LEBANESE AMERICAN UNIVERSITY

Investigating the adoption of integrated STEM education within classrooms: A case study

By

Nour Adel El-Sayegh

A thesis
Submitted in partial fulfillment of the requirements
for the degree of Master of Arts in Education

School of Arts and Sciences
December 2018

LAU
الجامعة اللبنانية الأميركية
Lebanese American University

THESIS APPROVAL FORM

Student Name: Nour El Sayegh I.D. #: 201508423

Thesis Title: Investigating the Adoption of STEM Education within Classrooms: A Case Study

Program: Master of Arts in Education

Department: Education

School: Arts and Sciences

The undersigned certify that they have examined the final electronic copy of this thesis and approved it in Partial Fulfillment of the requirements for the degree of:

Master of Arts in the major of Education

Thesis Advisor's Name: Iman Osta

Signature: [redacted] Date: 19 / 12 / 2018
Day Month Year

Committee Member's Name: Hagop Yacoubian

Signature: [redacted] Date: 19 / 12 / 2018
Day Month Year

Committee Member's Name: Mahmoud Natout

Signature: [redacted] Date: 19 / 12 / 2018
Day Month Year

Committee Member's Name: Bassem Kandil

Signature: [redacted] Date: 19 / 12 / 2018
Day Month Year

LAU
الجامعة اللبنانية الأميركية
Lebanese American University

THESIS COPYRIGHT RELEASE FORM

LEBANESE AMERICAN UNIVERSITY NON-EXCLUSIVE DISTRIBUTION LICENSE

By signing and submitting this license, you (the author(s) or copyright owner) grants the Lebanese American University (LAU) the non-exclusive right to reproduce, translate (as defined below), and/or distribute your submission (including the abstract) worldwide in print and electronic formats and in any medium, including but not limited to audio or video. You agree that LAU may, without changing the content, translate the submission to any medium or format for the purpose of preservation. You also agree that LAU may keep more than one copy of this submission for purposes of security, backup and preservation. You represent that the submission is your original work, and that you have the right to grant the rights contained in this license. You also represent that your submission does not, to the best of your knowledge, infringe upon anyone's copyright. If the submission contains material for which you do not hold copyright, you represent that you have obtained the unrestricted permission of the copyright owner to grant LAU the rights required by this license, and that such third-party owned material is clearly identified and acknowledged within the text or content of the submission. IF THE SUBMISSION IS BASED UPON WORK THAT HAS BEEN SPONSORED OR SUPPORTED BY AN AGENCY OR ORGANIZATION OTHER THAN LAU, YOU REPRESENT THAT YOU HAVE FULFILLED ANY RIGHT OF REVIEW OR OTHER OBLIGATIONS REQUIRED BY SUCH CONTRACT OR AGREEMENT. LAU will clearly identify your name(s) as the author(s) or owner(s) of the submission, and will not make any alteration, other than as allowed by this license, to your submission.

Name: Nour Adel El-Sayegh, 201508423

Signature: [redacted]

Date: 19 / 12 / 2018
Day Month Year

الجامعة اللبنانية الأميركية
Lebanese American University

PLAGIARISM POLICY COMPLIANCE STATEMENT

I certify that:

1. I have read and understood LAU's Plagiarism Policy.
2. I understand that failure to comply with this Policy can lead to academic and disciplinary actions against me.
3. This work is substantially my own, and to the extent that any part of this work is not my own I have indicated that by acknowledging its sources.

Name: Nour Adel El-Sayegh, 201508423

Signature: [redacted]

Date: 19 / 12 / 2018
Day Month Year

Dedication

To my husband, who always supported me and stood next to me in every step of my journey. Without you, none of this would have been achieved. My loving parents, Jana and Sama, your unconditional love keeps me going. My dearest Amal, you supported me from the first day I moved to Beirut, thank you for being there for me. My precious jewel, my Lana, everything I do in life is for you. To my devoted family and in-laws, nothing in life can ever replace you.

Acknowledgement

This thesis would not have been achieved without the support of many people. Million thanks to my wonderful mentor, Dr. Iman Osta, who supported me in every step, kept on pushing me forward, encouraged me and offered guidance throughout my journey. Dr. Osta, your patience, encouragement and knowledge kept motivating me. I learned a lot from your immense experience, and I will be forever grateful. Special thanks to my committee members, Dr. Mahmoud Natout, Dr. Bassem Kandil and Dr. Hagop Yacoubian, who offered guidance and insightful suggestions.

And finally, I would like to express my deep gratitude to my husband, parents, sisters, family and numerous friends who endured this long process with me, always offering support and love.

Investigating the adoption of integrated STEM education within classrooms: A case study

Nour El-Sayegh

ABSTRACT

Education is facing, in the 21st century, various global challenges such as climate change and pollution. Solutions to these problems require the integration of science, technology, engineering and mathematics (STEM). Driven by the need to promote a society that is literate in these fields, STEM education is gaining more popularity. This case study investigated the implementation of integrated STEM education by homeroom teachers in elementary classes in an American-education private school in Beirut. Thirty homeroom teachers, three coordinators and the director of teacher professional development office participated in the study. Observations were carried out during the implementation of two instructional units in grade-3 and grade-4 classrooms. Ten semi-structured interviews were conducted with the director, coordinators, grade-3 teachers and grade-4 teachers. All homeroom teachers from the remaining grade levels were surveyed. The findings revealed that the most frequently used strategies among teachers are student-centered approaches and inquiry-based methods. Less use is made of project-based learning and model construction. Technology is used as both, a tool for teaching and learning and as a resource to find activities. Teachers reported various types of support that they get from the school administration for enhancing their technological and pedagogical content knowledge (TPACK), including collaboration, coaching, professional development opportunities and different types of resources. In addition, different external and internal barriers were identified. External barriers include lack of vision, lack of space, financial barriers, curricular issues, lack of support and time constraints. Internal barriers include personal challenges, insufficient technological and content knowledge and insufficient teacher understanding of STEM education. Although this study is limited to one elementary school, the identified themes may be useful for other schools that intend to go into STEM, as it informs educators about the challenges they may face, so they may remedy the problems and barriers at the right time.

Keywords: *STEM Education; Elementary education; STEM teaching strategies; Teacher TPACK; Internal barriers; External barriers*

Table of Contents

Chapter **Page**

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Meaning
STEM	Science, Technology, Engineering and Mathematics
NGSS	Next Generation Science Standards
CCSSM	Common Core State Standards for Mathematics
CCSSI	Common Core State Standards Initiative

TPACK	Technological Pedagogical Content Knowledge
IB	International Baccalaureate
IB PYP	International Baccalaureate Primary Years Program
PYP	Primary Years Program
POI	Program of Inquiry
CPP	College Preparatory Program
ERC	Education Resource Centre
COP	Community of Practice
PBL	Problem-based learning
PjBL	Project-based learning
RTOP	Reformed Teaching Observation Protocol
TDOP	Teaching Dimension Observation Protocol
HWOO(3)	the classroom observations of the How We Organize Ourselves unit in grade-3
HTWW(3)	the classroom observations of the How The World Works unit in grade-3
WWA(4)	the classroom observations of the Who We Are unit in grade-4
HTWW(4)	the classroom observations of the How The World Works unit in grade-4
HWOO(3)L	the lab observations of the How We Organize Ourselves unit in grade-3
HTWW(3)L	the lab observations of the How The World Works unit in grade-3
HTWW(4)L	the lab observations of the How The World Works unit in grade-4
MSC	Math and Science Content
CEM	Student Cognitive Engagement in Meaningful Instruction
IBL	Inquiry learning, PjBL and PBL
FA	Teacher Instruction/ Formative Assessment
CIF	Common Instructional Framework
SE	Student Engagement
UOT	Use of Technology
MSC1	Math and science content information was accurate
MSC2	Teacher's presentation or clarification of mathematics or science content knowledge was clear
MSC3	Teacher used accurate and appropriate mathematics or science vocabulary
MSC4	Teacher/students emphasized meaningful relationships among different facts, skills, and concepts
MSC5	Student mistakes or misconceptions were clearly addressed (emphasis on correct content here)
MSC6	Teacher and students discussed key mathematical or science ideas and concepts in depth.
MSC7	Teacher connected information to previous knowledge.
MSC8	Appropriate connections were made to other areas of mathematics/science or to other disciplines.
MSC9	Appropriate connections were made to real-world contexts.

MSC10	Summary: Quality of Mathematics and Science Content
CEM1	Students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.
CEM2	Students were asked to explain or justify their thinking
CEM3	Students were given opportunities to summarize, synthesize, and generalize
CEM4	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena
CEM5	Students were asked to apply knowledge to a novel situation
CEM6	Students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena
CEM7	Summary: Quality of Student Cognitive Engagement in Meaningful Instruction
IBL1	Students were engaged in open-ended tasks or questions
IBL2	Students engaged in hands-on or real-life problem solving activities or a lab experiment
IBL3	Students developed their own questions and/or hypotheses to explore or test
IBL4	Students engaged in scientific inquiry process (tested hypotheses and made inferences)
IBL5	Students determined which problem-solving strategies to use
IBL6	Students had to present or explain results of project.
IBL7	Students worked on a project requiring creativity
IBL8	There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process
IBL9	There was an explicit evidence of students using engineering (or reverse engineering) design process
IBL10	Summary: Quality of Inquiry learning; Project-based learning; and Problem-based instruction
FA1	Teacher provided clear learning goals to students
FA2	Teacher provided clear criteria for success/examples of good work to students
FA3	Teacher used a variety of strategies to monitor student learning and understanding throughout the lesson
FA4	Teacher provided specific feedback to students.
FA5	Students were engaged in self- and/or peer-assessment.
FA6	Teacher adjusted or differentiated instruction based on evidence of student learning.
FA7	Students were given opportunities to reflect on their own learning.
FA8	Summary: Quality of Teacher Instruction/ Formative Assessment
CIF1	Students worked collaboratively in teams or groups
CIF2	Students used writing to communicate what they had learned

