. W. *Education in Thailand: An old elephant in search of a new mahoot*. Chennai, India: Springer.



South East Asian Ministers of Education Organization Regional Centre for STEM Education (2020). <http://seameo-stemed.org/>

Supot Hannongbua. (2013). STEM chuey kae wikrit kanrianwithayasad lae kanitsat dai ching rue? [Could STEM really help solve science and math education issues?] Powerpoint Presentation presented at STEM Thailand Forum, Bangkok, Thailand. July 31.

Thawat, Chitrakarn (2012). Kanpathana krabuankan rianru withayasad teknoloyi lae nawatakam phan program STEM [Development of the learning process through science, technology, and innovation across the STEM program].
<http://www.se-edlearning.com/wp-content/uploads/2013/11/stem.science.innovation.pdf>



Students' Conceptual Change in Chemistry Using Computer Simulation-Based Instruction

June Alexis S. Razonable

Philippine Normal University, Manila, Philippines
razonablejune@gmail.com

Abstract

Chemistry plays a vital role in Science, Technology, Engineering, and Mathematics (STEM) education. It is essential that the scientific literacy of Chemistry learners must be developed and be enhanced to achieve the goals of STEM. The main purpose of this study is to determine the effect of computer simulation-based instruction in enhancing a conceptual change of students in chemistry using a two-tier test. The study utilized the experimental research method, specifically the one-group quasi-experimental design and phenomenological approach. The participants of the study, composed of 54 Grade 10 students from Caritas Don Bosco School, were selected through purposive sampling. The instruments used were an achievement test in Chemistry and Physics Education Technology Project (PhET) computer simulations. The alternative conceptions of students in Chemistry were determined using the students' responses in the second tier of the achievement test. The effect of computer simulation-based instruction in enhancing conceptual change of students in Chemistry was determined by comparing the students' pre-test and post-test scores and by analyzing thematically the students' responses in the second tier of the achievement test. The PhET simulations used in the study are interactive research-based simulations developed by the University of Colorado. The statistical techniques used were frequencies, percentages, means and standard deviations, Kuder Richardson formula, and two-tailed t-test for dependent sample means. The results revealed that the a majority of the participants hold a number of alternative conceptions in particulate nature of matter, properties of gases, gas laws, pH scale and properties of acids and bases. The statistical result indicates that there is a significant difference between the pre-test and post-test scores. Thus, computer simulation-based instruction is effective in enhancing students' conceptual change in Chemistry; specifically in the topics of particulate nature of matter, gases, and acids and bases. Furthermore, the use of computer simulations resulted in the remediation of the majority of alternative conceptions in Chemistry of the participants.

Keywords: Alternative Conceptions, Conceptual Change, Computer Simulation, STEM

Science, technology, engineering and mathematics (STEM) is considered a major trend and issue not only in the field of academe but also to different sectors of the society. The focus is to motivate learners to recognize and potentially pursue STEM-related careers, thus increasing the possibility of producing highly skilled and well-qualified STEM professionals that will contribute to scientific progress (McDonald, 2016). Science, as a discipline, played a major



role in authenticating STEM education wherein learners can integrate scientific and mathematical concepts to further understand the applications of engineering and technology. Utilizing science as a STEM discipline involves providing real-life situations as research problems, leading to motivated and scientifically-skilled learners (Hernandez, et. al, 2014). Several fields in science also play individual and integrated roles in reforming STEM education. For chemistry, most engineering innovations and technological solutions such as nanotechnology and material science engineering use chemical concepts and principles as their fundamental basis. Likewise, laboratory experiments, chemical models and applications in chemistry can also engage learners in studying STEM-related disciplines. Thus, it is imperative that scientific literacy in chemistry must be strongly established in order to contribute to the improvement of STEM education.

Through the years, science education research has shown that students attending chemistry classes often have preconceived naïve ideas regarding the behavior of the natural world (Yan & Subramaniam, 2018). Aside from this, most of the concepts in chemistry are considered abstract and intangible, thus, making it difficult for the students to comprehend and understand the theories, principles, and ideas presented to them (Taber, 2018). With their preconceived ideas and abstract chemical concepts, these may lead the students to generate predictions and construct reasons that are in contrast from currently accepted scientific principles and processes. In addition, as they try to integrate new concepts into their already constructed knowledge structures, a variety of alternative (i.e., inaccurate) conceptions may occur.

Mulford and Robinson (2002) explained that alternative conceptions have a bigger role in chemistry learning in generating inaccurate answers to questions. Consciously or subconsciously, students create their own understanding of the behavior, properties or theories they experienced. They think that these understandings are acceptable because they make sense in line with their perception of the nature of their surroundings. As a result, when students encounter new information that is different from their alternative conceptions, they tend to reject this new information because they deem it as erroneous.

As a result, the role of educators is to provide opportunities to students to restructure these alternative conceptions and to reorganize existing knowledge to ideas that are scientifically acceptable. This process is usually referred to as “conceptual change.” Based on the constructivist theory, learning can be seen as a process of conceptual change. A conceptual change indicates that a learner creates new connections in his/her conceptual framework by actively replacing existing prescientific conceptions with scientifically acceptable explanations (Ozmen, 2007). In order to initiate conceptual change the learner must experience dissatisfaction with an existing conception and the new conception must also be intelligible, plausible and fruitful. Teaching methods that challenge existing ideas, force students to encounter contradictions and recognize counterexamples appear to enhance conceptual change. Among different teaching strategies, the use of computer simulation-based instruction can be utilized for this objective. Computer simulations can be used as vehicles for conceptual change since they allow the learners to observe a system of interconnections, apply changes in



the system, predict the corresponding results of these changes, then control the system to see the results. Learners play an active role in the learning process, including assessing and understanding new information in relation to the former knowledge acquired. Thus, they must be given a chance to take on independent tasks for constructing concepts and understanding the information given to them (Brock, 2004).

Since alternative conceptions can greatly impact learners' acquisition of new ideas and concepts, it is important for educators to develop teaching strategies and techniques that will prevent or remediate students' alternative conceptions. With the potential of computer simulations in enhancing students' conceptual change, the researcher wanted to determine the extent of using computer simulation-based instruction in enhancing the conceptual change of students in the area of Chemistry.

Limitations of the Study

The following are the limitations of the study:

1. The study focused on the effect of computer simulation-based instruction in the conceptual change of Grade 10 students in selected topics in chemistry. The topics that were included are: particulate nature of matter, gases, and acids and bases.
2. The analysis and interpretation of the results were based on the alternative conceptions determined by the researcher. Thus, the findings may not be applicable to situations that are not related to these alternative conceptions.
3. The study was limited to the use of Physics Education Technology Project (PhET) computer simulations (University of Colorado, 2020). Likewise, the activities that were integrated in the computer simulation-based instruction were aligned to the PhET computer simulations.
4. The researcher was not able to analyze students' own views and perceptions of science, which may have influenced their performance during the study. In addition, the "novelty effect" realizes that a small change in the learning environment for students may increase their motivation and results to positive learning. The probability that the participants' attitudes were affected by this novelty effect represents a limitation in the results of this study.
5. Students' responses do not represent their overall understanding of selected chemistry concepts because of the short amount of time allotted when they underwent the intervention. However, it can provide specific alternative conceptions of students.

Methodology

The researcher utilized both quantitative and qualitative research designs in addressing the objectives of the study. In terms of quantitative design, the experimental research method, specifically the one- group quasi-experimental design was implemented. In this study, an intervention was applied to one situation and its effect and difference were assessed and identified. The experiment consisted of one group: the Grade 10 level (n = 54); this group underwent computer simulation-based instruction (CSBI). In CSBI, PhET simulations were used.



These are interactive and research-based simulations created and developed by the University of Colorado. A researcher-made achievement test was administered to the students before and after the intervention as pre-test and post-test (See Appendix). The achievement test served as the controlled variable since the same set of questions were included in the pre-test and post-test. The results obtained from the Grade 10 level were used to determine if alternative conceptions were remediated and if students demonstrated a conceptual change in chemistry using the treatment. For the qualitative research design, the phenomenological approach was utilized. In this study, the students' conceptual changes in chemistry were determined using their qualitative responses in the second tier of the achievement test in chemistry (ATC).

To generate useful and reliable interpretations and analysis, the application of inferential statistics was employed in the study. The Kuder Richardson formula was utilized to determine the reliability of the ATC, both as pre-test and post-test results. Also, the two-tailed t-test for dependent sample means at 0.05 level of significance was used to determine whether the difference between the pre-test and post-test of Grade 10 is significant.

With regard to qualitative data analysis, students' explanations in the achievement test were analyzed thematically using Braun and Clarke's (2006) approach where data were read repeatedly to de-contextualize pieces of information from the original data. Information was categorized into similar, dissimilar components and later re-examined against the purpose of the study in order to generate themes. Calik and Ayas (2005) formulated a technique in sorting the content answer and reasoning in five categories. Using this method, the researcher was able to analyze the data in two ways. First, students' responses were categorized into different levels of understanding. Second, the alternative conceptions were further analyzed into several patterns. Table 1 shows the five categories and their corresponding criterion.

Table 1

Five Categories of Students' Responses.

Category	Symbol	Criterion
Sound understanding	SU	Responses that provided both the correct answer and reasoning
Partial understanding	PU	Responses that included either correct answer or correct reasoning while leaving another tier unanswered
Partial understanding with specific alternative conceptions	PS	Responses that included either correct answer with wrong reasoning or wrong answer with correct reasoning
Specific alternative conceptions	SA	Responses that included wrong answers in both tiers
No understanding	NU	Responses with blank or multiple responses

Source: Adapted from Calik and Ayas (2005)

Literature Review

Students hold on to a variety of alternative conceptions in school, especially in the area of science. Some of these alternative conceptions date back to decades ago while others arise every day with new studies (Pragle, 2010; Ahmed, 2018). As Wenning (2008) explained, alternative conceptions cover all fields of science. Specific alternative conceptions were somehow evident even in the subfields associated within each discipline. Gonzales-Espada (2003) theorized that students construct their alternative conceptions in science from a combination of common-sense experiences (experiential knowledge) and partially correct scientific information (conceptual knowledge). In the field of chemistry, a large percentage of students experience difficulties in understanding chemistry concepts due to the method of instruction, such as lecture, reading from the textbook, and using a knowledge-based approach, and this may lead to students having alternative conceptions (Ozmen et al., 2009). Horton (2007) clarified that alternative conceptions in chemistry are persistent. Sheehan (2017) conducted a review on studies on alternative conceptions and it showed that learners have several alternative conceptions on the following chemistry topics: particulate nature of matter, chemical bonding, stoichiometry, and equilibrium.

With these, several educators and researchers attempted to determine the most effective method or teaching model to address the problem of alternative conceptions. The common element among these models is that students must experience cognitive conflict when presented with a new idea (Wenning, 2008). From these learning models, the conceptual change theory is one of the approaches that was utilized to address alternative conceptions. Hewson (1981) defined conceptual change as a process where alternative conception is removed and replaced by a correct understanding. Learners must actively replace old knowledge with new ones and how they fit in their new mental framework.

Yang et al. (2016) stated that technology must be integrated in designing classroom activities in order to achieve desirable changes in learning behavior. Along this line, many educators developed ways and strategies to enhance students' understanding using technology. Barron et al. (2002) emphasized that technologies, specifically interactive technologies, provide thought-provoking environments that promote active involvement from the students during the learning process. From the different kinds of computer applications, simulations were considered to have the best potential for conceptual change. Computer simulations are software programs that are capable of emulating a certain model or system (Ramnarain & Moosa, 2017). Their capacity to recreate phenomena and to allow users to actively participate with the system lead to a unique way of assisting learners to conceptualize. Several studies were conducted with a focus on the relative effectiveness of computer simulations when integrated inside the science classrooms. According to Quellmalz et al. (2012), computer simulations have transformed into a widely-known method of instruction in the last 15 years. This is due to the emergence of commercially available software that is derived from scientific and technological models, which mirrored real life situations. In addition, Rutteb et al. (2012), who reviewed 51 articles from 2001 to 2010, concluded that using computer simulations can enhance learning in the traditional classroom.



Today, computer simulation is a vital instrument in teaching content, especially in the field of science education. Akcay et al. (2003) stated that simulation accompanied with computer instruction is more utilized compared to traditional methods of teaching. Norton and Wiburg (2003) explained that simulations are interesting and realistic, can motivate learners and provide continuous learning within numerous sessions, can help achieve desired goals within a reasonable amount of time, are appropriately random and unpredictable, and focus on significant content not trivial details. They are distinctive instructional strategies since they represent reality.

One advantage of using computer simulations is that they have the capacity to promote conceptual change in students. Hirashima et al. (2013) attempted to document the use of computer simulations in developing countries by including computer simulations in hands-on laboratory activities with a focus on the area of chemical bonding. The results showed that computer simulations offer feedback that decreases the abstract nature of chemistry concepts. They concluded that computer simulations provide learners the opportunity to visualize chemical reactions at a microscopic level. A similar research study was done by Akcay et al. (2013) to determine the effects of computer simulations on students' success and attitudes in teaching chemistry via implementation of several tests like achievement, logical thinking ability, chemistry attitude scale, computer attitude scale, and simulation attitude scale. They found that there is a significant difference between the achievement and attitude in chemistry between the experimental and control groups. Likewise, a study on using a computer simulation-assisted conceptual change model to analyze students' conceptual change on the kinetic theory of gases showed a significant increase in scientifically-acceptable conceptual change in the participants upon using computer simulations (Samsudin et al., 2019).

However, there are studies that resulted in little or no effect in utilizing simulations to remediate alternative conceptions. In their comparative study, Walker et al. (2006) found that there was no significant difference on the achievement of learners who underwent fieldwork or simulation-based instruction. Educators observed that it is difficult to evaluate the learning outcome when using simulation-based instruction. Simulations are limited to frameworks and processes and cannot be utilized to teach individual concepts or sequences of events. They focus on learning about possible consequences in a given situation, not about certainties. Maddux et al. (1997) enumerated possible limitations in simulations, such as time-limitations; possible generation of threat and anxiety; difficulty in direct intervention; objectives mismatch; and generation of a competitive focus.

In synthesis, a vital component of the learning process is the identification and remediation of alternative conceptions, thus teachers must be aware of their learner's preconceived ideas and the need to reconstruct them. The literature implies that students' preexisting beliefs affect how they understand new scientific concepts and principles and have a major role in subsequent learning. It is shown that in many instances science learning difficulties happen because students' alternative conceptions are not taken into account. The literature also suggests that alternative conceptions, mostly in chemistry, are persistent and

highly resistant to remediation by traditional teaching methods because of their abstract nature. This implies that other teaching strategies must be utilized to address alternative conceptions. The literature enumerated the positive effects of using computer-based technologies, especially, computer simulations, in remediating students' alternative conceptions. However, mixed results were obtained from different studies on the effect of using computer simulations. Also, there is a lack of research on the extent of the effect of computer simulations in changing students' conceptions into beliefs that are scientifically accepted. This forms the basis for this study which was designed to examine the extent of using computer simulations in preventing and remediating alternative conceptions in chemistry.

Discussion of Results

Based on the results from the students' responses, the alternative conceptions were determined. The following PhET simulations were selected to initiate conceptual change in the participants. *States of Matter: Basics* (Figure 1a) was chosen since it can show the different properties of the three states of matter based on different conditions such as type of molecule and temperature. On the other hand, Figure 1b shows the simulation *Gas Properties*. In this simulation, the learners have the chance to conduct experiments to observe changes in volume, temperature and pressure of a gas based on the stimulus applied to the system. Lastly, *pH Scale* (Figure 1c) allows the learners to observe pH changes and ion concentrations based on the sample solution and volume of solvent.

Figure 1

Sample Screenshots of PhET Simulations.

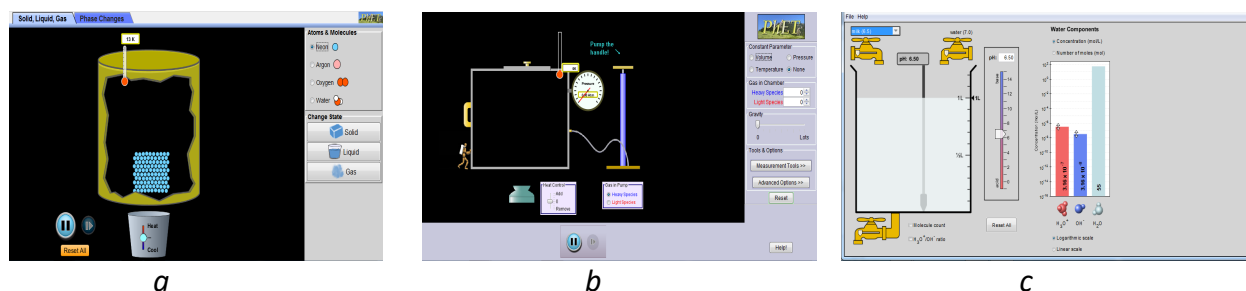


Table 2 compares the percentage of students who provided correct responses either in the first tier only, or in both tiers of the pre-test and post-test. In general, students' understanding during the post-test was higher compared to the pre-test. These results are similar with previous studies involving two-tier diagnostic instruments (Othman et al., 2008; Artdej et al., 2010) wherein a majority of the students performed better in the first tier of the test items than in both tiers.



Table 2

Percentages of Students Correctly Answering the First Tier and Both Tiers of the Achievement Test in Chemistry.

Item	Pre-test (%)		Post-test (%)		Item	Pre-test (%)		Post-test (%)	
	First Tier	Both Tiers	First Tier	Both Tiers		First Tier	Both Tiers	First Tier	Both Tiers
1	89	72	89	87	16	26	15	54	50
2	74	17	76	67	17	81	61	85	83
3	33	22	61	59	18	50	22	56	56
4	20	6	39	39	19	37	22	61	56
5	54	6	57	56	20	70	46	76	70
6	65	7	74	57	21	67	26	61	46
7	74	15	65	59	22	59	37	70	61
8	17	4	35	35	23	80	54	87	76
9	24	4	48	44	24	52	31	69	67
10	93	70	78	70	25	46	33	61	59
11	87	46	87	83	26	61	37	57	56
12	78	31	85	83	27	30	11	52	48
13	59	44	69	61	28	44	33	54	50
14	24	11	46	44	29	44	19	70	65
15	80	69	83	83	30	39	24	59	56

As can be seen from Table 3, further analysis of the test scores using *t* test showed that there were statistically significant differences between pre-test and post-test results of the achievement test. These results suggest that students' conceptual change in selected topics in chemistry was enhanced using CSBI. This is similar to findings reported in the literature which points to the positive effects of computer simulation in enhancing students' conceptual change in chemistry (Akca, 2003; Ozmen, 2007; Sentongo, 2013).

Table 3

Comparison of the Pre-Test and the Post-Test Scores in Achievement Test in Chemistry.

Measures	Pretest			Posttest			<i>t</i>	<i>p</i>	Interpretation
	<i>N</i>	Mean	<i>SD</i>	<i>N</i>	Mean	<i>SD</i>			
Achievement Test in Chemistry	54	26	9.40	54	38	9.88	6.31	< 0.05	Significantly different

Table 4 includes the data from the pre-test and post-test representing the percentage of student responses containing sound understanding (SU), partial understanding (PU), partial



understanding with specific alternative conceptions (PS), specific alternative conception (SA), and no understanding (NU) as classified based on each chemistry concept.

Table 4

Percentages of Student Responses for Achievement Test in Chemistry.

ITEM	SU (%)		PU (%)		PS (%)		SA (%)		NU (%)	
	A*	B*	A	B	A	B	A	B	A	B
1	72	87	0	0	20	6	6	7	2	0
2	17	67	2	0	67	13	15	20	0	0
3	20	59	4	0	11	4	59	33	6	4
4	6	39	0	0	15	0	65	56	15	6
5	6	56	4	0	44	2	37	41	9	2
6	7	57	4	2	52	13	26	26	11	2
7	15	59	4	4	56	2	20	35	6	0
8	4	35	2	0	11	0	74	61	9	4
9	6	44	4	4	17	0	56	48	19	4
10	69	70	6	0	24	7	0	20	2	2
11	46	83	7	2	33	2	6	13	7	0
12	31	83	7	2	39	2	11	9	11	4
13	44	61	6	4	11	2	24	31	15	2
14	11	44	2	2	17	0	56	52	15	2
15	69	83	6	0	6	0	13	13	7	4
16	15	50	2	2	11	7	52	33	20	7
17	61	83	6	0	19	2	13	11	2	4
18	22	56	11	0	20	0	33	35	13	9
19	22	56	0	2	17	6	46	37	15	0
20	46	70	7	4	17	4	22	20	7	2
21	26	46	7	0	33	15	22	33	11	2
22	37	61	4	2	20	9	24	28	15	0
23	54	76	11	2	17	9	11	6	7	0
24	31	67	7	2	20	7	28	24	13	0
25	31	59	9	0	7	7	41	30	11	4
26	35	56	9	0	19	6	30	33	7	6
27	13	48	4	0	15	6	48	35	20	11
28	33	50	4	0	9	4	37	43	17	4
29	19	65	2	2	24	6	35	24	20	4
30	24	56	0	0	15	6	35	37	26	2

**Legend: A – pre-test ; B – post-test*

As shown in Table 5, the percentage of students with alternative conceptions in properties of solid particles decreased after implementing CSBI. These results indicate that the



simulation was successful in initiating students' conceptual change. The computer simulation *States of Matter: Basics* was specifically designed to remedy such alternative conceptions since students were given the chance to differentiate the properties of the three states of matter. However, no significant change was observed in the percentage of students with alternative conceptions for the motion of solid particles. Although the simulation shows the vibration of the solid particles, students were not able to associate this with the motion of the solid particles. As Talanquer (2004) suggested in his common-sense chemistry explanatory framework, the learner assumes that the models of the microscopic world of particles are a reduced version of the macroscopic world. This will lead them to believe that atoms are stationary when the whole object is not moving.

In relation to the role of heat during phase changes, students were successful in remediating their alternative conception for this concept. On the other hand, the proportion of students with alternative conception in properties of liquid increased. A similar result was obtained with the alternative conception in the effect of decreasing temperature on the motion of particles. The increase in percentage may arise due to students' confusion with how liquid particles were presented in the simulation. In the computer simulation, liquid particles are shown as "flowing" past one another. Students may have perceived this motion as particles expanding inside the container. Likewise, when the simulation showed that the speed of particles decreases while removing heat, they inaccurately predicted that the particles will eventually stop.

Table 5

Percentages of Students' Alternative Conceptions (Particulate Nature of Matter) Identified in the Pre-Test and Post-Test.