CIF3	Teachers asked open-ended questions that required higher level thinking.
CIF4	Teachers provided assistance/scaffolding when students struggled
CIF5	Students engaged in discussion with each other
CIF6	Summary: Overall rating of Quality of Common Instructional Framework implementation
SE1	Students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions).
SE2	The time in class was spent productively on meaningful tasks
SE3	Teacher pursued the active engagement of all students.
SE4	Students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem).
SE5	Students showed perseverance when solving math/science problems.
SE6	Summary: Student Engagement
UOT1	Technology was used to a high extent (as a proportion of time of the lesson and intensity of use)
UOT2	Students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding
UOT3	Students used technology to generate or manipulate one or more representations of a given concept or idea.
UOT4	Students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective).
UOT5	Students used technology to practice skills or reinforce knowledge.
UOT6	Technology was used but did not appear to provide any added benefit
UOT7	Teacher used technology to achieve instructional goals. (Emphasis on the "teacher" here)
UOT8	Summary: Use of technology
R2A	Which of these approaches do you adopt in your classroom? (questionnaire item)
R2A-PjBL	Project-based learning (questionnaire item)
R2A-PBL	Problem-based learning (questionnaire item)
R2A-M	Building models (questionnaire item)
R2A-T	Technology integration (questionnaire item)
R2A-H	Hands-on activities (questionnaire item)
R2A-Q	Open-ended questioning (questionnaire item)
R2A-D	Discussions (questionnaire item)
R2A-RW	Connections to real-world contexts (questionnaire item)
R2A-G	Group work (questionnaire item)
R2A-P	Student presentations (questionnaire item)
R2A-L	Lecturing (questionnaire item)
R2Tech	How do you use technology (questionnaire item)
R2Tech-R	I use technology as a resource to find ideas and activities (questionnaire item)

R2Tech-H	I use technology at home to prepare my lessons (questionnaire item)
R2Tech-T	I use technology as a tool for teaching in class (questionnaire item)
R2Tech-C	I use technology for coding, programming and other activities (questionnaire item)
R2S	Which of the following do you adopt with your students (questionnaire item)
R2S-QH	I encourage students to develop their own questions and/ or hypothesis (questionnaire item)
R2S-R	I ask students to research a topic (questionnaire item)
R2S-O	I request students to make observations (questionnaire item)
R2S-D	I request students to record data (questionnaire item)
R2S-I	I ask students to interpret the results of their exploration (questionnaire item)
R2S-P	I ask students to define a problem (questionnaire item)
R2S-C	I allow students to think of the criteria of a solution (questionnaire item)
R2S-B	I ask students to brainstorm their ideas (questionnaire item)
R2S-S	I ask students to draw sketches or diagrams to visualize the solution (questionnaire item)
R2S-G	I ask students to generate multiple potential solutions (questionnaire item)
R2S-RD	I request students to redesign their model (questionnaire item)
R2S-SP	I encourage students not to give up when solving a problem (questionnaire item)
R2S-OC	I provide students with occasions to critique others’ reasoning (questionnaire item)
R2S-A	I allow students to reason abstractly (questionnaire item)
R2S-Pat	I ask students to look for patterns (questionnaire item)
R2S-Pre	I encourage students to attend to precision (questionnaire item)
R2S-Con	I ask students to construct viable arguments (questionnaire item)
R2S-Mod	I encourage students to model with math (e.g. write an equation to describe a situation) (questionnaire item)
R3R	What kind of resources are provided by the school that influence your content knowledge, teaching practices and/ or technology integration? (questionnaire item)
R3R-Lib	School library (questionnaire item)
R3R-Text	Textbooks (questionnaire item)
R3R-New	Magazines/ newspapers (questionnaire item)
R3R-Onli	Online web resources (e.g. YouTube videos, GoogleDocs, Phet simulations, Padlet, Story jumper, etc.) (questionnaire item)
R3R-Tuto	Tutorials (questionnaire item)
R3R-Coor	Coordinator’s assistance (questionnaire item)
R3B	What are the barriers that interfere with the implementation of STEM education at the school? (questionnaire item)
R3B-CK	Limited content knowledge in science/ technology/ engineering or

	mathematics (questionnaire item)
R3B-SCA	Limited familiarity with the student-centered approaches (e.g. problem-based learning, inquiry learning, project-based learning, etc.) (questionnaire item)
R3B-Mot	Lack of motivation to learn and adopt new approaches (questionnaire item)
R3B-Tech	Limited technology resources available at the school (questionnaire item)
R3B-Str	Poor facility structure (e.g. small classroom sizes, poor lab conditions, etc.) (questionnaire item)
R3B-Time	Time constraints (questionnaire item)
R3B-Curr	Need to finish the curriculum (questionnaire item)
R3B-Res	Limited materials and physical resources (e.g. material kits) (questionnaire item)
R3B-PD	Insufficient professional development opportunities (questionnaire item)
R3B-Coll	Limited collaboration (questionnaire item)
R3B-Meet	Insufficient faculty and staff meetings to discuss issues and solutions related to STEM education (questionnaire item)

Chapter 1

Introduction

Various global challenges are present in the 21st century, such as climate change, health issues, lack of water and energy sources, pollution, agricultural production, resource management and biodiversity. Solutions to the global problems require the integration of the scientific, technological, engineering and mathematical concepts. Therefore, experts in the field of science, technology, engineering and mathematics (STEM) are needed in the workforce. Driven by the need to promote a society literate in the aforementioned fields, STEM education is gaining popularity in the 21st century. Hence, many educators and schools aim to promote students' interest in the STEM fields, and to enhance students' understanding and ability to apply concepts from the four disciplines. However, much ambiguity still remains concerning integrated STEM education and how it is effectively implemented in schools.

As integrated STEM education removes the barriers between the four STEM disciplines and emphasizes innovation, many attempts have been made to enhance integration of STEM education in schools. First, in the USA, certain reforms such as the Next Generation Science Standards (NGSS) and Common Core State Standards for Mathematics (CCSSM) advocate for integrating STEM content and practices by allowing students to develop deep connections among STEM domains (Guzey, Moore, & Harwell, 2016; Kelley & Knowles, 2016). Although there are attempts to promote STEM education, Hacker criticized the movement of STEM education and described STEM as a myth, which serves the needs of technological industries (as cited in Apple, 2017). Hence, educators are urged to prepare their students with the essential skills needed to succeed in the field of technology and engineering.

Second, many researchers (Corlu, Capraro, & Capraro, 2014; Kelley & Knowles, 2016; Wells, 2016) developed models for integrated STEM education that educators may adopt in the classrooms. Corlu et al. (2014) developed a STEM education model that focuses on integrating mathematics and science in the classroom, emphasizing the role of the teacher as a facilitator. Kelley and Knowles (2016) developed a conceptual framework for integrated STEM education that reflects an interrelated system between the skills and abilities (i.e. engineering design, mathematical thinking, technological literacy and scientific inquiry) from the STEM disciplines. Wells (2016) developed the PIRPOSAL model that emphasizes teaching mathematical and scientific concepts through engaging students in “technological and engineering design-based learning” (p. 12).

Moreover, several researchers (Capobianco & Rupp, 2014; Slavit, Nelson, & Lesseig, 2016) investigated different strategies that teachers may use to implement integrated STEM education in the schools. Capobianco and Rupp (2014) investigated the process of planning and implementing engineering design-based instruction by fifth- and sixth-grade STEM teachers from six schools, while, Slavit et al. (2016) examined the collective work of teachers in a STEM-focused school where they implemented project-based learning instruction.

Despite the attempts to enhance implementation of integrated STEM education in schools, one may not find a unified strategy or specific procedures to implement integrated STEM education. As different strategies were examined in the literature, teachers adopt diverse strategies in their classrooms to implement integrated STEM education, most of which have strengths and pitfalls.

1.1 Context and statement of the problem

In Lebanon, the educational system is structured in two phases, basic education and secondary education. Basic education is divided into two levels: Elementary level and intermediate level. The elementary level is split into two cycles; the first cycle includes grades 1, 2 and 3, and the second cycle includes grades 4, 5 and 6. In some schools that follow non-Lebanese programs, the elementary level includes five grade levels, and grade-6 is included in the intermediate level. The intermediate level consists of grades 7, 8 and 9. Secondary education includes grades 10, 11 and 12. In addition, students are expected to sit for official national exams by the end of grade 9 to obtain the Brevet certificate and by the end of grade 12 to obtain the "General Secondary Education" certificate.

Two types of schools are found in Lebanon, which are the public schools and the private schools. The public schools are managed by the Ministry of Education, whereas the private schools are managed by associations or individuals. While the implementation of the national curriculum is mandatory in public schools, the private schools may implement other programs, such as the American, French, International Baccalaureate (IB) or German programs. As STEM education is relatively new in Lebanon, it is observed that STEM education is present at different levels for some of those programs and schools. While some schools may be unaware of the meaning of STEM education, others may be implicitly or explicitly implementing STEM education. Hence, it is important to conduct formal systematic research to draw an informed picture on the status of STEM education implementation in a school in Lebanon. The current study will gather and present information about the implementation of integrated STEM education within the elementary grade levels in a specific private school in Beirut.

1.2 Purpose of the study

As diverse strategies that reflect integrated STEM education exist, and since limited, if not no research investigated the implementation of integrated STEM education within classes in Lebanon, the study aims to investigate the implementation of integrated STEM education by homeroom teachers in elementary classes in a private school in Beirut.

1.3 Research questions

The following research questions will guide the study:

1. What are teachers' and administrators' perceptions and beliefs about integrated STEM education and relevant strategies?
2. What are the strategies that homeroom teachers use within the elementary classes that reflect integrated STEM education?
3. What kind of support do homeroom teachers get to develop their technological pedagogical content knowledge (TPACK) for properly implementing STEM education?
4. What are the challenges and barriers that hinder proper implementation of integrated STEM education within elementary classes?

1.4 Definition of terms

With respect to the research questions, two terms need to be defined, which are *integrated STEM education, technological pedagogical content knowledge (TPACK)* and *perceptions and beliefs*.

1.4.1 Definition of integrated STEM education

Researchers have provided several definitions of integrated STEM education. A unified definition of integrated STEM education is thus debatable, and no clear consensus in the literature is found. Sanders (2009) defined integrated STEM education as “approaches that explore teaching and learning between/ among any two or more of the STEM subject areas, and/ or between a STEM subject and one or more other school subjects” (p. 21). Brown, Brown, Reardon and Merrill (2011) defined STEM education as a “standards-based, meta-discipline reading at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but address and treated as one dynamic, fluid study” (p. 6).

Honey, Pearson and Schweingruber (2014) provided a broad definition of integrated STEM education and described it as “working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines” (p. 52). Moore, Matins, Guzey, Glancy and Siverling (2014) provided a different definition of integrated STEM education. They defined integrated STEM education as “an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (Moore et al., 2014, p. 38).

Furthermore, Kelley and Knowles (2016) defined integrated STEM education as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p. 3). Moreover, Wells (2016) proposed a definition of integrated STEM education which is an "application of engineering design-based learning approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education" (p. 12).

While some definitions (Brown et al., 2011; Moore et al., 2014; Sanders, 2009) included integration and connection between at least two STEM subjects, others (Honey et al, 2014; Moore et al, 2014; Kelley & Knowles, 2016) added the component of context as essential to the learning process. Honey et al. (2014) and Moore et al. (2014) emphasized teaching the content of one STEM subject using contexts from other STEM disciplines. While Moore et al. (2014) focused on teaching the content using real world problems, Kelley and Knowles (2016) emphasized the authenticity of the context and viewed STEM teaching as an approach. Thus, the STEM subjects are not considered as disciplines, but as an interrelated system between skills and abilities from the STEM subjects. However, teaching STEM content within an authentic context may not be possible in all circumstances, thus limiting the proposed approach by Kelley and Knowles. All definitions except for the one proposed by Wells (2016) missed the component of designing solutions. Wells (2016) noted the application of engineering-design based approaches through working on projects, using technological tools and designing solutions.

Considering the various definitions proposed by different researchers, the definition that will be adopted in the study will be a combination of the different definitions. Therefore, in this study, integrated STEM education is defined as an approach to teaching that integrates at least two STEM disciplines bound by STEM practices within an authentic context and/ or real-world problems, and provides the students the opportunity to apply engineering-design based approaches to find and test solutions.

1.4.2 Definition of technological pedagogical content knowledge (TPACK)

TPACK, an emerging form of knowledge proposed by Mishra and Koehler (2006), goes beyond the content, pedagogical and technological knowledge, and is central for effective teaching with technology. Teachers with strong TPACK understand the representations of concepts using technology; the pedagogical strategies that utilize technology to teach specific content; the approaches, procedures and technologies that facilitate students' understanding of difficult concepts; and ways of using technology to build on students' prior knowledge and develop new epistemologies (Mishra & Koehler, 2006). Application of technology is influenced by each learning context, and one may not assume that a single technological solution is applicable to all situations. Hence, educators need to consider technology integration in teaching vis-a-vis pedagogy and content knowledge as these components are in a "state of dynamic equilibrium" (Mishra & Koehler, 2006, p. 1029); a change in one of the components influences the other two.

1.4.3 Definition of perception and beliefs

Perception is defined as “the way in which something is regarded, understood or interpreted” (Perception, 2018), whereas beliefs is defined as “something one accepts as true or real; a firmly held opinion” (Belief, 2018).

1.5 Rationale and significance of the study

Various international researchers have studied the implementation of integrated STEM education in schools and within the classrooms. Concerning the Lebanese context, the researcher searched in the databases of the Lebanese American University (LAU), American University of Beirut (AUB), Balamand University, Lebanese University, Université Saint Joseph (USJ) and Shamaa to identify Lebanese studies related to STEM education. Keywords including “STEM education”, “Integrated STEM education”, “Science, Technology, Engineering and Mathematics”, “SMET” and “Implementing STEM” were used. However, no research was found about the topic in Lebanese settings that the current study aims to investigate. Since STEM education is gaining popularity worldwide, and the educational system in Lebanon is different from the systems in other countries, this study will contribute to the literature on the topic.

Moreover, in Lebanon, STEM education is relatively new and the implementation of integrated STEM education may be present at different levels and various scopes in schools. Some schools may not explicitly include STEM education in their vision, mission, goals or strategic plan. The teachers, on the contrary, may adopt STEM education in their pedagogical approaches. Other schools may include STEM education as part of their vision, mission and goals, yet others may not be aware of the meaning of integrated STEM education or its approach in teaching and learning.

Therefore, there is a need to understand the way STEM education is implemented in a school in Lebanon. This case study attempts to provide insight about the topic in an elementary school in Lebanon whose administration is aware of the STEM approach to teaching and learning and explicitly applies it.

Moreover, the study needs to be conducted because practitioners and researchers need to be aware of the different strategies that reflect integrated STEM education, that are used currently in the classrooms in a school in Lebanon. Educators need to be aware of the support that teachers get to promote their TPACK and the barriers that hinder the implementation of STEM education. Consequently, the educators may anticipate the challenges if integrated STEM education will be applied in another school in Lebanon. In addition, the study will help principals and administrators to devise plans to support teachers and remedy the barriers that are faced in implementing STEM education. Hence, the results of the study will provide educators and researchers with in-depth description about the implementation of integrated STEM education within a specific school in Lebanon.

Finally, educators and schools worldwide are interested in promoting STEM literate youth that are able to compete in the workforce. Brown (2012) conducted a meta-analysis regarding the current status of STEM education research. He noted that further research is needed in descriptive classroom applications for practitioners to determine STEM education initiatives in the classrooms, and understand teacher reflections of STEM teaching and learning. Hence, the study will provide a descriptive interpretation of the way STEM is adopted in a school in Lebanon, which adds to the cultural and contextual aspects of the research. The context of the study, being conducted in a school that follows the IB PYP, is unique as researchers (Lamberg & Trzynadlowski, 2015; Tseng, Chang, Lou, & Chen, 2013; Stohlmann, Moore and Roehrig, 201) haven't highlighted the adoption or implementation of STEM education within that program, especially because the PYP's vision reflects several aspects of STEM education. For example, Stohlmann, et al., (2012) studied the implementation of STEM education in a school that follows an integrated curriculum Project Lead The Way; Lamberg and Trzynadlowski, 2015 conducted their study in STEM-focused schools which follow a STEM program. Having this study conducted in a school that follows the IB PYP will offer a different perspective on the adoption of STEM education. In this way, the study will contribute to the global literature in the field.

1.6 School context

The participating school is a private co-educational school in Beirut, and it caters for students with high socio-economic status. The school supports the preschool (KG 1 to 3), elementary (grades 1 to 5), middle (grades 6 to 9) and secondary (grades 10 to 12) levels of education. It offers five different programs: International Baccalaureate Primary Years Program (IB PYP), International Baccalaureate (IB), Lebanese, French and College Preparatory Program (CPP). The IB PYP is offered at the preschool and elementary levels, while the remaining four programs are offered at the middle and secondary levels. The study will take place in the elementary school, which serves as the foundation for subsequent levels.

The school's vision is "to inspire learners of today to be global citizen leaders of tomorrow", and its mission is to "educate young men and women to be capable of initiative and critical thinking, who will serve as role models in a global society…Graduates of [the school] will have developed self-discipline, problem-solving abilities, social responsibility, self-confidence, and awareness of, and respect for, the interdependence of nations in all their diversity". The school's objective is to provide a secure environment for students to develop their skills and abilities at the academic, social, physical and ethical levels. The school aims to "develop students' personal qualities and skills leading to international mindedness, intellectual curiosity, effective communication, creative expression, compassion, community building and responsible citizenship". At the academic level, the school aims to "develop individual potential and an attitude of life-long learning". At the ethical level, the school aims to "promote values of integrity, service and respect for individual differences and for the environment". At the social level, the school aims to "develop civic and global awareness, leadership, team spirit, and a commitment to social justice". At the physical level, the school aims to "promote physical education and athletics program that values sportsmanship and healthy living".

More specifically, the elementary school aims to "provide a safe, welcoming environment that fosters a love of learning through a student focused, inquiry based approach to teaching and learning. Learning focuses on connecting the various disciplines". The school aims to teach students through:

"questioning, inquiring, exploring and doing. The teacher acts as a guide/facilitator to help students discover and understand concepts, principles and generalizations. The ultimate goal of education at the Elementary School is to help children become internationally minded individuals who are compassionate, caring, empathetic, responsible, and knowledgeable. The aim is to develop risk-takers, children with life-long learning skills like critical thinking and problem solving. Self-awareness is promoted through questioning, exploring, reflecting and self-assessment."

Although STEM education is not indicated in the vision, mission or objectives, different STEM education aspects are reflected. In STEM education, students construct their own knowledge through various approaches, including inquiry-based learning, problem- and project-based learning, while the teacher acts as a facilitator. In addition, STEM education aims to remove the barriers between the disciplines and to promote the students' 21st century skills, which include critical thinking, communication, collaboration, creativity, problem solving, etc. In the school's document, these STEM aspects incorporate global leadership, international mindedness, inquiry-based learning, critical thinking, creativity, lifelong learning, problem solving, questioning, exploring, doing, connection between disciplines, reflecting, self-assessment and facilitation.

1.7 Description of the IB PYP

As mentioned earlier, the participating elementary school follows the IB PYP program, which aims to develop internationally minded lifelong learners who participate actively in their learning process. The students are expected to be accountable for their own learning and explore national and global issues in real-life contexts. The IB learners are expected to be: "inquirers, knowledgeable, thinkers, communicators, principled, open-minded, caring, risk-takers, balanced and reflective" (International Baccalaureate Organization [IBO], 2012, p. 3).

Schools adopting the IB PYP follow the *PYP Program of Inquiry (POI)*. The standard framework of the *PYP POI* incorporates six themes: "Who we are, where we are in place and time, how we express ourselves, how the world works, how we organize ourselves, and sharing the planet" (IBO, 2012, p. 3). These themes are organized into units of inquiry, which include: "Central idea, key concepts, related concepts and lines of inquiry" (IBO, 2012, p. 4).

Moreover, the students are expected to develop and nurture their social skills (e.g. responsibility, respect, conflict resolution, etc.), communication skills (e.g. listening, presenting, writing, etc.), thinking skills (e.g. analysis, synthesis, evaluation, etc.), research skills (e.g. questioning, observing, collecting data, etc.) and self-management skills (e.g. organization, time management, informed choices, etc.) as they learn (IBO, 2012). This set of skills reflect the 21st century skills, which need to be developed among students to prepare them for their adult roles and to meet future challenges (Pellegrino & Hilton, 2013). In addition, STEM education fosters the development of 21st century skills through its different characteristics such as tinkering, problem-solving, hands-on activities, integration of disciplines, collaboration, etc. Morrison (2006) emphasized that STEM education develops students who are problem solvers, inventors, innovators, logical thinkers, self-reliant and technologically literate.