Alternative Conceptions to be Corrected	Pre-test (%)	Post-test (%)
1. Solid particles have the same properties with liquid and gas particles.	41	24
2. Solid particles have no motion.	20	22
3. Liquid particles have the same properties with gas particles.	17	26
4. Heat destroys the particles of substances.	17	0
5. As temperature decreases, molecules will either move faster or stop moving.	19	26

Table 6 shows that students have conceptions that are in contradiction with Boyle's Law. After using the computer simulation, the percentage of students with this alternative conception decreased. This is further supported by the correct responses and explanation of students in Items 14, 15 and 19. These test items assessed students' understanding about Boyle's Law. There was an improvement in the number of students who gave correct answers for the three items. A similar result was obtained for the alternative conception of Graham's



Law. Using the PhET simulation, students were able to observe in real-time the speed of a light mass molecule and a heavy molecule. Also, they were able to see that the different gases they pumped inside the container mixed spontaneously in uniform distribution.

The effectiveness of the simulation is highly evident in Conceptions 4 and 5 (Table 6). The computer simulation utilized by the students include a closed container interface where gas molecules are contained. Students were able to observe that the number of gas particles remain constant even after changing the values of pressure, volume or temperature.

In contrast, an alternative conception in the temperature-volume relationship (Item 12) by 7% (Table 6) of students. This may generate from students' misunderstanding of Boyle's Law. They may have associated the relationship of pressure and volume as similar to that of temperature and volume. Talanquer (2004) identified this as "fixation" where learners apply principles and interpretations in an automatic fashion. This results in a mental set of explaining a situation with a concept that is applicable for a different situation.

Table 6

Percentages of Students' Alternative Conceptions (Gases) Identified in the Pre-Test and Post-Test.

Alternative Conceptions to be Corrected	Pre-test (%)	Post-test (%)
1. At constant temperature and number of gas particles, pressure and volume are directly proportional.	54	41
2. Gas molecules do not exhibit diffusion.	41	15
3. Heavier gas particles will move faster.	22	15
4. In a closed container of gas molecules, a change in variable (temperature, pressure or volume) will lead to a change in the number of gas particles.	41	0
5. At constant temperature, the volume decreases.	15	0
6. At constant pressure and number of gas particles, temperature and volume are inversely proportional.	0	7

The findings in Table 7 suggest that conceptual change in students' understanding of acids and bases was enhanced through CSBI. There was a decrease in the percentage of students with alternative conceptions in interpreting pH scale. There is clear evidence in the sample responses below that students were able to reconstruct their previous knowledge of pH scale into scientifically acceptable ones. Conceptual change is also evident in concepts involving hydroxides and hydrogen ions as both percentages decreased. With this, the integration of computer simulation was deemed highly successful in remediating students' alternative conceptions in acids and bases.



Table 7

Percentages of Students' Alternative Conceptions (Acids and Bases) Identified in the Pre-Test and Post-Test.

Alternative Conceptions to be Corrected	Pre-test (%)	Post-test (%)
1. A substance with a pH below 7 is a base while a substance with a pH above 7 is an acid.	50	15
2. Hydroxides are acidic and have low pH levels.	30	6
3. Substances with higher pH levels have a higher concentration of hydrogen ions and are considered as basic.	41	28

Conclusion

Evidence shows that computer simulations can contribute to the conceptualization of ideas and understanding and that the process of conceptual change can be facilitated by integrating computer simulations in the learning environment. However, it does not support that computer simulations or any other computer-related technology can be used as a stand-alone instructional technique. This study also reinforced the idea that instruction involving computer simulations provides a conducive cognitive learning environment where learners can be tested in terms of understanding basic chemistry concepts, reconstructing alternative conceptions, and general response to constructivist instruction. However, there are several challenges to researchers in the area of constructivist uses of simulations to promote conceptual change. One is that constructivist instructional theory offers an approach to learning that involves many variations from traditional instruction, making it difficult to isolate variables for experimental manipulation. Another challenge is accurately measuring the conceptual change of learners after employing computer simulation-based instruction.

The following recommendations are offered as possible ways to improve this study, for related research, and to inform practitioners of technology education:

1. With the benefit gained from using technologies like computer simulations, it is imperative that educators must have technological literacy in order to integrate these innovative tools in their teaching strategies and methods.
2. As the role of computers expands in our schools it is necessary to chart a course of research that stays abreast of the emerging technologies and how they interface with the characteristics of the learner as well as the overall learning environment.
3. Developing more refined typologies for simulations, uses of simulations within the larger learning environment, conceptions, and alternative conceptions will help clarify

the discourse in the area of conceptual change strategies. The role of the learner's epistemological disposition in achievement and conceptual change is also a viable area for continued study.

4. Since the findings also show that some students retain their alternative conception even after integrating computer simulation in their instruction, some techniques such as conceptual change text, demonstration, or analogies may be combined with computer simulation to increase the effectiveness of the instruction.



June Alexis S. Razonable, MA Ed., has taught subjects such as Chemistry, Physics, Electronics and Robotics. He obtained his bachelor's degree from the University of the Philippines Los Baños and received his master's degree in Chemistry Education from the Philippine Normal University. Mr. Razonable's research studies focus on educational technology, pedagogical approaches, and test construction. He also serves as an author for a grade school science textbook and a coach for academic contests and competitions.

References

- Ahmed, M., Opatola, Y., Yahaya, L., and Sulaiman, M. (2018). Identification of alternative conceptions of genetics held by senior school students in Ilorin, Nigeria, using a three-tier diagnostic test. *KIU Journal of Sciences*, 4(1), 97-104.
- Akcay, H., Feyzolu, B., & Tuysuz, C. (2003) The effects of computer simulations on students' success and attitudes in teaching chemistry. *Educational Sciences: Theory and Practice*, 3(1), 20-26.
- Artdej, R., Ratanaroutai, T., Coll, R. K., & Thongpanchang, T. (2010). Thai Grade 11 students' alternative conceptions for acid-base chemistry. *Research in Science & Technological Education*, 28(2), 167-183.



- Barron, A. E., Ivers, O. W., & Lilavois, K.S. (2002). *Technologies for education: A practical Guide*. (4th ed.). USA Libraries Unlimited.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101.
- Brock, P. A. (2004). *Educational Technology in the Classroom*. Englewood Cliffs, New Jersey: Educational Technology Publication.
- Calik, M., and A. Ayas. (2005). A comparison of level of understanding of eight-grade students and science student teachers related to selected chemistry concepts. *Journal of Research in Science Teaching*, 42, 638-637.
- Gonzales-Espada, W. (2003). A last chance for getting it right: Addressing alternative conceptions in the physical sciences. *The Physics Teacher*, 41, 36-38.
- Hernandez, P. R., Bodin, R., Elliott, J. W., Ibrahim, B., RamboHernandez, K. E., Chen, T. W., & de Miranda, M. A. (2014). Connecting the STEM dots: measuring the effect of an integrated engineering design intervention. *International Journal of Technology and Design Education*, 24(1), 107-120.
- Hewson, P. (1981). A conceptual change approach to learning science. *European Journal of Science Education*, 3(4), 383-396.
- Hirashima, T., Shinihara, T., Yamada, A., Hayashi, Y. & Horiguchi, T. (2017). Effects of error-based simulation as a counterexample for correcting MIF misconception. In: André E., Baker R., Hu X., Rodrigo M., du Boulay B. (eds) *Artificial intelligence in education. AIED 2017. Lecture Notes in Computer Science*, vol 10331. Springer, Cham. https://doi.org/10.1007/978-3-319-61425-0_8
- Horton, C. (2007). Student alternative conceptions in chemistry. *California Journal of Science Education*, 7(2), 1-78.
- Maddux, C. D., Johnson, D. L., & Willis, J. W. (1997). *Educational computing: Learning with tomorrow's technologies*. Boston, MA: Allyn & Bacon.



- McDonald, C. (2016). STEM education: A review of the contributions of the disciplines of science, technology, engineering, and mathematics. *Science Education Journal*, 27(4), 530-569.
- Mulford, D. R., & Robinson, W. R. (2002). An inventory for alternate conceptions among first-semester general chemistry students. *Journal of Chemical Education*, 79(6), 739-744.
- Norton, P., & Wiburg, K. (2003). *Teaching with technology: Designing opportunities to learn* (2nd ed.). Belmont, CA: Wadsworth/Thomson Learning Inc.
- Othman, J., Treagust, D. F., and Chandrasegaran, A. L. (2008). An investigation into the relationship between students' conceptions of the particulate nature of matter and their understanding of chemical bonding. *International Journal of Science Education*, 30, 1531 – 1550.
- Ozmen, H. (2007). The effectiveness of conceptual change texts in remediating high school students' alternative conceptions concerning chemical equilibrium. *Asia Pacific Education Review*, 8(3), 413-425.
- Ozmen, H., Demirciodlu, H., & Demirciodlu, G. (2009). The effects of conceptual change texts accompanied with animations on overcoming 11th grade students' alternative conceptions of chemical bonding. *Computer and Education*, 52(3), 681-695.
- Pragle, J. (2010). Alternative conceptions. *Undergraduate Review: a Journal of Undergraduate Student Research*, 12, 37-42.
- Quellmalz, E., Timms, M., Silbergliitt, M., & Buckley, B. (2012). Science assessment for all: Integrating science simulations into balanced state science assessment systems. *Journal of Research Science Teaching*, 49(3), 363-393.
- Ramnarain, U. & Moosa, S. (2017). The use of simulations in correcting electricity misconceptions of grade 10 South African physical science learners. *International Journal of Innovation in Science and Mathematics Education*, 25(5), 1-20.
- Rutteb, N., van Joolingen W., & van der Veen, J. (2012). The learning effect of computer simulations in science education. *Computer and Education*, 58(1), 136-153.



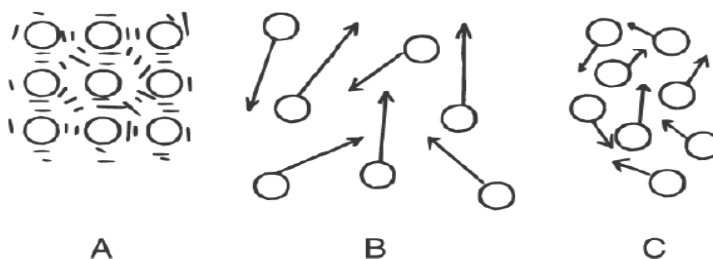
- Samsudin, A. Azizah N., Sasmita, D., Rasmitadila, R., Fatkhurrohman, M., Supriyatman, S., & Wibowo, F. (2019). Analyzing the students' conceptual change on kinetic theory of gases as a learning effect though computer simulations-assisted conceptual change model. *Universal Journal of Educational Research*, 8(2), 425-437.
- Sentongo, J., Kyakulaga, R., & Kibirige, I. (2013). The effect of using computer simulations in teaching chemical bonding: Experiences with Ugandan learners. *International Journal of Educational Science*, 5(4), 433-441.
- Sheehan, M. (2017). *Perspectives on the problem of alternative conceptions* [Doctoral dissertation, University of Limerick]. University of Limerick Institutional Repository. <http://hdl.handle.net/10344/6569>
- Taber, K. (2018). Alternative conceptions and the learning of chemistry. *Israel Journal of Chemistry*, 59(6-7), 450-469.
- Talanquer, V. (2004). Common sense chemistry: A model for understanding students' alternative conceptions. *Journal of Chemical Education*, 83(5), 811-816.
- University of Colorado (2020). *PhET interactive simulations*. Retrieved from <https://phet.colorado.edu/>.
- Wenning, C. (2008). Dealing more effectively with alternative conceptions in science. *Journal of Physics Teacher Education Online*, 5(1), 11-19.
- Walker, C., Greene, B., & Mansell, R. (2006). Identification with academics, intrinsic / extrinsic motivation, and self-efficacy as predictors of cognitive engagement. *Learning and Individual Differences*, 16(1), 1-12.
- Yan, Y. & Subramaniam, R. (2018). Using a multi-tier diagnostic test to explore the nature of students' alternative conceptions on reaction kinetics. *Chemistry Education Research and Practice*, 19, 213-226.
- Yang, J., Yu, H., Gong C., & Chen, N. (2016). Students' perceptions and behaviour in technology-rich classroom and multi-media classroom. *EURASIA Journal of Mathematics Science and Technology Education*, 13(3), 621-647. <https://doi.org/10.12973/eurasia.2017.00636a>

APPENDIX

Achievement Test in Chemistry Integrated Science 10

General Instruction: Read each item carefully and write the letter of the best answer on the space provided. Afterwards, provide a detailed scientific explanation for your choice.