1.8 Description of the IB PYP as implemented in the school

All of the IB PYP criteria discussed above are included in the school's document, including the IB learner profile, the standard framework of the *PYP POI,* the unit of inquiry and the set of skills that need to be developed. Although the *PYP POI* has a standard framework, it can be adapted to meet the school's needs. Thus, the *PYP POI* is adapted and developed by the PYP coordinator and the homeroom teachers at the participating school. For instance, in the unit of inquiry for grade-3, "how the world works”, the central idea that is developed by the coordinators and the homeroom teachers is “exploring light allows people to use it to meet their interest and needs”. The key concepts include “function, causation and form”, the related concepts include “forms of energy, consequences and behavior”, the subject area is “sciences (materials and matter)”, the lines of inquiry include “different sources of light; the uses of light to meet people’s needs; exploring the different behaviors of light”.

The content areas, including mathematics, science, technology, social studies and language are covered in the aforementioned six transdisciplinary themes. The school’s curriculum is a transdisciplinary curriculum, which integrates the individual disciplines together, while preserving the essence of each subject. Hence, mathematics, science, technology, social studies and language are taught by homeroom teachers.

Regarding mathematics, students move through the concrete, pictorial and abstract stages to learn new concepts, and they gain the mathematical skills and literacy as they make connections across concepts and processes. The processes that are emphasized include problem solving, connections, reasoning, communication and representation. Concerning science, students engage in scientific practices as they collect, observe, measure, record and present data. In addition, students explore the scientific concepts and processes through relating them to real-world issues. Regarding technology, students are expected to acquire technological literacy; they need to learn and use different forms of technologies and apply them in their daily lives. Therefore, the transdisciplinary nature of the *PYP POI* removes the traditional barriers among the different disciplines, and STEM education is reflected in the different disciplinary practices; the students need to develop mathematical reasoning, engage in scientific inquiry and develop technological literacy.

Chapter 2

Literature Review

In this section, the literature pertaining to the implementation of integrated STEM education in schools and within classrooms is reviewed. The purpose of the literature review is to provide a knowledge base for the current study, highlight the strengths and weaknesses of existing research, and serve as a point of reference when discussing the findings of this study (Merriam, 2009). As mentioned in the Introduction, the researcher searched various databases of Lebanese universities about the topic, and found that Lebanese studies on implementation of integrated STEM education in the classrooms are lacking. Therefore, Western literature is reviewed. This section is divided into seven sections: Approaches for STEM integration, conceptual framework for integrated STEM education, strategies for STEM education, types of support for STEM education, internal barriers to STEM education, external barriers to STEM education and conclusion.

Educators are aiming to promote implementation of STEM education in schools. STEM education requires the integration of science, technology, engineering and mathematics whereby the traditional barriers between the four disciplines are removed. Hence, educators need to promote students' understanding and ability to apply concepts from the four disciplines through engaging students in active learning, hands-on applications and problem-solving (Nadelson et al., 2013).

2.1 Approaches for STEM integration

Research was conducted about the implementation of integrated STEM education in schools. As a unified definition is debatable, much ambiguity still remains concerning the meaning of integrated STEM education and the way it is implemented in schools. Since STEM education requires integration of disciplines, some researchers (Hurley, 2001; Bybee, 2013) suggested certain approaches for integration. According to Hurley (2001), integration of mathematics and science can occur using five approaches: Sequenced (mathematics and science are taught sequentially), parallel (mathematics and science are taught simultaneously), partial (mathematics and science are taught partially together), enhanced (one of the disciplines is taught as the major discipline, while the other one is used to support the teaching of the major discipline), and total (both disciplines are taught together as major disciplines with equal importance).

While Hurley (2001) focused on integrating science and mathematics, Bybee (2013) incorporated technology and engineering design as part of the integration. According to Bybee (2013), STEM education may be integrated using any of the following approaches: (a) science is taught as the dominant discipline and mathematics, technology or engineering are included to support teaching science; (b) mathematics and science are taught separately, but are connected by an engineering or technology program; (c) two or more disciplines are combined to produce a new course, where the integrated disciplines have equal importance; (d) mathematics and science are taught sequentially (one discipline precedes the other) and technology and engineering are integrated throughout the math and science lessons; (e) the disciplines are taught in a trans-disciplinary approach, where the STEM disciplines are utilized to understand and resolve a contemporary challenge.

Hurley (2001) and Bybee (2013) noted that there is not a single best approach, yet the educators who adopt any of the approaches need to make the integration explicit to students. Students need to understand the way they are using and applying their knowledge in STEM contexts.

2.2 Conceptual framework for integrated STEM education

According to Kelley and Knowles (2016), integrated STEM education requires teaching and connecting STEM content to at least two STEM disciplines within an authentic context. Making crosscutting connections among STEM disciplines is at the core of a well-integrated STEM education that will promote student learning. However, over the past decades, teachers seemed to struggle in connecting STEM disciplines in an integrated manner, thus the subjects were taught as isolated disciplines. As a result, students are unable to apply their knowledge in authentic and integrated contexts. Therefore, researchers proposed a conceptual framework that seeks to tackle the limitations of current integrated practices. The framework is grounded in learning theories and STEM education pedagogies which will guide educators and provide a clear picture of a well-integrated STEM education.

As shown in Figure 1, the proposed framework comprises of six components: Situated STEM learning, engineering design, mathematical thinking, scientific inquiry, technological literacy and community of practice. Kelly and Knowles (2016) illustrated the framework as an integrated system of block and tackle of four pulleys (engineering design, mathematical thinking, technological literacy, scientific inquiry) that lifts a load (situated STEM learning). The pulleys of the system are connected by a rope (community of practice). Each component of the framework will be discussed in detail below.

Figure 1. Figure 1. Graphic of conceptual framework for STEM learning. Reprinted from "A conceptual framework for integrated STEM education," by T. R. Kelley and J. G. Knowles, 2016, International Journal of STEM Education, 3, p. 4. Copyright 2016 by the Creative Commons. Reprinted with permission.

2.2.1 Situated STEM learning

Situated STEM learning is based on the *situated cognition theory*, which emphasizes the importance of physical and social contexts of any learning activity. Papert believes that knowledge is situated and learners should be immersed in the situations and be connected to their environment to gain understanding (as cited in Ackermann, 2001). When students learn new knowledge and skills, they need to know how to apply them. It is not enough to develop the needed knowledge base; learning should be grounded in a situated context to make the learning experience authentic and relevant to the student’s real-life. Therefore, when teachers engage students in authentic learning, the experience is representative of real-life STEM practices.

2.2.2 Engineering design

Kelley and Knowles (2016) described engineering design as the key to subject integration. Engineering design provides students with an authentic context to connect the disciplines as they engage in the design process. Students will be able to apply the engineering practices and use science inquiry and mathematics to conduct experiments regarding the function of the prototype/ model/ potential design. While working on solutions for practical problems, students will be able to construct their own learning and build on their prior knowledge through applying their scientific knowledge and mathematical concepts and skills. Besides, when mathematical reasoning and analysis are incorporated within design solutions, students will be able to connect math concepts together and understand the relevance of math in real-life problems.

More specifically, engineering design consists of eight phases of engagement that the student encounters when s/he faces an engineering challenge and attempts to resolve the problem. These phases include: *Problem identification, ideation, research, potential solutions, optimization, solution evaluation, alterations and learned outcomes.* At each phase, the students are driven by their need to know and ask questions (Wells, 2016).

Students are encouraged to *identify the problem* through questioning about a social/ human need that needs to be met, defining the problem and formulating a problem statement. Then, the students will brainstorm different *ideas* among each other to discuss possible design solutions. As students brainstorm, they need to think of the criteria (i.e. principles that evaluate performance of something), parameters (i.e. limitations imposed by context) and constraints (i.e. limitations beyond the control of the designer and hinder the design process). Afterwards, the students will *research* about the problem and solutions to explore the topic further, and examine in-depth the science, engineering, mathematics and technology components of the solution.

Then, the students will analyze the different solutions and draw sketches, representations or diagrams in order to visualize the alternative solutions. Afterwards, they will select the most plausible solutions based on their analyses. After agreeing on the *potential solutions*, the students will need to *optimize* their potential designs through experimenting the how well the components function within the selected potential designs, revisiting their designs and beginning constructing a prototype/ model.

Afterwards, students will test the constructed model, analyze the data and interpret the results to *evaluate the solution*. If the students identified issues in the prototype/ model, they will make *alterations,* redesign and retest. By the end of the design process, the students will communicate and discuss their findings and the iterations of their designs to clarify their *learned outcomes*.

2.2.3 Scientific inquiry

The key to genuine understanding of the science concepts is application of scientific knowledge. Scientific inquiry allows students to think and act like scientists, and provides the opportunity to apply the knowledge by conducting scientific investigations. The students are encouraged to hypothesize, ask questions, be curious, and be open to new ideas and skepticism; they are engaged in the scientific practices rather than merely learning about the science content.

When students engage in scientific inquiry, they need to observe a certain phenomenon, define the problem, formulate a question or hypothesis, research, articulate the expectations, carry out investigations, interpret the results of their investigations, reflect on the findings and communicate their findings (Kelley & Knowles, 2016; Wells, 2016).

Questioning is an essential driver in scientific inquiry. Teachers need to stimulate students' prior knowledge, which serves as the initial building blocks for further questioning. In addition, the teachers should pose *what if* questions which require critical thinking on behalf of the students. Therefore, students will use their prior knowledge, synthesize the factual information that they already know and diverge their thinking to promote new understandings of new concepts (Kelley & Knowles, 2016; Wells, 2016). In order to effectively implement an inquiry-based approach, teachers need to be knowledgeable of the constructivist approaches, to enhance their pedagogical content knowledge and to experience authentic scientific investigations.

2.2.4 Technological literacy

Technological literacy is essential in STEM education, and teachers need not limit technological literacy to objects and artifacts. Many teachers use technology to facilitate student learning and instruction. However, it is essential to distinguish between using technology and developing technological literacy. Herschbach proposed two perspectives of technology: *Engineering perspective* and *humanities perspective* (as cited in Kelley & Knowles, 2016, p. 6).The *engineering perspective* views technology as using and making objects and artifacts, whereas the *humanities perspective* considers the human purpose of technology. Technology serves human needs and influences the economy, environment, society and culture. Thus, technology is more than merely tools or artifacts, and STEM educators need to be aware of the humanities aspect of technology.