For Question 1, use the diagram below.



- _____ 1. The diagrams represent the movement and distribution of particles in different states of matter. Which statement about the diagrams is TRUE?
- A. A is liquid, B is solid, and C is gas.
 - B. A is liquid, B is gas, and C is solid.
 - C. A is solid, B is gas, and C is liquid.
 - D. A is solid, B is liquid, and C is gas.

Scientific Explanation:

- _____ 2. What will happen to the movement of particles when the temperature is lowered?
- A. The particles will stop moving.
 - B. The particles will move more slowly.
 - C. The particles will move more quickly.
 - D. The particles will escape the attractive forces of other particles.

Scientific Explanation:

- _____ 3. Which of the following correctly describes table salt?
- A. It takes the shape of its container.



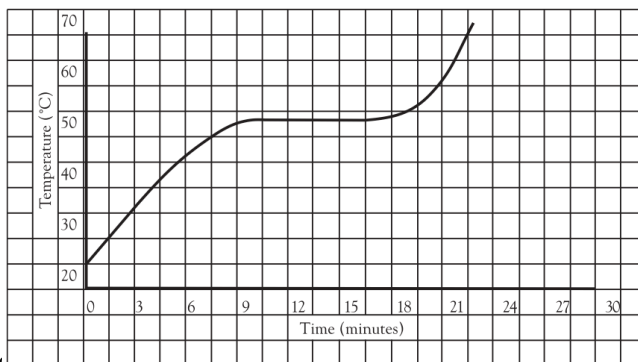
- B. Its particles can flow past one another.
- C. Its particles of matter are close together.
- D. It can be compressed into a smaller volume.

Scientific Explanation:

- _____ 4. When solid salt crystals are dissolved in a glass of water, they form a clear homogeneous solution in which the crystals are not visible. If the beaker is left out at room temperature for a few days, the crystals reappear at the bottom and on the sides of the glass. What type of phase change took place?
- A. freezing
 - B. deposition
 - C. sublimation
 - D. evaporation

Scientific Explanation:

For Question 5, use the graph below.



- _____ 5. A sample _____ its temperature recorded as a function of time. A graph of the data is shown above. At about what temperature is the heat added being used to melt the substance?
- A. 25°C
 - B. 41°C
 - C. 53°C
 - D. 60°C

Scientific Explanation:

- _____ 6. A solid being heated stays at a constant temperature until it is completely melted. What happens to the heat energy put into the system during that time?
- A. The heat energy escaped from the system.
 - B. The heat energy was converted to another form.
 - C. The heat energy was released to the surrounding.
 - D. The heat energy breaks down the bonds between the solid particles.



Scientific Explanation:

- _____ 7. Water cools from 2°C to -2°C. During this time, what happens to the motion of the molecules?
- A. The motion of the molecules stops.
 - B. The motion of the molecules increases.
 - C. The motion of the molecules decreases.
 - D. The motion of the molecules remains the same.

Scientific Explanation:

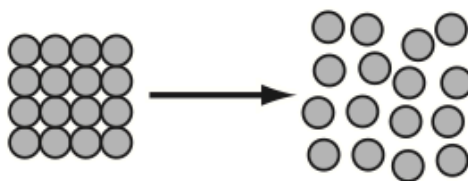
- _____ 8. Which of the following correctly pairs a phase of matter with its description?
- A. Solid: Particles have no motion.
 - B. Liquid: Particles expand to fill any container in which they are placed.
 - C. Gas: Particles have higher amount of energy than when in the liquid phase.
 - D. Liquid: Particles are more strongly attached to one another than when in the solid phase.

Scientific Explanation:

- _____ 9. A hiker carries drinking water in a cloth-covered metal container called canteen. During the summer, the hiker wets the cloth covering so that the water in the canteen stays cool. Which of the following statements explains why a wet covering keeps the water cool?
- A. A wet covering transfers coolness to the water in the canteen.
 - B. A wet covering insulates the canteen better than a dry covering.
 - C. Evaporation of water from the covering transfers heat away from the canteen.
 - D. Condensation of water from the covering transfers heat away from the canteen.

Scientific Explanation:

_____ 10. The diagram below represents a phase change for some copper atoms.



Which of the following phase changes are the copper atoms undergoing?

- A. gas to liquid
- B. liquid to gas
- C. solid to liquid
- D. liquid to solid

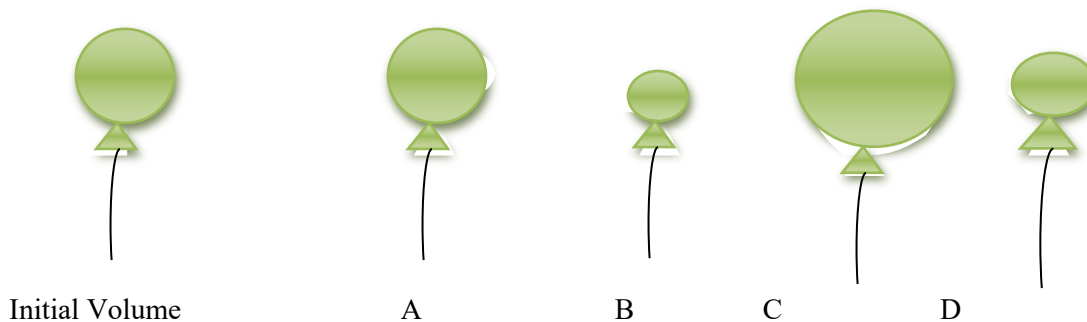
Scientific Explanation:

_____ 11. An aerosol can is heated. Which of the following statements is true?

- A. The pressure inside will increase.
- B. The density of the gas inside will increase.
- C. The number of gas particles inside will decrease.
- D. The kinetic energy of the gas particles inside will decrease.

Scientific Explanation:

_____ 12. A balloon filled with helium gas is warmed and the temperature is changed from 160 K to 315 K. At constant pressure, which of these diagrams shows the new volume of the balloon caused by the change in temperature?



Scientific Explanation:

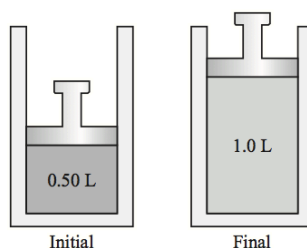
D. The deep-red colored gas remained on the bottom of the beaker.

Scientific Explanation:

- _____ 17. A gas confined in a closed container is heated. What will happen to the gas molecules?
- A. They will move faster.
 - B. They will settle to the bottom of the container.
 - C. They will collide with each other less frequently.
 - D. They will collide with the wall of the container less frequently.

Scientific Explanation:

- _____ 18. The illustrations below represent the expansion of a gas in a cylinder of an engine. The piston moves as the gas volume changes.



What could have been done to the gas in the cylinder to bring about this change in volume?

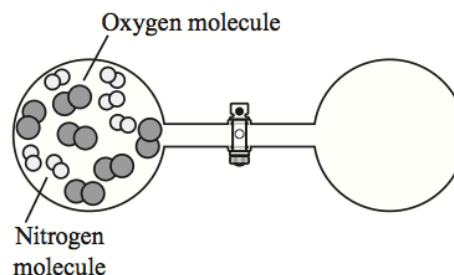
- A. Half of the molecules were released.
- B. The absolute temperature was doubled.
- C. The condensation rate for the gas was doubled.
- D. The amount of heat in the gas was reduced by one half.

Scientific Explanation:

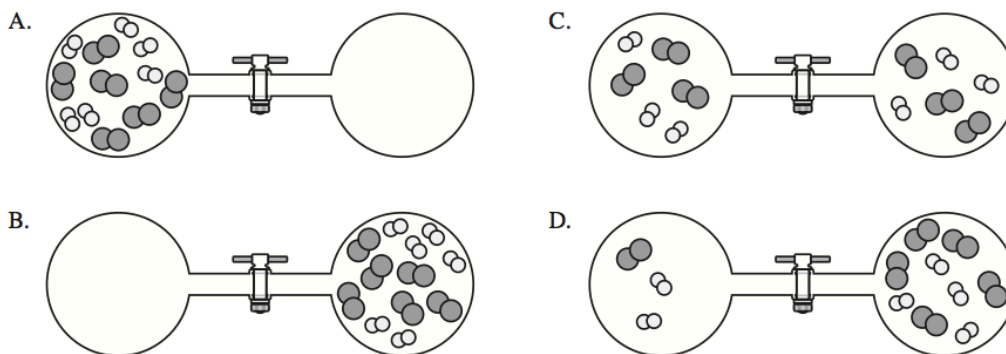
- _____ 19. Large helium-filled balloons are used to carry instruments to altitudes high above Earth's surface. These balloons are used to collect data related to Earth's atmosphere. As the balloons rise to higher altitudes, the atmospheric pressure decreases. What will happen to the volume of the balloons assuming the temperature and number of gas molecules remain constant?
- A. The volume will decrease.
 - B. The volume will increase.
 - C. The volume will remain the same.
 - D. The volume will increase, then decrease.

Scientific Explanation:

20. Oxygen (O_2) and nitrogen (N_2) molecules are contained in a flask, which is separated from a second flask by a closed valve, as shown below. The second flask, of equal volume, is a vacuum.



The valve separating the two flasks is opened. Which of the following diagrams represents the **most likely** arrangement of molecules after the valve is opened?



Scientific Explanation:

21. Rudy just spilled a strong acid on the floor tiles. What must he do first before cleaning up the mess?
- Let the acid puddle dry.
 - Add a small amount of vinegar.
 - Wipe the tiles with cloth immediately.
 - Put a solution containing baking soda in it.

Scientific Explanation:



-
22. Water in an aquarium must be kept at a particular pH level so that the fish stay healthy. What is the best way to prevent water from becoming too acidic or too basic?
- A. Add acid to the water.
 - B. Add a buffer to the water.
 - C. Put the pH paper into the aquarium.
 - D. Fill the aquarium with colored water.

Scientific Explanation:

23. Your chemistry teacher asked you to test Substance Y using a litmus paper. You have noted that the blue litmus paper turns to red. How will you classify the substance?
- A. basic B. acidic C. neutral D. metallic

Scientific Explanation:

24. The pH of milk is 6.4. Based on this information, which of the following statements **best** describes milk?
- A. It is very basic.
 - B. It is very acidic.
 - C. It is slightly basic.
 - D. It is slightly acidic.

Scientific Explanation:

25. The table below contains data for water samples from four sources.

Analysis of Water Samples

Source of Water	Sample Volume (mL)	pH
Rain	5	5.7
Creek	20	7.9
Pool	10	7.4
Faucet	20	6.8

Nancy analyzed water samples from several sources: rainfall, a nearby creek, a swimming pool, and her kitchen faucet. She recorded her data in the table. Which sample was **most** acidic?



- A. rain B. pool C. creek D. faucet

Scientific Explanation:

- _____ 26. The pH of four different solutions of common materials is measured. Which of the following lists the solutions in order from most acidic to most basic?