In order to develop technological literate students, they need to engage in authentic problem solving that involves using technological tools. They need to know the appropriate type of technology to use for a certain task, the function of the technological tool, how the tool serves the purpose of the activity and when they can use the technological tool (Schmidt & Fulton, 2016). In this way, the students are thinking critically about technology.

2.2.5 Mathematical thinking

Students need to know how to think and reason mathematically rather than apply their procedural knowledge to solve formulas and equations without understanding the mathematical concept. For students to engage in mathematical thinking and to understand mathematics in-depth, they need to be given opportunities where they can make sense out of what they are doing. Kelley and Knowles (2016) emphasized that STEM education provides an appropriate context where students can engage in mathematical analysis. In STEM-related activities or tasks, students will be able to learn mathematics, apply the learned mathematical concepts and see their connections to real world problems.

According to the National Council of Teachers of Mathematics [NCTM] (2000) standards, mathematical thinking is promoted in a classroom that encourages students to explore mathematical concepts, make connections to prior knowledge and use different strategies to complete a given task. Students need develop their *own* understanding of mathematics.

Consequently, the Common Core State Standards Initiative [CCSSI] (2010) developed the Common Core State Standards for Mathematics which describes the practices that students should perform and achieve when studying mathematics.

First, students need to “make sense of the problem and persevere in solving them” (CCSSI, 2010, p. 6). Mathematically proficient students are able to explain the meaning of the problem, analyze the givens and information and make assumptions about the viable solutions. The students need to think logically and constantly ask themselves “Does this makes sense?” (CCSSI, 2010, p. 6). For instance, elementary students can use concrete objects or pictures to conceptualize and solve the problem.

Second, students need to “reason abstractly and quantitatively” (CCSSI, 2010, p. 6). They are able to decontextualize, which means to create abstractions and represent a given situation symbolically.

Third, students need to “construct viable arguments and critique the reasoning of others” (CCSSI, 2010, p. 6). Mathematically proficient students are able to understand and use their assumptions to construct arguments. They can analyze situations, use counter-examples, justify their conclusions and respond to others’ arguments.

Elementary students can formulate their arguments using concrete referents including objects, pictures, sketches, diagrams, etc.

Fourth, students need to “model with mathematics” (CCSSI, 2010, p. 7). Students are able to use mathematics to solve everyday problems. For instance, elementary students can write a simple equation (addition, subtraction, etc.) to describe a situation.

Fifth, students need to “use appropriate tools strategically” (CCSSI, 2010, p. 7). Students are able to use the available tools (e.g. pencil and paper, calculator, ruler, spreadsheet, etc.) to solve a problem and they can recognize the tools’ benefits and limitations. The students can also use the technological tools to understand the mathematical concepts in-depth.

Sixth, students need to “attend to precision” (CCSSI, 2010, p. 7). They are able to communicate their results and conclusions precisely to others. They can explain a certain concept in their own words, use clear definitions, communicate the meanings of the symbols they use, specify the units, write clear problem statements and calculate accurately.

Seventh, students need to “look for and make use of structure” (CCSSI, 2010, p. 8). They are able to identify a certain pattern or structure. For instance, they can notice that five and six more results in the same amount as six and five more.

Finally, students need to “look for and express regularity in repeated reasoning” (CCSSI, 2010, p. 8). They can recognize when the calculations are repeated and try to search for general methods or shortcuts to solve a given problem. They constantly evaluate the reasonableness of their procedure and intermediate results.

2.2.6 Community of practice

All the aforementioned components of the framework are connected with students' and educators' community of practice. Wenger, McDermott and Snyder (2002) have discussed the idea of communities of practice. People who form a community of practice share a common problem, issue or concern and interact together regularly in order to solve the issues at hand and "deepen their knowledge and expertise" (Wenger et al., 2002, p. 4). Communities of practice enable people to interact informally, share their wide range of expertise, contribute to the community and design solutions to problems (Wenger et al., 2002).

The community of practice considers the social aspect of learning and stems from the idea that knowledge is dynamic and social. People do not live in a vacuum, and knowledge constantly changes with new innovations and advances in the society. Hence, people learn best by interacting, thinking, working and collaborating together to deepen their knowledge and solve common issues (Wenger et al., 2002).

Communities of practice constitute three crucial elements: "domain of knowledge…community of people…and shared practice" (Wenger et al., 2002, p. 27). The domain of knowledge allows people to share a common identity and purpose. The community of people enables participants to interact, be accountable and base their relationships on respect and trust. The shared practice allows members to share ideas, solutions, tools, stories, expertise, materials, etc. (Wenger et al., 2002).

The community of practice provides opportunities for educators with diverse professional expertise to engage together and work on integrating STEM education in a comprehensive manner. It enables teachers coming from different fields to collaborate together, share their knowledge, find solutions to problems, implement solutions and assess them together. Teachers teaching different subjects and coming from a wide range of expertise are provided opportunities to work together and share their ideas. This form of interaction will allow them to learn from each other, promote their knowledge in different STEM subjects, create new teaching strategies, assess their effectiveness and compare their results to each other.

2.3 Perceptions and beliefs about STEM education

As mentioned previously, researchers (Brown et al., 2011; Honey et al., 2014; Kelley & Knowles, 2016; Moore et al., 2014; Pearson & Schweingruber, 2014; Sanders, 2009; Wells, 2016) have provided several definitions of integrated STEM education. A unified definition of integrated STEM education is thus debatable, and no clear consensus in the literature is found. Brown et al. indicated that there is a limited understanding of the meaning of STEM education in schools (as cited in Lamberg & Trzynadlowski, 2015). Lamberg and Trzynadlowski (2015) highlighted that the lack of a clear and unified definition of STEM education could be likely a reason for having diverse conceptualizations and approaches for applying STEM education. In their study, Lamberg and Trzynadlowski (2015) found that teachers do not share a common understanding of STEM education, indicating that they have different perceptions of the meaning of STEM. Many teachers indicated that STEM is equivalent to integration; some described that STEM content areas are integrated through reading; others defined the acronym “STEM” without providing a detailed description of its meaning and suitable teaching methods (Lamberg & Trzynadlowski, 2015).

Similarly, Shernoff, Sinha, Bressler and Ginsburg (2017) explored the challenges faced by teachers to develop or implement STEM curricula and instruction. Their findings revealed that one of the most frequent challenges is lack of understanding as many teachers expressed uncertainty in how to implement STEM.

Moreover, Roehrig, Park, Wang and Moore (2011) investigated teachers’ perceptions and beliefs of STEM education and how they are reflected through the classroom practices. The researchers found that teachers’ perceptions and beliefs influenced the way they delivered their lessons. For instance, one teacher thought that STEM education is equated to problem solving, and she believed that problem solving is essential for STEM, hence she focused on problem solving processes in her classroom. Another teacher perceived STEM as integration of disciplines with an emphasis on engineering design, and she believed that her students will benefit from integrated STEM. Thus, her classroom practices reflected applications of engineering design projects related to real life (Roehrig et al., 2011).

2.4 Strategies for STEM education

Many researchers (Corlu, Capraro, & Capraro, 2014; Ejiwale, 2013; Lamberg & Trzynadlowski, 2015; Stohlmann et al., 2012) investigated different strategies that teachers may adopt in their classrooms that enhance the implementation of integrated STEM education, which will be further discussed in detail.

2.4.1 Student-centered approaches

Student-centered approaches are one of the important strategies that aid in the implementation of STEM education in classrooms. Student-centered approaches allow students to construct their knowledge as they are actively involved in their learning process, and the teacher acts as a facilitator. In a student-centered environment, students become self-directed, utilize their higher order thinking skills and take responsibility for their own learning. In a school that was implementing integrated STEM education, Stohlmann et al. (2012) found that students worked together on presentations, designed machines, built race cars and participated in class discussions and developed their own ideas. Similarly, Ejiwale (2013) noted that teachers need to encourage students to engage in cooperative learning through working with peers and being accountable for the group work. Parker, Stylinski, Bonney, Schillaci and McAuliffe (2015) emphasized that student-centered teaching is essential for implementing STEM education. They found that the students were engaged in active learning and held accountable for their own learning, whereas the teachers encouraged deep thinking and student autonomy.

Discussions are essential in a student-centered classroom. As students are constructing their knowledge, they need to work together and share their opinions and knowledge. Gao and Schwartz (2015) reported that discussion sessions highly engages students as they are encouraged to research, work in teams, practice their inquiry skills, problem solving skills and communication skills, and teach their peers.

However, the student-centered approaches need to be situated in context and to integrate concepts from at least two disciplines to provide students with meaningful learning experiences. Hence, teachers need to use strategies that provide students with an authentic context to apply the concepts learned from the four disciplines. In the STEM education model, Corlu et al. (2014) argued that math and science are connected to real life and are dependent on one another in order to construct knowledge. Thus, teachers need not teach the two subjects as isolated disciplines. For instance, math teachers may use science as an application, adopt problem-solving teaching strategies and encourage students to engage in quantitative reasoning.

Hands-on activities are one way that allows students to apply their knowledge from multiple disciplines, which is important in STEM education. Students can act like scientists, engineers or mathematicians when they tinker, create and experiment actively. Lamberg and Trzynadlowski (2015) emphasized that students need to explore, research, calculate, create, engineer and engage in hands-on science and math activities. The researchers found that the teachers who constantly involved their students in hands-on activities had an engaging classroom. Students showed interest in learning, were eager to apply their knowledge and understood well the subject matter (Lamberg & Trzynadlowski, 2015). Similar results were reported by Gao and Schwartz (2015). They found that students enhanced their problem solving abilities, mathematical and quantitative skills and integrative abilities when engaged in hands-on activities.

Furthermore, engineering design challenges, problem-based learning (PBL) and project-based learning (PjBL) are different strategies that involve the students in hands-on activities and authentic learning. These strategies provide students the opportunity to work on ill-structured problems and real-life situations, thus enhancing the students' problem solving skills and learning experiences. Strimel (2014) indicated that STEM education should be authentic, and its authenticity lies in providing students the opportunity to work on real-world problems and relate their learning experiences to real-life issues. However, the real-world problems should not be the traditional well-structured problems whose solutions require specific steps and formulas. Instead, they need to be ill-structured, which include incomplete information and can be solved using different solutions (Strimel, 2014). Therefore, the students can use their higher order thinking skills as they are challenged to think of innovative solutions.

2.4.2 Engineering design challenges

STEM education can be implemented through using engineering design challenges as the context in the classroom. The students can learn the engineering design processes and apply their engineering practices when they participate in engineering design challenges. Guzey, Moore and Harwell (2016) noted that a STEM classroom should involve students in engineering design challenges. However, a well-implemented challenge should allow students to research, explore or develop the appropriate technologies to resolve the problem. In addition, the students need to consider the risks, safety, constraints and alternative solutions, and learn from their failure (Guzey et al., 2016). Lesseig, Nelson, Slavit and Seidel (2016) emphasized that design challenges increase student motivation and classroom engagement. Students were challenged to solve an ill-defined problem and challenges related to real life. Besides, they were determined to accomplish the task despite the uncertainty or failure that accompanied the task.

Furthermore, Capobianco and Rupp (2014) investigated the process of planning and implementing engineering design-based instruction by elementary STEM teachers. They found that the teachers planned well for engineering design based lessons and activities and incorporated suitable engineering practices. However, the classroom observations revealed lack of alignment between the planned and implemented engineering design-based instruction. The teachers concentrated on the introductory phases of the design process such as identifying the problem and planning, and dedicated a limited amount of time for other important engineering practices such as design testing, communicating results and re-designing (Capobianco & Rupp, 2014).

In addition, Roehrig, Moore, Wang and Park (2012) found that some STEM teachers started their unit with an engineering design challenge. The students designed, researched, considered different constraints (e.g. budget constraints), drew sketches, developed and tested prototype designs, and modified their designs. However, Roehrig et al. (2012) found that connections to mathematics and science were not made explicit as students were working on the engineering design challenges. There was limited integration of the scientific and mathematical concepts, and the teachers and students focused on the engineering aspect.

Furthermore, Guzey, Ring-Whalen, Harwell, and Peralta (2017) differentiated between *add on, explicit* and *implicit* engineering integration, with explicit integration being the most beneficial type as students make explicit connections to scientific concepts. When engineering design is used as *add on*, the students are involved in a culminating project where they solve the problem through trial and error instead of using a systematic problem solving approach based on scientific evidence. On the other hand, *explicit* integration allows students to learn science through engineering design. *Implicit* integration falls in between these two types as engineering is rarely made explicit in the science lessons and vice versa. However, this type of integration still focuses on learning engineering and science (Guzey et al., 2017). Moreover, Dare, Ellis, and Roehrig (2018) investigated science teachers' implementation of STEM curricular units in physical science classrooms. Their findings revealed that connections to mathematics and science were not made explicit as students were working on the engineering design challenges. There was limited integration of the scientific and mathematical concepts, and the teachers and students focused on the engineering aspect (Dare et al., 2018).

2.4.3 Project-based learning

As opposed to engineering design challenges, PjBL allows students to work on authentic and real-world problems or challenges, and does not require students to follow the engineering design phases rigidly (i.e. *Problem identification, ideation, research, potential solutions, optimization, solution evaluation, alterations and learned outcomes* (Wells, 2016)). In PjBL, students need to use concepts and apply practices, including the engineering design practices, from multiple disciplines to reach the end product (i.e. project) (Lesseig et al., 2016). PjBL requires utilization of several technological tools, inquiry, critical thinking, collaboration, group work, interactive discussions and practical activities (Lesseig et al., 2016; Tseng et al., 2013).

Roehrig et al. (2012) stated that some teachers choose to integrate two disciplines (science and engineering) through PjBL. The teachers assigned an engineering design project as an end product to a science unit. For instance, the students were asked to design a submarine that would sink and float as a project for the unit on chemical reactions. The students were expected to use their scientific knowledge about chemical reactions to achieve the changes in the density. Roehrig et al. (2012)

concluded that the teachers integrated well science and engineering, and the strategy brought a meaningful learning experience for the students.

Moreover, Tseng et al. (2013) adopted PjBL as a strategy to implement integrated STEM education. They found that PjBL resulted in positive outcomes concerning the four STEM disciplines and the students were motivated to learn. The students used science and mathematics to solve real-world problems and acquired a deeper scientific and mathematical knowledge through application and practical work. In addition, the PjBL strategy improved students' technological literacy as they identified the positive and negative impacts of technology on society, health, economy and environment (Tseng et al., 2013). Regarding the engineering aspect, the students applied their engineering practices as they worked on their projects.

2.4.4 Problem-based learning

In a PBL classroom, the students are encouraged to use their knowledge and apply the concepts and skills from multiple disciplines to solve interdisciplinary real-world problems. The process of PBL includes presentation of the problem, identification of issues, individual and group work, application and resolution (Smith, Douglas, & Cox, 2009). For instance, Strimel (2014) stated that he constantly engages his students with authentic learning as they attempt to find solutions for recent real-world issues, such as earthquakes and tsunamis. For instance, the students need to explain the event, identify the problem and apply scientific inquiry to resolve the devastating effect of natural disasters. Similarly, Morrison, Roth McDuffie and French (2015) found that problem solving and inquiry investigation was evident in all STEM classrooms. The teachers utilized relevant and real-world problems, which motivated students to work and increased their classroom engagement. The students were engaged in understanding and defining the problem, asking questions, developing solutions and applying their knowledge from the different STEM disciplines.

Asghar, Ellington, Rice, Johnson and Prime (2012) emphasized that using the PBL approach to integrated STEM education offers several benefits: (a) promotes comprehensive understanding of connections among the disciplinary concepts, (b) fosters students' innovative thinking, (c) encourages application of scientific inquiry, (d) promotes deeper understanding of mathematical concepts and (e) enhances collaborative learning and group work. In addition, Asghar et al. argued that PBL is more directed by students than PjBL and engineering design challenges, and teachers are not required to provide specifications/ criteria for an end product. In PBL, students are encouraged to define the problem, identify the resources needed, and develop their own solutions although in PjBL, the teacher might give the students the freedom to choose their own solutions (Asghar et al., 2012).

2.4.5 Technology integration

While some researchers advocate for any form of technology integration in STEM education, others argue that the type of technology integrated matters. Lamberg and Trzynadlowski (2015) indicated that any form of technology, such as laptops, iPads and smart boards, can be used to implement STEM education. The students used their laptops and iPads to explore and research about topics and they developed various technologies (e.g. rubber bank and soda straw rockets). Furthermore, Gao and Schwartz (2015) stated that using technology in a STEM classroom helps students visualize phenomena that are difficult to picture. They reported that technology integration facilitates classroom engagement, aids in explaining difficult theories and concepts and enhances students' digital communication skills. In their study, the teachers incorporated simulations, videos and visual demonstrations in their STEM lessons, and the students participated in classroom and online discussions, shared their opinions and asked questions (Gao & Schwartz, 2015).

Despite the positive outcomes of technology integration, the way technology is integrated in the classroom influences students' learning experiences. For instance, replacing the lecture with a video or a PowerPoint presentation does not necessarily result in classroom engagement or active learning. Brown et al. (2011) argued that the mere use of technology (e.g. laptops) does not result in technological literacy. The technological aspect in STEM education goes beyond the use of technology, and includes learning about technology and its concepts (Brown et al., 2011). Moreover, Parker et al. (2015) emphasized that teachers who use technology that is aligned with STEM practices tended to adhere to student-centered approaches more than teachers who use instructional technologies. They found that the students were actively engaged in STEM practices when the teachers allowed them to use technology in a manner that is relevant to their real-lives (e.g. using geographic information systems). In contrast, the teachers who used technology to present the lesson, such as online demonstrations or videos for instruction, tended to have passive learners, who showed minimal interest in the lesson.

2.5 Types of support for STEM education

Teachers need to continually promote their technological pedagogical content knowledge (TPACK) in order to effectively implement integrated STEM education. As teachers come from different backgrounds, many teachers may have adequate technological knowledge or content knowledge in specific disciplines, but lack them in other areas, leading to ineffective pedagogies. Moreover, several researchers (Ejiwale, 2013; Lamberg & Trzynadlowski, 2015; Stohlmann et al., 2012; Roehrig et al., 2011) have emphasized the importance of developing adequate content and technological knowledge regarding the STEM fields and practicing STEM-based pedagogical approaches to facilitate students' understanding. However, providing support through different means is crucial to achieve adequate TPACK.

2.5.1 Collaboration

One way to provide support is through engaging in a community of practice (COP), a term mentioned earlier in the paper, and collaboration (Wenger et al., 2002). In a COP, teachers collaborate together, share their ideas and benefit from each other's experiences. Stohlmann et al. (2012) reported that teachers implementing integrated STEM education promoted their knowledge in different STEM subjects through collaboration. Planning the units and lessons together enhanced their confidence in the subject matter since each teacher is knowledgeable in one specific discipline (science, technology or mathematics). During their meetings, the teachers asked questions, shared their teaching strategies and discussed the effectiveness of their teaching methods.

Similarly, Lamberg and Trzynadlowski (2015) emphasized the importance of communication, collaboration and allocating adequate common planning time as aspects of support for teachers. They found that teachers engaged in STEM unit planning teams to enhance their TPACK as each teacher was an expert in a specific STEM content area. As a result, the teachers were able to plan and implement project-based units that were connected to different STEM disciplines. Besides, Roehrig et al. (2011) argued that collaboration between teachers is essential for implementing effective STEM education. They found that many teachers had gaps in different STEM disciplines and many of them suggested that they could benefit from a networking system. For instance, some teachers faced difficulties in technology integration due to their limited technological literacy, thus they avoided integrating it in their classrooms.

2.5.2 Professional development

Another way to provide support for teachers' TPACK is through involving teachers in professional development opportunities that train them in the strategies for integrated STEM education. Ejiwale (2013) asserted the significance of investment in effective and sustainable professional development programs. The programs need to promote teachers' knowledge in STEM fields and provide training in the teaching methods of integrated STEM education. Besides, Lamberg and Trzynadlowski (2015) found that teachers benefited from attending professional development workshops that provided training in strategies such as problem-, engineering design- and inquiry-based learning. Teachers enhanced their teaching strategies and adopted them in their classrooms.

Additional work by Parker et al. (2015) deals with conducting a year-long technology-intensive professional development for teachers. The researchers investigated whether the teachers integrated at least one of the technology applications in their classes and whether the integration aligned with STEM education. The findings suggested that an intensive professional development did not influence the teachers' technology integration. However, there were significant differences in terms of the quality of technology being integrated. The teachers who participated in the professional development integrated technology in a student-centered approach and made their applications relevant to real-world situations compared to the teachers who did not participate in the professional development.