Battery acid = 1.0 blood = 7.4 laundry detergent = 9.5 lemon juice = 3.5

- A. battery acid, lemon juice, blood, laundry detergent
B. lemon juice, battery acid, blood, laundry detergent
C. laundry detergent, blood, lemon juice, battery acid
D. battery acid, blood, laundry detergent, lemon juice

Scientific Explanation:

- _____ 27. Calcium hydroxide, $\text{Ca}(\text{OH})_2$, is used as a soil conditioner in home gardens. When mixed with water, it releases hydroxide ions. Which of the following is the **most likely** pH for a solution of calcium hydroxide and water?

- A. 1 B. 3 C. 7 D. 10

Scientific Explanation:

- _____ 28. The table below shows the pH values of some substances used in the chemical industry. Which substance has the highest concentration of hydrogen ions?

Chemical Formula and Concentration of Substances	pH
HCN (0.1 M)	5.1
CH_3COOH (0.1 M)	2.9
KCl (0.1 M)	7.0
KOH (0.1 M)	13.0
NaHCO_3 (0.1 M)	8.5

- A. HCN B. KOH C. NaHCO_3 D. CH_3COOH

Scientific Explanation:



- _____ 29. Equal volumes of 1 molar hydrochloric acid (HCl) and 1 molar sodium hydroxide (NaOH) are mixed. What will happen to the mixture?
- A. It will become slightly acidic.
 - B. It will become weakly acidic.
 - C. It will become nearly neutral.
 - D. It will become weakly basic.

Scientific Explanation:

- _____ 30. Magnesium hydroxide, also known as milk of magnesia, is used as an antacid and laxative. Which of the following is the possible pH of magnesium hydroxide?
- A. 1 B. 4 C. 7 D. 10

Scientific Explanation:

----- end of test -----

Exemplary STEM Education Focusing on the Geology and Culture of Niijima Islands in Japan with Cross-Cutting Concepts

Tomohiro Takebayashi^{1,2} * and Yoshisuke Kumano¹

1: Graduate School of Science and Technology, Shizuoka University, Japan

2: Museum of Natural and Environmental History, Shizuoka, Japan

*Corresponding author: taketomo.geology@gmail.com

Abstract

In Earth and Space STEM education, students learn about the Earth's environment and history from rocks and minerals. East Asia and Southeast Asia have multiple plate subduction zones and volcanic islands and exhibit a different geology than in Europe and the US, which are on the continental crust. Societies in each country, e.g., livelihoods, cultures, industries, and the arts, thrive on the resources and energy of the Earth's crust, therefore, they are diverse. In this study, we focused on the geological structure of the Ring of Fire (RoF) and the geological culture of the region and explored STEM education that makes use of these characteristics. We used qualitative methods to develop teaching materials (field research on Niijima, mineral identifications, and questionnaires to children) and to try to make them practical in informal settings. Our research found the presence of several values; crystal-clear beta quartz (Mineralogy and Gemology), contrasting rocks occurrence of rhyolite and basalt on an island (Petrology), the island's unique culture (human-nature connection), technological and industrial development (Resource Engineering and the Arts [glasswork]), and a distinct sand, source rock and outcrop (Earth System Sciences [material cycles]), which have the potential to further develop earth system education and cross-cutting conceptual STEM education.

Key words: Earth and space STEM education, geology, rock crystal, quartz, Niijima Island, Earth system, cross-cutting concepts

Thousands of islands are distributed in East Asia and Southeast Asia, and many countries have sandy beaches. The sands of the beach are part of the material cycle in the earth system and contain information on the regional geology, originating from the rocks (source rock) or organisms. When sands, source rocks, and outcrops are all collectively prepared as teaching materials, students can compare their common patterns, systematically combine their findings, and consider the energy and causes of the change from source rocks to sands. These ideas fit into the cross-cutting concepts of Science, Technology, Engineering, and Mathematics (STEM) education.

Moreover, the countries of East Asia and Southeast Asia are part of the Plate Subduction Zone and the Ring of Fire (RoF), which are more active in tectonic activity (including volcanic activity) than their continental counterparts and exhibit unique geology. In fact, East Asia and

Southeast Asia have diverse and beautiful natural environments and thrive with unique Asian cultures (e.g., industry and the arts). STEM education shares the concept of Earth system science education and advocates the importance of learning about the beauty of nature and the connection between people and nature.

However, few previous studies of geology education have discussed the education of geology in the STEM field, which includes (1) STEM educational materials with clear samples of source rock and sand, (2) mineral diversity and its effects on the local culture (e.g., arts and industries), and (3) the development of specimens in pursuit of the aesthetic beauty of minerals (which supports “STEAM” education that includes the Arts). Therefore, this study considers the development of the cross-cutting concepts of STEM education and Earth system science education from Japanese geology.

To develop an Earth and space STEM education that focuses on minerals in Japan, our first focus was on the unique geology of Japan. Japan has many volcanos and characteristically mass-produced “rock crystals” (Rock crystals are popular gemstones which means that they are made of transparent quartz that is visible to the naked eye [FrondeI, C., 1962; Webster & Anderson, 1983]). The 23.64 km² Niijima island, offshore from Tokyo, has sand beaches that are composed of mostly rock crystal sand, which is rare in the world, and we focused on the mineralogical and geological characteristics of the area. The biggest attraction of the geology in Niijima is the rock crystal sandy beaches, and in the Habushiura sand beach, where the rock crystal contains more than 70% of the constituent minerals of the sand from the seaward to the landward side (Kitamura et al., 2003). Moreover, the island has industry and fine art, which take advantage of the geology of the area and the mineral characteristics of the island, and these minerals attract attention in the field of construction and fine art all over the world. Therefore, the novelty of this study is to discuss Earth and space STEM Education from the perspective of both the mineralogy in pure science, and STEM education.

The value of this study is that from a geological perspective, Earth system science, using the most familiar seaside sands, has been developed and thus focuses on the geology of Asian countries. We therefore aim to develop Earth and space STEM education unique to Asia. To not devise STEM education that focuses on the minerals of the area is wasting a great treasure. The results of a geological, cultural, and industrial survey of Niijima, Tokyo, found a high potential for use in STEM education.

Definitions and Background

STEM education and Earth System Science Education

The theoretical basis of this study is STEM education as outlined in the Next Generation Science Standards (NGSS) in the United States (U.S.), which advocates three distinct and equally important dimensions to learning sciences in years K-12 (3D-Learning) (National Research Council [NRC], 2012). Japanese science education has the same structure as the NGSS’s Disciplinary Core Ideas (DCIs), with Earth and Space Sciences independent. An instructional approach to Earth system education is proposed in Project 2061 (AAAS,1989). It removes the boundaries between the four domains of physics, chemistry, biology, and geology, and emphasizes the interconnections within the subjects. Earth system education has seven goals of understanding related to the Earth system as a planet. One of these goals is to learn about the

Earth's natural beauty and natural continuous systems (Mayer and Kumano, 1999; Mayer, 2014). This idea of an Earth system is now carried over into STEM education. Since 2009, the U.S. federal government has increasingly promoted STEM education at the national level (Public Law 114–329 [Congressional Record, Vol. 162 (2016)]), which includes amendments to PL 114–59 (Congressional Record Vol. 161. [2015]).

Studies of STEM education have increased rapidly in Japan in recent years; with STEM education, which suited the culture and the context of Japan (e.g., with STEM education, which suited school education in Japan; with a comparative study of STEM of Japan and an overseas model (e.g., Kumano, 2014; Okumura and Kumano, 2016; Sakata and Kumano, [2018]). The Japanese Government has mentioned STEM and STEAM education at the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) since 2019 (Matsubara, 2019; Tamura, 2019). In Japan, STEM education is just beginning to take root.

Rock-to-sand process and cross-cutting concepts (Science)

The crosscutting concepts are (1) patterns; (2) cause and effect: mechanism and explanation; (3) scale, proportion, and quantity; (4) systems and system models; (5) energy and matter: flows, cycles, and conservation; (6) structure and function; and (7) stability and change (Duschl, 2012; NGSS, 2013). Systems concepts in STEM include ideas shared with Earth systems education that encourage students to learn about the connections and continuity of nature (e.g., the rock and water cycles), the beauty of nature, and the relationship between people and nature.

Geological Methods and Qualitative Case Study Methods (Informal)

Geological Sample Preparations

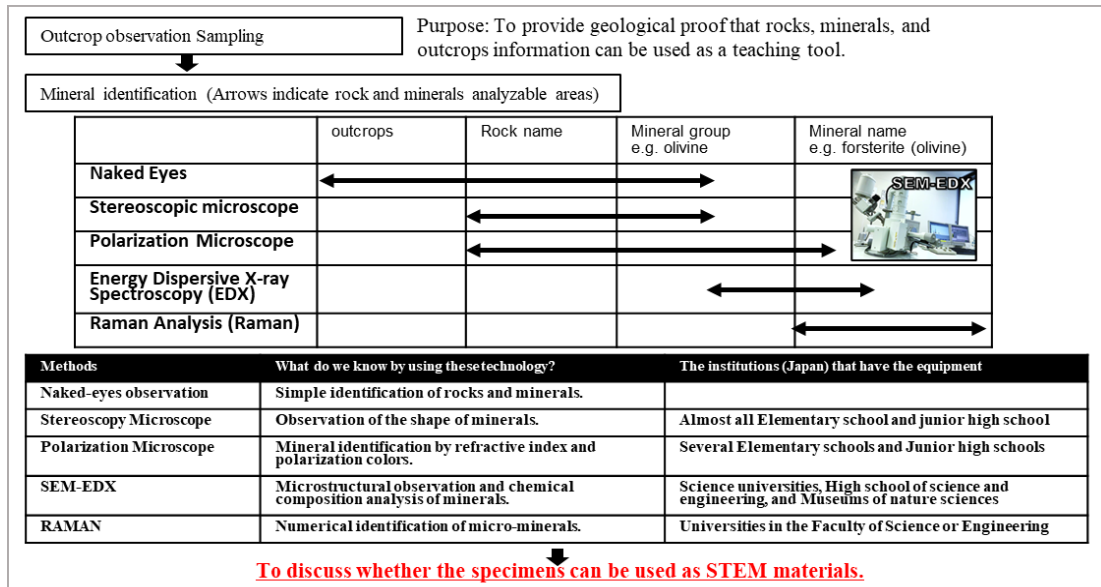
The authors conducted a field geological survey and mineral identification using machines in preparation for STEM materials. We hypothesized that outcrops can indicate an earth system's origin of rocks and minerals, and this geological preparation is intended to provide scientific evidence of the relationship between sand and source rocks. The rock composition of the island consists mostly of rhyolite, and the northern part of the island (Wakago area) is composed of basalt (Isshiki, 1987, Location and Geological map of Niijima island: Appendix A). First, the sampling locations were Habushiura beach, Wakago coast, and Ishiyama (each place is located outside the national park areas). Second, the minerals were identified and analyzed using the instruments noted in Figure 1. Detailed identification of the outcrop minerals increases the confidence in the material. Detailed analytical data are in Appendix B.

Field Surveys of the Island (Culture, Industry, Art, Technology)

We observed outcroppings near the anti-firestone mining site (industry) and building materials in the village (traditional culture), and we interviewed Osamu Noda, director of the Niijima Glass Art Center (culture and art).

Figure 1

The Process of Geological Sample Preparations. © 2020 by Tomohiro Takebayashi.