Furthermore, Nadelson, Seifert, Moll and Coats (2012) designed a professional development program which tackled teachers' knowledge regarding STEM concepts and strategies. The researchers aimed at increasing teachers' comfort in applying STEM strategies and enhancing their knowledge in STEM subject matter through providing instruction, networking, collaborating and socializing. Their findings revealed that the program influenced teachers' comfort positively, promoted their confidence in applying STEM strategies and enhanced their knowledge in STEM concepts (Nadelson et al., 2012).

2.5.3 Coaching

Coaching is a useful technique that enhances teachers' TPACK. The coach needs to be qualified in STEM education who has an adequate knowledge base about integrated STEM education. Hence, s/he will guide the teacher in developing STEM lessons and assist the teacher in applying suitable teaching strategies. Lamberg and Trzynadlowski (2015) emphasized the central role of STEM coaches in assisting teachers in implementing integrated STEM education. The teachers affirmed that the coaches supported them in planning and implementing the STEM lessons.

Similar results were reported by Parker et al. (2015). The teachers were involved in two-week professional development, and they received coaching as they implemented the skills and knowledge acquired through their professional development. The STEM coaches assisted teachers in lesson planning and acquiring materials. Most of the teachers reported that the coaches were a source of encouragement, and they played a major role in improving the teachers' pedagogical and content knowledge and technology integration (Parker et al., 2015).

Furthermore, in the study conducted by Czajka and McConnell (2016), a professional STEM coach assisted an instructor throughout a semester to modify her teaching practices. The coach revised the lessons given, developed student-centered activities and coached the instructor in applying STEM teaching methods (e.g. hands-on activities, problem solving, designing solutions, inquiry, etc.). The collaboration, discussions and interviews with the professional coach along with reflection on teaching practices influenced the teachers' TPACK (Czajka & McConnell, 2016). The teacher was able to connect concepts from different disciplines and knew how to integrate appropriate technologies in the classroom.

In this promising but limited study, Czajka and McConnell (2016) implemented coaching with one instructor. The instructor was willing to change her teaching practices and was aware of alternative teaching strategies, yet she lacked time and expertise in planning and implementing new strategies in her classrooms. In most cases, the coach might be an outsider and not part of the teachers' community. Hence, not all instructors or teachers may be willing to work with a coach and permit the coach to observe their classes on a daily basis.

2.5.4 Physical resources

The school should support the teachers with physical resources in order to properly implement STEM education. The physical resources include digital technologies, electronic resources, library, textbooks, labs, spacious classrooms, material kits and tools. In their study (2015), Lamberg and Trzynadlowski investigated how elementary teachers implement STEM education in their classrooms. One of their findings revealed that the physical resources influenced the way STEM was implemented. Therefore, they recommended that one way to support teachers for implementing STEM teaching is through the physical resources. Many teachers stated that their school provides them with different resources including laptops, iPads, wireless notebooks, Smart Boards, science kits and STEM labs. For instance, they affirmed that the technological resources are useful for students to research, read, write, create presentations and use interactive websites.

2.6 Internal barriers to STEM education

Research concerning STEM education suggests that there are various barriers, internal and external, to successful implementation of STEM education in schools. The internal barriers include issues related to teachers' self-efficacy, beliefs, skills and knowledge. Teaching the STEM disciplines in an integrated manner requires good conceptual understanding. Lack of sufficient content knowledge in any of the STEM disciplines poses a challenge to the teachers to connect the disciplines in a comprehensive manner. Therefore, teachers will not be equipped with the needed skills to make external connections among the STEM disciplines. Asghar et al. (2012) found that many teachers were concerned about their content knowledge regarding the different STEM disciplines. Guzey et al. (2016) reported that science teachers found difficulty in connecting the scientific concepts to the planned engineering challenges, and struggled with integrating mathematical concepts into their lessons.

Moreover, limited familiarity with the pedagogical approaches and strategies for STEM education constitutes another barrier for teachers. Teachers need to shift from teacher-centered teaching to a student-centered one to implement STEM education. Schmidt and Fulton (2016) investigated the implementation of STEM education through inquiry-based teaching. The researchers trained and involved the teachers in the inquiry process before implementing it in their classrooms. The results revealed that the inquiry approach seemed challenging to the teachers from a pedagogical perspective. The teachers reported that they were not familiar with the inquiry-based approach, and the act of engaging in the process was a struggle, thus many of them were not encouraged to use inquiry in other science units (Schmidt & Fulton, 2016).

Furthermore, teachers' self-efficacy and beliefs play an important role in teaching. Stohlmann et al. (2012) defined teachers' self-efficacy as the "teachers' beliefs about their capabilities to produce a desired effect on student learning" (p. 30). New strategies for STEM education are constantly being developed, and teachers need to stay abreast about the recent approaches and technology tools. If teachers do not believe that they are capable to use novel approaches in teaching, they will lack the motivation to learn and avoid adopting new approaches and technologies in their classrooms. Schmidt and Fulton (2016) reported in their study that teachers who felt uncomfortable in adopting PBL approach to STEM education exhibited resistance in incorporating it in their lessons. The resistance remained even after being involved in a workshop where the teachers engaged in the STEM-PBL approach.

2.7 External barriers to STEM education

Even if the teachers are willing to adopt new strategies, the external barriers hinder the implementation of new approaches to teaching. Roehrig et al. (2011) indicated that all teachers in their study gave positive feedback regarding technology integration for STEM education. The teachers believed that technology is essential for STEM teaching. However, they struggled in using technology due to the limited technology resources available at the school. Research indicates different external barriers, including lack of resources, poor condition of the available facilities, time constraints and inadequate school or administrative support.

Inadequate resources and poor condition of the school’s facilities are considered two of the major barriers for ineffective implementation of STEM education. Ejiwale (2013) noted that many schools lack appropriate facility structure (e.g. poor lab conditions and overcrowded classrooms) and lack the needed resources and materials (e.g. digital technology and material kits for design and construction). Shernoff et al. (2017) explored the challenges faced by teachers to develop or implement STEM curricula and instruction. The teachers identified insufficient resources and instructional material as a barrier. Similarly, Stohlmann et al. (2012) reported that teachers would not have been able to carry out the STEM activities without the materials and resources. The teachers were supplemented with electronic technology materials (e.g. design programs, robotics software, calculators, etc.) and material kits for the projects, such as construction tools. Besides, the classroom size and space were essential for students to have adequate space in order to work on their projects, roam easily around the classroom and store the materials and projects in an organized manner (Stohlmann et al., 2012). Hence, the facility needs to be well-equipped with the appropriate tools and structure for the students to tinker and construct their own learning.

Time constraints serve another barrier to implementation of STEM education. Teachers have several duties to complete, such as grading papers, planning activities, assisting students in their projects, attending meetings and participating in professional development workshops. Hence, they will not have the adequate time to learn new approaches and implement them effectively in their classrooms. Shernoff et al. (2017) found that many teachers mentioned lack of time, for collaborative planning and for STEM instruction, as a barrier. Furthermore, Parker, Abel and Denisova (2015) argued that teachers are pressured to learn new strategies, implement them and assess their effectiveness without providing them with adequate time to complete these actions. In their study, all of the teachers reported that inadequate time serves as a major barrier to learn and adopt new teaching practices related to integrated STEM education.

Furthermore, teachers are required to finish the curriculum and cover the lessons' and unit's objectives in a limited amount of time. Asghar et al. (2012) indicated that teachers are constantly tensed between covering the curriculum content and allocating time for STEM-based activities or projects. However, the teachers ended up focusing on covering the curriculum materials in order to meet the general objectives of the unit and the specific objectives of the lessons. Similarly, Moore and Smith (2014) argued that curricula need to be changed to include STEM contexts for teaching science and mathematics content in meaningful ways.

Furthermore, Lesseig et al. (2016) found that teachers had difficulty creating engineering design challenges that are interdisciplinary due to the curricular challenges and time restraints. The engineering design challenges were supposed to integrate science and mathematics. However, these challenges did not align with the school's curricular goals as they involved understanding of different scientific concepts which were not required to be addressed at the same grade level. In addition, the teachers admitted that they focused on science contents and engineering design processes, and did not have adequate time to make in-depth connections to mathematics (Lesseig et al., 2016). Similarly, El-Deghaidy, Mansour, Alzaghibi and Alhammad (2017) explored the contextual factors that hinder applying STEM pedagogy among science teachers. One of the main barriers identified was lack of STEM activities in the curriculum. Hence, teachers were overloaded with the curriculum and incorporating STEM-related activities within classrooms.

Finally, it is crucial for the school system and administration be knowledgeable of STEM education and be willing to support educators in implementing it. The lack of administrative and school support hinders adopting the STEM approach and implementing integrated STEM education. Teachers need a supportive environment to learn new strategies and cultivate meaningful STEM learning experiences. According to Asghar et al. (2012), administrative and school support includes (a) offering professional development opportunities, (b) developing a common vision and writing clear goals, (c) assigning regular faculty and staff meetings to discuss issues and solutions related to STEM education, (d) allocating sufficient time for teachers to collaborate and work in teams, (e) providing teachers with feedback regarding their implementation of STEM education, (f) acknowledging teachers' efforts through providing rewards and incentives. Moore and Smith (2014) argued that many teachers do not know how to teach disciplinary content using authentic STEM contexts, and schools need to support the change for STEM education. Moore and Smith (2014) emphasized that this support is carried out through engaging teaching in professional learning experiences, which will prepare them to implement STEM education.

2.8 Conclusion

In conclusion, STEM education is gaining popularity in the 21st century and educators are aiming to promote students' understanding and ability to apply concepts from the four disciplines. Diverse strategies that reflect integrated STEM education are found in the literature and could be implemented to enhance students' STEM learning experiences. For effective implementation, policymakers and administrators need to sustain an environment that encourages the implementation of STEM education and design supportive facility structures. In addition, they need to provide teachers with the needed support through providing access to physical tools, resources and suitable professional development opportunities. Furthermore, teachers need to enhance their TPACK through professional development, engagement in community of practice and assistance of STEM coaches. However, barriers in implementation are inevitable as teachers may not have adequate resources, are restrained with time and lack motivation.