Comparison of Rock Crystal Sand and Siliciclastic Sand from Different Parts of Japan (Gemology, Earth System Education)

We showed elementary school (ES) students (n = 22, grades 5–6) and junior high school (JHS) students (n = 19, grade 3 [international grade 9]) in Shizuoka prefecture white sand containing quartz and feldspar minerals obtained from all over Japan (Figure 2). After students observed the sands, we asked them which sand they considered most beautiful. The comparative sample was selected based on the following samples: (1) Sand containing the same type of mineral as Niiijima (rock crystals contents different); (2) local sand (the prefecture where the children live); (3) white sand containing various kinds of minerals.

Figure 2

Various Sands Observed by Students with the Naked Eye and a Magnifying Glass. Photos © 2020 by Tomohiro Takebayashi.



Note: Identification of the sands in Figure 2: (a): β - (beta-) quartz sand from Ibaraki prefecture; (b) white sand of Nakatajima from Shizuoka prefecture (local); (c) Kikugahama beach sand from Shimane prefecture; (d) Koiji-ga-hama sand from Aichi prefecture; (e) the “singing-sand “from Tottori prefecture; and (f) and (f’) rock crystal sand from Niijima.

How Results Compare with STEM Integration and Cross-Cutting Concepts

The potential for integration of geology in STEM education will be considered based on contemporary geological research methods and discussed considering the results of the geological survey. First, petrology and geology methods will be discussed by organizing them into S, T, E, and M (See **Differences Between Traditional Geology Education and STEM Education [STEM Integration]** on p. 84). Secondly, integration of geology with mathematics and engineering are discussed based on Nijman’s field research results (See **Examples of Mathematical Analysis** on p. 84 and **Examples of Teaching Local Geology from an Engineering Perspective** on p. 85). Thirdly, the results of this study are synthesized and discussed with the cross-cutting concepts (See **Proposal for Class Lesson: The Relationship Between the Geology of Niijima Islands and the Cross-Cutting Concepts of STEM** on p. 86).

Practice at Science Festival in Gotenba City (Case Study)

In Japan, science festivals are held annually for students at science museums or civic halls in cities across the country (Practice Report in Japan: Inagaki, 2009), where a variety of educational institutions set up small science booths and offer hands-on science classes. In 2017, our research team participated in the Science Festival held in Gotenba City. We presented a booth-style exhibition of Niijima samples for 10–15 minutes. We used a post-exhibit questionnaire (lasting about two minutes—one sentence in free writing) asking “What did you learn for the first time?” to determine what the students were interested in and were able to learn. There were two tables in the exhibition booth, and the visitors took turns looking at sand and rock samples (Table 1). The visitors could learn the definitions of rocks, observe the sands and rocks to discover the relationship between them, learn about mineral resources, and learn to recognize parts of the Earth’s system.

Table 1
The Program at the Science Festival in Gotenba 2017

Contents	Experiencer	STE(A)M
Rock and mineral definitions	1) Observation: Rocks and minerals. 2) Using a polarization microscope: Students can understand that rock is made of minerals.	S of STEM: To give basic definitions of rocks and minerals.
Rock crystal sand and Black sand from Niijima (using a stereoscopic microscope)	1) Observation: Sands from Niijima. 2) The rock crystal stimulates children's curiosity. 3) Students compare the color and surface.	S of STEM: Asking questions (e.g., How does sand form? What is the reason for the contrasting colored sand?) M (Mathematics) Scale: Observations on different scales: (1) naked eye, (2) loupe, (3) microscope.

Contents	Experiencer	STE(A)M
Rhyolite and basalt (using a stereoscopic microscope)	<ol style="list-style-type: none"> 1) Observation: The source rocks of sands from Niijima. 2) Students compare the color and surface. 3) Students compare the sands and rocks from Niijima 	M (Mathematics) Scale: Observations on different scales: (1) naked eye, (2) loupe, (3) microscope. Pattern: color, surface. System: Compare the observations.
Exhibition of glass artworks	<ol style="list-style-type: none"> 1) Art appreciation 	Beauty (Art and Science): The artificial and natural materials.
About mineral resources in Niijima	<ol style="list-style-type: none"> 1) Students are given a technical explanation. 	Convey tradition and culture (viewpoint by the definition of museum education; e.g., ICOM [International Council of Museums] 2019 Kyoto). Communicate the relationship between people and nature (viewpoint of Earth system science).
Questionnaire	<ol style="list-style-type: none"> 1) Students write in one sentence about what they learned for the first time. 	

Results

Comparison of Outcrop Features

The sandy beaches of the island are a contrasting color of black and white in the Habushiura and Wakago areas (Figure 3). In the Wakago area, there is a boundary between rhyolite and basalt. The rocks around the Ishiyama are rhyolite. The color of the sandy beach and the cliffs of the outcrops are very similar, thus offering observational clues for students to analyze and discuss the weathering process.

Figure 3

A View of the Sampling Areas



Note: (a) Habushiura; (b) Wakago; (c) Rhyolite-Basalt boundary (Wakago); (d): Ishiyama overlook. Images (e) and (f) are satellite images by Google-Earth, of (a) and (b), respectively. Photos a-d © 2020 by Tomohiro Takebayashi.

Relationships Between Sands and Rocks Based on Mineral Identification (Science)

Rock crystal (identification: beta-quartz) sands of Habushiura beach and the rocks (rhyolite) of the Ishiyama area were found to be the same compositional minerals. The black grains of sand and outcrop rock (basalt) of the cliffs of the Wakago area were found to be the same composition minerals. As a result, we were able to estimate the source rocks of the sand from outcrop observations and instrumental analysis with high accuracy. The results of the detailed analysis are shown in Appendix B. Teachers can show students the comparison of source rocks and cliffs to sand.

Connecting Mineral Resources to the Culture of Niiijima (Art, Technology, and Engineering)

We found from our field work on Niiijima island that the geology is integrated with the life and culture of the islanders. First, Niiijima glass is made from regional rocks and minerals and is a light green color (Figure 4 a, b). The beauty of the products and the mine-value of Niiijima's glass resources have been globally recognized. Since 1987, the International Glass Art Festival has been held annually to share Niiijima's glass materials with artists worldwide. Second, the fire-resistant rock (biotite rhyolite) known as *Kouka-seki* (Watanabe, 1914) is in demand domestically and overseas because of its strong fire-resistant and sound-absorbing properties (Figure 4 c). It has been used for the stone steps of shrines (Figure 4 d) and the walls of buildings in the village (the outside washroom of Maeda residence in Niiijima has been registered as a cultural property of national importance [ACA 2004; No. 13-0171]). Human society (culture) exists within the earth system and has developed depending on the natural environment. We can study the geology (science) and then discuss how they are used (technology and engineering).

Figure 4

The Connection Between Mineral Resources and the Culture of Niiijima



Note: (a) Niiijima glass; (b) glasswork using Niiijima's minerals; (c) stone steps that remain in the island's shrines; (d) *Kouka-seki* mine (entrance). The rock is still used as a building material. Photos © 2020 by Tomohiro Takebayashi.

Results of a Comparison of Aesthetics of Quartz Sands

Twenty ES students (91%; $n = 20/22$) and 14 JHS students (74%; $n = 14/19$) chose the rock crystal sand of Niiijima island as their preferred sand because they liked its transparency and its shiny property. As a result, this rock crystal was considered by most students in the study as a “beautiful” mineral.

Results of Questionnaires at the Science Festival (Gotemba City)

We received 90 responses from students (ages 6-15 years old) to the question, "What did you learn for the first time?" Their responses can be roughly divided into the following: (1) the relevance of mineral resources to our lives (n = 34), (2) the structure of rocks and minerals (n = 29), (3) how sand is formed (n = 14), and (4) other impressions of polarization microscopy (including vague answers such as "I enjoyed it"; n = 13). The following responses from children (younger than 10 years old) who had not completed geology in elementary science: "That rocks become sand" (age 8) and "That rocks become sand when they break" (age 9). Contents of Niijima glass and refractory bricks: "I never imagined that rocks and minerals were a resource for glass cups" (age 8); and "Minerals are useful in many places, and they are also used in traditional crafts" (age 15). The students' artistic and aesthetic perspective was that "the rocks and ores were so beautiful and clean" (age 9) and "The Earth is made of rocks. It was amazing because the rocks contained a beautiful material." (age 12).

Discussion

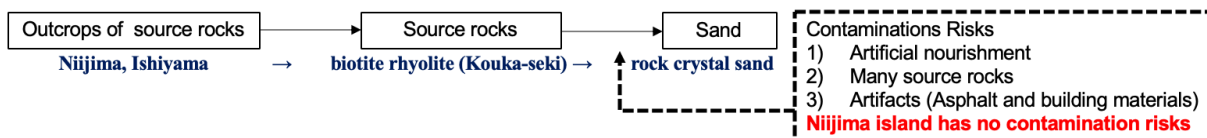
Using Easy to Understand Specimens to not Make Sands Process Misleading

The source of the sands can be estimated from observation, since the outcrops (cliffs) and sand on the beach are the same color. In addition to this speculation, we have added scientific credibility by proving petrologically that the sand and source outcrops constituent minerals are the same (source rock estimation). Therefore, this material is assured of geological confidence and can represent a part of Earth system science. Information that clarifies the relationship between outcrop, rock, and sand can support the discussion section below.

Compared to outcrops of source rocks in Japan, where the source of supply is far from the sandy beaches making the composition more complex due to the inflow of rocks from upstream to downstream, the sandy beaches in Niijima have no contaminant problems. Additionally, beach nourishment has been completed in almost all prefectures with beaches in Japan (Goto et al., 2007). Therefore, nourished sandy beaches may make it difficult to hypothesize the source rocks. The process by which sand is formed from rocks is shown in Figure 5.

Figure 5

The Process of Sand Formation from Rock. © 2020 by Tomohiro Takebayashi.



Differences Between Traditional Geology Education and STEM Education (STEM Integration)

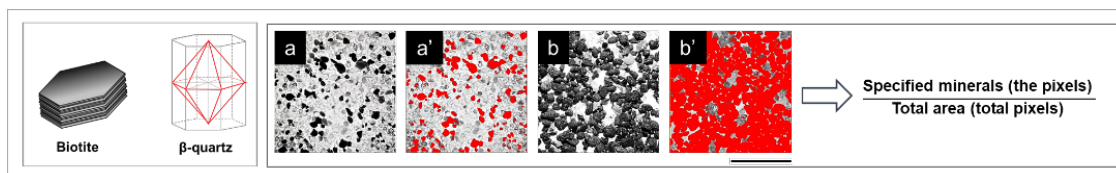
What can children learn from integrating the geology of the Niijima island into STEM education? What is the difference between conventional geoscience education in Japan and STEM education? We will investigate Japan's current science education in Japan based on the Courses of Study (MEXT 2017a, b) and discuss the potential for expansion through the integration of STEM and geology. ES and JHS in Japan are compulsory education (Japanese Constitution) and textbooks, teaching materials, and teaching plans are determined based on the Courses of Study by MEXT. Science education in Japan includes geology, and textbooks are often used in this domain. In ES, students learn about erosion, transport, and sedimentation by water, and in JHS, they observe rocks in the strata and memorize their names and characteristics. The Course of Study's geology domain of Science is written with the goal of understanding natural phenomena (S) and recommends the use of microscopes and loupes when examining the characteristics of rocks (T). However, there is no domain of engineering, and mathematics put in geoscience education in Japan, such as tying it to industry (E), focusing on crystal structures (M), discussing it numerically (M), or making samples to observe (T and E). The greatest value of this study is the inclusion of T, E, and M in the petrological method (See **Proposal for Class Lesson: The Relationship Between the Geology of Niijima Islands and the Cross-Cutting Concepts of STEM** on p. 86). In addition, the island itself lends itself to S (Asian Geology and Earth System), T and E (Glass craft and building material [including Art]), E (Industry), and M (beta-quartz crystal system).

Examples of Mathematical Analysis

Mathematics includes geometry and algebra. All minerals have a crystalline structure and appear in regular shapes and angles. On the other hand, computer technology has been developed so that anyone with computer access and knowledge can perform complex calculations (e.g., measuring distances from satellite images, calculating material content from the number of pixels in an area, and calculating large numbers using Excel) (Figure 6).

Figure 6

Crystal Structure and Calculation of Sand Mineral Composition



Note: Scale bar = 1 cm. (a), (a') are the sand from Habushiura and (b), (b') are the sand from Wakago (red color indicates minerals). © 2020 by Tomohiro Takebayashi.

Evaluating the Attractiveness of Rock Crystal from Gemological and Mineralogical Perspectives (Earth System Science Education)

The results of this study show that almost all students described the rock crystal on Niijima as “beautiful” because of its shiny, colorless, and transparent appearance, which shows that they were paying attention to the characteristics that are unique to rock crystal. The students found almost all of the rock crystals of Niijima to be more attractive than the sand containing few rock crystals (e.g., β -quartz sand from Ibaraki) and the sand composed of silicate minerals (e.g., sinking sand from Tottori).

Human Society and the Natural Sciences (Future Perspective)

From an aesthetic perspective, rock crystal may be considered a work of art created by the Earth, and both adults and children find it beautiful. The art on Niijima island utilizes the regional mineral resources, and the island hosts the International Glass Art Festival annually to share the value of Niijima’s mineral resources and glasswork with artists across the world. Artists from around the world have recognized the value of Niijima's mineral resources and glasswork. There are two types of art on Niijima: natural art created by the Earth and art extracted using our technologies. It is a fusion of nature and human society and is part of the Earth system. The globally shared values are as follows: (1) Understanding the relationship between human society and the Earth (NRC, 2012; IESO, 2016), (2) feeling the beauty of the Earth’s nature (ESSC, 1988), (3) valuing children's sensibilities (STEAM vision), (4) inheriting cultures and traditions (Global Slogan of ICOM 2019 Kyoto; Japan (Shizuoka) case: Takebayashi, 2020), and (5) educating children to think from a broader perspective (NGSS, 2013). Rock crystal sand has the potential to connect a variety of academic disciplines. There is a variety of ways to approach teaching, for example with perspectives on culture (History), glasswork (Art, Engineering, and Technology), minerals (Geology), and from local life (Social Sciences).

Examples of Teaching Local Geology from an Engineering Perspective

The development of science and engineering with the advancement of technology has had consequences for human society and the natural environment (NGSS 2012). The following statement is included in the Course of Study for middle school in Japan: *Students understand that a variety of materials are widely used in human lives and society, through observation and experimentation* (MEXT 2017b). As a practical example, minerals have been used as ores for human life. An example of engineering education is the case of a science teacher in Niijima, who asked the students to observe the rocks, and discuss how they can benefit human society, e.g., Kouka-seki has the features of lightness, fire-resistance, hard but easy to cut, and acid resistance (Sciences), which can be integrated into Engineering. On the other hand, glass art is a part of the island's culture. In East Asian and Southeast Asian countries and regions, rocks, minerals, and sands from volcanoes are used for industrial and traditional crafts. An example of a volcanic island, Ijen mountain (Indonesia) is a volcano with a world-famous blue flame caused by native sulfur (Science), and the sulfur is mined for a craft and mineral-resource industry. Therefore, regional class teachers can use innovative geological STEM education specific to a country or region by focusing on the geology and regional industries.

Student Learning (Gotenba Festival)

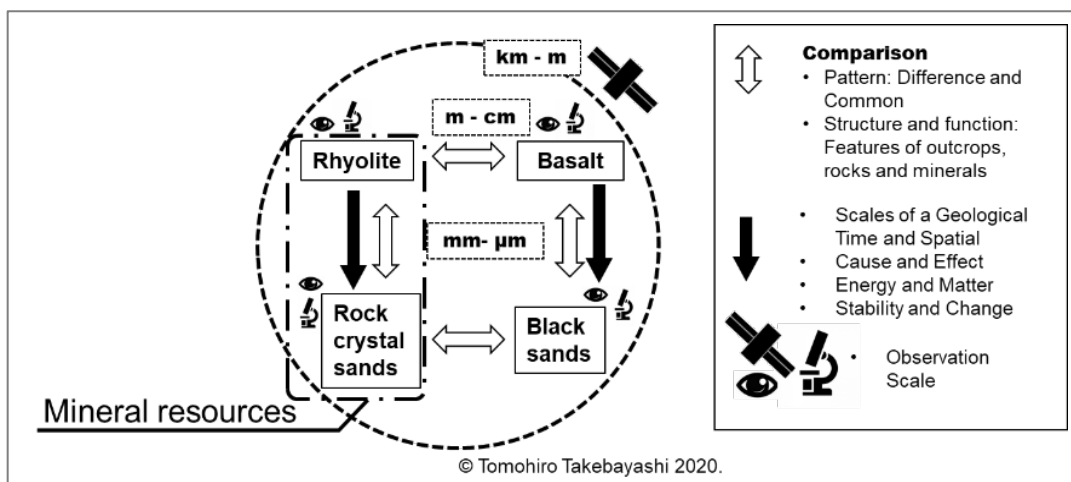
In Japanese science education, geology begins in the fifth grade of ES (MEXT, 2017a, b). However, the results of the questionnaire showed that several children in grades lower than fifth grade learned that rocks are made up of grains and that sand is formed from rocks (Science). In other words, the samples we collected were easy to understand by observations, even for beginners. The students' responses confirmed that some students had learned for the first time that stones are useful in our society, which a 15-year-old student described in the questionnaire in relation to traditional crafts. We were also able to highlight the use of minerals in society at our booth (Art, Technology, and Engineering).

Proposal for Class Lesson: The Relationship Between the Geology of Niijima Islands and the Cross-Cutting Concepts of STEM

In Niijima, Rhyolite and rock crystal sand, and basalt and black sand are contrasting colors, and anyone can discover the structure and their common or different patterns of rocks and minerals. Scale allows us to consider the measures of space and time. For instance, from satellite images, outcrop photos, naked eye observations, and microscope images use a variety of spatial scales: cliff (km-m); rocks (m-cm); and minerals (mm- μ m), and simultaneously we can imagine the geological time scale of the process of making sand from rocks. Energy is necessary to make sand from rock, and we can think of energy changes and effects, such as energy to carry materials, energy to break the materials, and potential energy (e.g., what would cause a rock to break?). A specimen with a clear sequence of material cycles can be adapted to the cross-cutting concepts. From another perspective, Niijima has an industry that utilizes drift rock and is deeply connected to nature and human society. Therefore, there is a system that connects the relationship between the earth and people, and it has great promise to be a viable STEM teaching tool (Figure 7).

Figure 7

The Relationship Between the Geology of Niijima Islands and the Cross-Cutting Concepts of STEM. Graphic © 2020 by Tomohiro Takebayashi.



Conclusion

As it is easy to identify the source rocks and cliffs in the sand of Niijima, it is therefore easy to understand the process of formation of sand from rocks (part of Earth's material cycle), even for beginners. Niijima's quartz sand is highly transparent, free of inclusion minerals, and colorless as a gemstone. The results of this study showed that the students found the rock crystal to be beautiful, and it stimulated their curiosity. The rock crystal sand on the beaches on Niijima island is derived from Japanese volcanic activity (rhyolite) and forms in the Asian plate subduction zone (volcanic island). The rock crystal of Niijima is most likely beta quartz, a mineral produced at high temperatures. Rock crystal sands have a different formation process than stable crustal (continental) quartz. Therefore, the rock crystal sand beaches are the product of a unique geology, volcanic rhyolite in origin, from the Pacific Rim volcanic belt. On the other hand, traditional industries in Niijima utilize local rocks and minerals to make Kouka-seki and glass art. The islanders live by the benefits of nature. Therefore, by combining industry and art with geology, we can apply it to Earth System Education pass on Japan's traditional culture to students.

Technological advances have made it possible to perform complex numerical calculations on home computer software. For example, satellite technology, microscopy measurements, and image analysis are available with home computer specs. The development of computers and the Internet for the public to use has made science, technology, engineering, and mathematics accessible to citizens in ways that were once only available to specialized institutions. It is expected that future society will provide more opportunities for children to experience more specialized research (e.g., the Japanese case: Society 5.0 [Cabinet Office, 2016]).

All Asian countries have unique and diverse geology and cultures. Earth and Space STEM education can thus be made specific to an area by focusing on the geology and culture of the area. The nature of planet Earth is diverse, and this natural diversity creates variations in the industries, technologies, and arts of each country. The aim of STEM education is to encourage children to design the future society. Therefore, it is important that future generations learn about their country's uniqueness to continue the arts, industries, and traditions that are specific to their country. This paper presents a new STEM frontier that focuses on the geology of Asia.



Tomohiro Takebayashi has a Master's degree in science education and is now a Ph.D. student at the Graduate School of Science and Technology, Shizuoka University and a part-time lecturer in geology at University of Yamanashi. Mr. Takebayashi's research is in earth and space science STEM education, focusing on rocks and minerals. He is also a committee member of Earth Science Week Japan.



Yoshisuke Kumano is a professor of science education at Shizuoka University where he teaches Curriculum Studies, Science Education Methods, Seminar in Science Education, and others. He had the honor to receive a full time Fulbright grant from 1989 to 1991 and 2012 for education research in the U.S. Dr. Kumano received his Ph.D. in science education from the University of Iowa in 1993. His research now focuses mainly on STEM education reforms for Japan, working with his Ph.D. students as well as students in other courses. He is the current President of the East Asian Association for Science Education (EASE).

References

- American Association for the Advancement of Science. (1989). *Science for all Americans*.
<http://www.project2061.org/publications/sfaa/online/sfaatoc.htm>
- Cabinet Office (Japan). (2016). *The 5th science and technology basic plan* (Cabinet decision on January 22, 2016). <https://www8.cao.jp/cstp/kihonkeikaku/%honbun.pdf>.
- Duschl, R. A. (2012). The second dimension - crosscutting concepts. *The Science Teacher*, 9 (2), 34-38.
- Earth System Science Committee. (1988). *Earth system science*. Washington, D.C.: National Aeronautics and Space Administration.
- Fron del, C. (1962). *The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana, 7th Edition. Vol. III, Silica Minerals*. pp 192-194. Hoboken, NJ, U.S.: Wiley & Sons.
- Goto, M. (2005). *An empirical study on the development of an education system based on an international comparative study of earth system education*. Final Report of Grant-in-Aid for Scientific Research (B) 2003-2004, Japan Society for the Promotion of Science. 472p

- Inagaki, Y. (2009). Youngster's science festival. *Bulletin of the Japan Science Foundation Science Museum*, 3, 65-70.
- Isshiki, N. (1987). Geology of the Nii Jima district. With geological sheet map at 1:50,000. *Geological survey of Japan*, 85p. Ibaraki.
- International Earth Science Olympiad. (2016). *Statutes of the international Earth science Olympiad (Version 4)*, November 1, 2016).
http://www.ieso-info.org/wp-content/uploads/2012/11/STATUTES_OF_THE_INTERNATIONAL_EARTH_SCIENCE_OLYMPIAD_V.4_PUBL_NOV-01-2016-1.pdf.
- Kumano, Y. (2018). The Theoretical & Practical Research on the Development of Next Generation STEM Learning between Japan and the US, [Grant-in-Aid for Scientific Research (B), Japan Society for the Promotion of Science (JSPS)], Interim report of research results. Vol.2, (16H03058), 11-15.
- Kitamura, T., Arita, M., Isobe, K. & Sudo, S. (2003). White sand from Niijima and Shikinejima, *Geological News*, 582, 19-35.
- Matsubara, K. (2019). *International trends in STEM/STEAM education as a cross-curricular study for the development of qualifications and abilities*. Curriculum Division, Ministry of Education (Japan), Culture, Sports, Science and Technology. Ministry of Education, Culture, Sports, Science and Technology.
https://www.mext.go.jp/b_menu/shingi/chukyo/chukyo3/004/siryo/icsFiles/afiel/2019/09/11/1420968_6_1.pdf.
- Mayer, V. J. & Kumano, Y. (1999). The role of system science in future school curricula. *Studies in science education*, 34, 71-91.
- Mayer V. J. (2014). *Global science literacy (Vol. 15)*. Springer Science & Business Media. 242p.
- Ministry of Education, Culture, Sports, Science and Technology (Japan) (2017a). The course of study in Elementally school (Heisei 29th [2017] Year Notice),
https://www.mext.go.jp/component/a_menu/education/micro_detail/icsFiles/afiel/2019/03/18/1387017_005_1.pdf
- Ministry of Education, Culture, Sports, Science and Technology (Japan) (2017). The course of study at school in Junior high school (Heisei 29th [2017b] Year Notice),
https://www.mext.go.jp/component/a_menu/education/micro_detail/icsFiles/afiel/2019/03/18/1387018_005.pdf
- National Research Council (2012). *A framework for K–12 science education: Practices*,



crosscutting concepts, and core ideas. Washington, DC: National Academies Press.

- NGSS Lead States (2013). *Next Generation Science Standards for states by states.* Washington, D.C.
- Okumura, J., and Kumano, Y. (2016). A practical study on the extension of students' biological knowledge and transformation of scientific thinking in Bio-STEM developmental learning in high school biological embryogenesis experiments. *Journal of Science Education*, 40(1), 21-29.
- Sakata, S., & Kumano, Y., (2018). Attempting STEM education in Informal Japanese educational facilities through the theme of "sand." *K-12 STEM Education*, 4(4), 401-411.
- Swamy, V., Saxena S. K., Sundman B., & Zhang J. (1994). A thermodynamic assessment of silica phase diagram. *Journal of Geophysical Research* 99(1), 787–11,794.
- Tanabe, M. (2019). Integrated learning time and STEAM education, From the perspective of enrichment of integrated inquiry time. Curriculum. Ministry of Education, Culture, Sports, Science and Technology. https://www.mext.go.jp/content/1421972_2.pdf
- Takebayashi, T. (2020). Expectations of increased activity of science communicators in Japan in the future, as expected from the state of museums discussed at ICOM Kyoto 2019 CECA. *Japanese Association of Science Communication*, 10 (1), 44-45.
- United States Congress (2015). To define STEM education to include computer science, and to support existing STEM education programs at the National Science Foundation., Pub. L. No. 114-59, 129 stat. 540 (2015). <https://www.congress.gov/114/plaws/publ59/PLAW-114publ59.pdf>
- United States Congress (2017). To invest in innovation through research and development, and to improve the competitiveness of the United States., Pub. L. No. 114-329, 130 stat 2969 (2017). <https://www.congress.gov/114/plaws/publ329/PLAW-114publ329.pdf>
- Webster, R., & Anderson, B. W. (1983). *Gems: Their sources, descriptions, and identification.* London: Butterworths. 1006p.

Acknowledgements

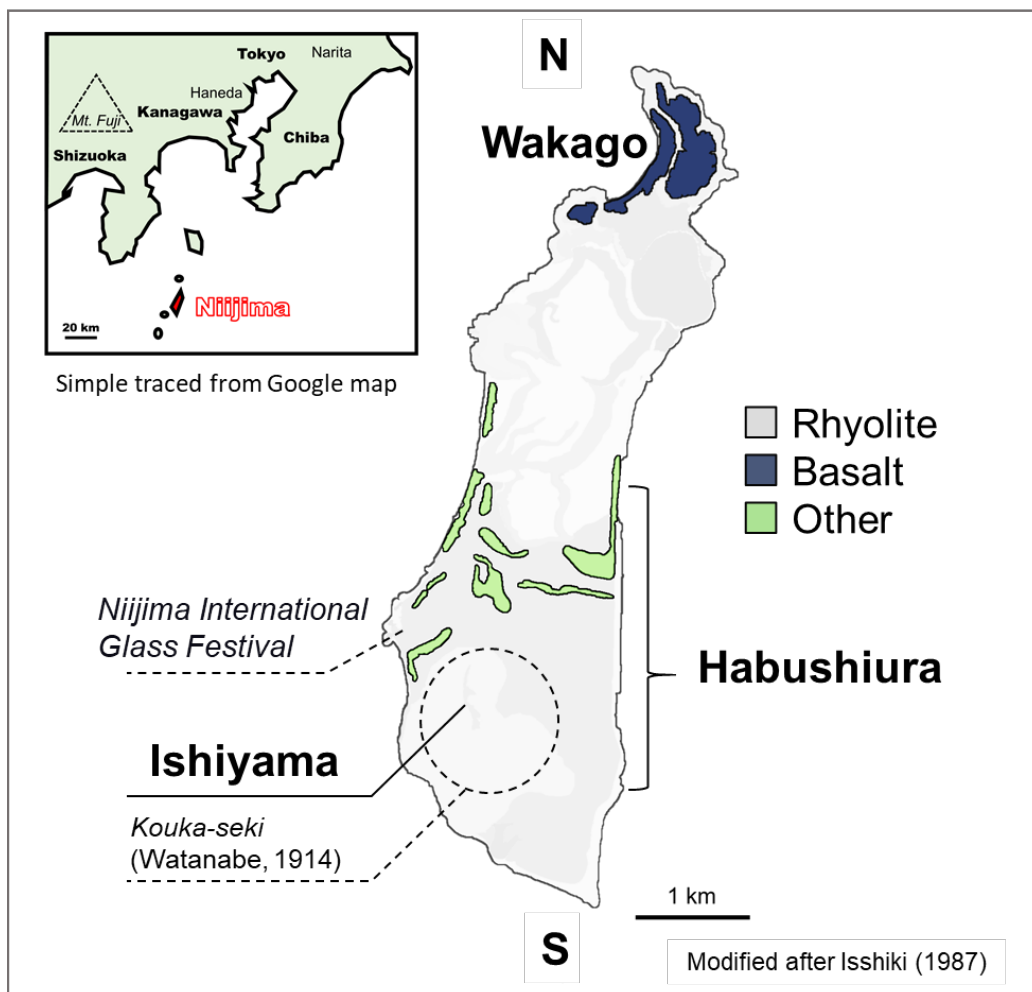
This study was completed with the help of many, including the following: Noda, O. (Director of the Niiijima Glass Center); Prof. Emeritus Enjoji M. (Waseda Univ.); Prof. Kawamoto, T. (Shizuoka Univ.) /Raman analysis equipment: Japan Society for the Promotion of Science (JSPS) KAKENHI Grant-in-Aid for Scientific Research (B) 16H04075; Dr. Ishikawa, M. (Shizuoka Univ., Hamamatsu Campus Instrument Center); Mr. Kato, R. (Shizuoka University); Mr. Sasak, H. (Shizuoka University); and Mr. Haruta, K. (Waseda University).

Appendix A

Location of Niiijima: Traced by the authors from Google Maps, based on a modification by Isshiki (1987). The rocks on Niiijima are grouped into rhyolite, basalt, and others (e.g., sedimentary). The island's Habushiura Beach, Wakago, Ishiyama, and villages are designated outside of the national park. The study was done outside of the national park boundary.

Figure A

The Location and geological map of Niiijima island. Locality map: Simple traced from Google map; Geological Map: Modified after Isshiki (1987).



Note: The area of Niiijima Island is 23.64 km²

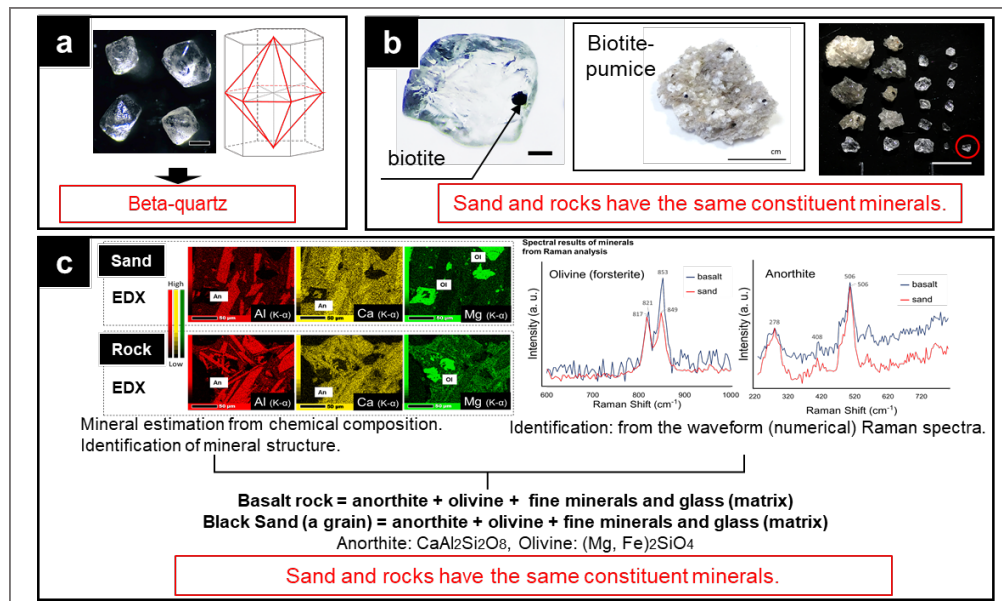
Appendix B

In the Habushiura area, almost all rock crystals have a grain size of around 500 μm , are colorless, transparent, and have no inclusion minerals. Several grains have a unique crystalline structure of β -quartz (high temperature [about 573°C at one atmosphere of pressure]), hexagon without columnar surface (Swamy et al., 1994) (Figure B [a]). In addition, a possible biotite mineral was identified on the surface of the particles (Figure B [b]). The rhyolites from the outcrop near the beach are pumice and coarse-grained rhyolite. The pumice is composed of biotite and clear quartz (grain). Around Ishiyama are biotite rhyolite (pumice), clastic (sedimentary rock with pre-existing mineral fragments), and rock crystal. The rock structure is composed of glassy asbestos and quartz and biotite exist as phenocrysts (large crystals). Many quartz particles similar to those found in the Habushiura area were found in the clastic material.

The black sand (single grain) and basalt in the Wakago area have very fine matrix minerals. Rock and sand were found to be very similar in mineral composition based on the distribution of chemical composition (EDX). Furthermore, their constituent minerals were numerically proven by Raman analysis to be of the same species (same wavelength) (Figure B [c]).

Figure B

Information about Sand Crystals Observed and Measured in the Study.



Note: (a) beta quartz and crystal system (scale bar = 1 mm); (b) Biotite on the surface of the quartz from Habushiura (scale bar = 0.01 mm), biotite pumice from near Ishiyama, and clastic rocks and quartz from Ishiyama (scale bar = 1 mm). (c) The information that can be obtained from the results of chemical composition mapping and Raman analysis. Data © 2020 by Tomohiro Takebayashi.