Chapter 3

Methods

In this section, a detailed description of the methods that were used in the study is presented. The purpose of the methods' section is to provide the study's research design, sampling method, procedure and instruments for data collection and analysis. In addition, various components that influence the study such as validity, reliability, researcher's bias and piloting the instruments are addressed in this section. The methods' section is divided into eight parts: Type of method, participants, procedures, data analysis method, validity and reliability, researcher's bias and assumptions, ethical considerations and table connecting procedures to research questions.

3.1 Type of method

The proposed research is a case study. Hence, the study will provide a descriptive analysis and interpretation of the elementary school as various and diverse elements were studied. In addition, the case study will illuminate the reader's understanding of how STEM education is adopted in the participating school. In order to achieve this holistic and descriptive analysis, the study used mixed methods of research as qualitative and quantitative methods were used to address the study's research questions. According to Yin (2008), a case study is defined as an "empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident" (p. 18). For the purpose of the study, a case study is the most suitable research method, as the study aimed to investigate the topic within specific grade levels (elementary classes) in one private school in Beirut. Moreover, the number of participants involved in the study is limited and not representative of schools in Lebanon or Beirut.

Another reason for selecting a case study as the research design, is the descriptive nature of the product of the study. The researcher used various instruments to study in depth the STEM implementation in the elementary school. Therefore, the findings are richly descriptive as the researcher investigated multiple variables of the entity to better understand the phenomenon (Merriam, 2009).

3.2 Participants

The study was conducted in a private school in Beirut. Purposive convenience sampling is adopted to select the site. The participating school was selected based on its familiarity with the meaning of integrated STEM education. In an informal interview conducted with the elementary school principal, she stated that the school does not follow a formal STEM program, yet the teaching approach and activities that are used in classes reflect many STEM aspects, such as inquiry-based learning.

The school has six sections of each one of the five elementary grade levels: Three English sections and three French sections. Each section is taught by one homeroom teacher. Therefore, all elementary teachers, a total of 30 teachers, were selected for the study.

Second, the coordinators who work in the elementary school include a math coordinator, an IB-PYP coordinator and a technology integration coordinator. The school does not have a science coordinator. Therefore, only three coordinators were selected for the study. Besides, the director of professional development, who works in the Educational Resources Centre (ERC), was selected for the study to provide information regarding teacher professional development. All the chosen participants were interviewed in a face-to-face semi-structured manner.

In summary, the participants selected for the study included all homeroom teachers (30 teachers) of the elementary, coordinators (three coordinators) and the director of the ERC. These participants constitute a purposive sample selected due to their availability and being information-rich sources who can provide information pertinent to this study. Each homeroom teacher teaches his/ her class mathematics, science, social studies and language. Technology is supposed to be integrated throughout the lessons taught. However, since the topic is about integrated STEM education, the study will focus on mathematics and science lessons that are taught by the homeroom teachers.

3.3 Procedures

The procedures that were carried out to collect data for the study include class observation, interviewing and surveying. The aim is a deep understanding of the case at hand, rather than generalization of results. The use of different procedures and instruments to collect data helps in the triangulation of results and enhances the validity and reliability of the study (Patton, 1990). For instance, the interviews allowed the researcher to understand in depth the respondents' attitudes, beliefs, experiences, perceptions and knowledge about the topic (Fraenkel, Wallen, & Hyun 2012; Merriam, 2009). Observations allowed the researcher to monitor and note down detailed description of teachers' and students' behaviors, activities and actions. Each procedure and its instrument will be described in detail.

3.3.1 Observations

Observations were conducted to explore directly the strategies used by teachers in the math and science classes and their interactions with their students. Hence, the observations yielded information pertinent to the second research question.

Non-participant classroom observations were conducted. The researcher observed classes without participating in the tasks/ activities/ projects that happen, and without interacting with the teacher or students. Two grade-3 sections and two grade-4 section were selected to carry out the observations. These two grade levels were chosen because the elementary school principal stated in the informal interview that these grade levels have the most STEM-based activities compared to other grade levels.

Since the school implements the IB PYP Program of Inquiry, and mathematics is integrated in a transdisciplinary manner, only science classes were observed. The observations were conducted to examine teachers' strategies and teaching methods that reflect integrated STEM education, and to observe the activities and interactions that occur.

For each chosen grade level, two sections were selected to conduct the observations. The observation period was over one instructional science unit in each section, which takes approximately six weeks. Hence, observations were conducted for four instructional units (approximately 30 sessions): Two science units in grade-3 and two science units in grade-4. The sections were chosen randomly using the lottery technique; the section codes were written on pieces of paper and placed in two containers (one container for each grade level), and the researcher drew two papers from each container (one from the grade-3 level container and one from the grade-4 level).

In addition, the school implements a *Science Lab and Makerspace Program*, which was observed as well. The program is part of the curriculum and students are involved in the program during the school hours. After the teachers complete a lesson or unit, students go to the science lab where they work on activities or tasks related to the topic covered. In the informal interview conducted with the elementary school principal, she indicated that in the *Science Lab and Makerspace Program*, students engage in conducting experiments and making projects, such as recycling paper, making their own thermometer, building a city model with its infrastructure, simulating the digestive system, etc. Observations were conducted in the *Science Lab and Makerspace* classes. The number of sessions for the latter observations were done throughout a six week period, one session (45 minutes) each week, a total of 6 sessions.

3.3.1.1 Observation instrument

In order to conduct the class observations, an observation protocol was used. Several classroom observation protocols, including *Reformed Teaching Observation Protocol* (RTOP) (Sawada et al., 2002), *Teaching Dimensions Observation Protocol (TDOP)* (Hora, Oleson, & Ferrare, 2013) and *Inside the Classroom: Observation and Analytic Protocol* (Weiss, Pasley, Smith, Banilower, & Heck, 2003) were reviewed. Although these protocols are structured, they do not allow the observer to take field notes or respond to statements by writing comments. In addition, these protocols are not specific for STEM unlike the *STEM Classroom Observation Protocol* (Appendix A). The chosen protocol has been used to observe the instructional and teaching practices in several STEM schools in the United States, and it includes various indicators for STEM practices (Edmunds, Arshavsky, Lewis, Hutchins, & Coyle, 2017).

Moreover, the *STEM Classroom Observation Protocol* is structured and open-ended (Edmunds et al., 2017). It provides the researcher with a set of statements that the observer scores on a 4-point Likert scale, ranging from “not observed” (= 0) to “very descriptive of the observation” (= 3). In addition, the protocol provides space for the observer to write down qualitative notes and record specific examples that reflect the observed practices.

The observation protocol is divided into two parts. The first part includes general class information, such as brief description of class, lesson topic, lesson goals, curriculum materials, etc. The second part assists data collection across eight dimensions, which are (Edmunds et al., 2017):

1. Mathematics and Science Content
2. Student Cognitive Engagement in Meaningful Instruction
3. Inquiry learning; Project-based learning; and Problem-based instruction
4. Teacher Instruction/ Formative Assessment
5. Common Instructional Framework
6. Student Engagement
7. Use of Technology
8. Classroom Culture

Each dimension comprises of specific indicators / statements / activities that reflect examples of instructional practices. The observer will rate the instructional practices based on the extent (number of times/ duration) to which the particular practice is observed. The rating scale ranges from 0 to 3 as described below (Edmunds et al., 2017):

1. A rating of 0 means that the instructional practice was *not observed*.
2. A rating of 1 means that the instructional practice was *minimally* observed.
3. A rating of 2 means that the instructional practice was observed *to some extent*.
4. A rating of 3 means that the instructional practice was *very descriptive of the observation*.

Within each dimension, there are several indicators, and there is an overall summary rating that represents the extent and quality of implementation of the instructional practices (Edmunds et al., 2017). However, for some dimensions, the summary rating is not an average of each indicator as some indicators are more important than others. A high rating (i.e. rating of 2 or 3) in the more important indicators will permit a high summary rating. Therefore, a weighted average will be calculated; coefficients of 1 and 2 will be given to the less important and more important indicators, respectively. In addition, within each dimension, the observer should record observation notes and specific examples to justify the ratings that were given.

Moreover, the *STEM Classroom Observation Protocol* is a reliable instrument. During its development, Edmunds et al. (2017) first conducted three training sessions for four site observers, where they examined video clips of real science and mathematics classes, using the STEM Observation Protocol and Guide. After the training sessions, the observers conducted site visits, and two observers observed each classroom. The day following the site visits, the two observers met, discussed their field notes and ratings, and agreed on the common scores for all the protocol's indicators. Inter-rater reliability was calculated for the conducted observations, and the results showed high inter-rater agreement among the observers, ranging from 83.3% to 100% agreement for the individual dimensions and 93.7% for the eight summary ratings (Edmunds et al., 2017).

3.3.1.2 Pilot observation

To increase the reliability of the observation protocol for the present study, The STEM Classroom Observation Protocol was piloted in two classroom sections that are not part of the study, to make sure that all the statements apply to the study’s context, and make some adjustments related to cultural/ language/ context/ system incompatibilities. The piloting was carried out twice: in a grade-2 section and a grade-4 section (Appendix B). The topics that were taught for grade-2 and grade-4 are water filtration and oil spill, respectively. Before conducting the pilot observation, the researcher requested from the elementary school principal the two-week schedule of grade-2 and grade-4. The principal gave the researcher the freedom to choose the classes that she intends to observe. In addition, the elementary school principal informed the teachers who are responsible for teaching the selected grade-2 and grade-4 sections about the pilot observation.

On the day of piloting, the researcher briefly introduced the teacher to the research that she is conducting and the purpose of the pilot observation. First, the researcher was intending to observe each section of the protocol for a certain period of time (10 minutes). However, as she was observing, the researcher noticed that dividing the protocol into separate sections to be observed is not feasible, because several elements from different sections can be observed simultaneously. For instance, statement 3b “students engaged in hands-on or real-life problem solving activities or a lab experiment” found in section 3 of the observation protocol, *inquiry learning, project-based learning and problem-based instruction*, was observed concurrently with statement 7c “students used technology to generate or manipulate one or more representations of a given concept or idea” found in section 7, *use of technology*. As a result, whichever statement is observed in the class will be checked and specific examples will be recorded accordingly. Furthermore, the researcher will fill the observation protocol over three slots of time to identify how frequent the indicator is repeated throughout the session. The session is 45 minutes and each slot will cover a 15-minute period.

Moreover, the indicators related to ethnicity and race will be removed from the protocol as they do not fit the school context and its culture. The indicators are found on the first page of the protocol and they are “Teacher Ethnicity” and “Classroom Race/ Ethnicity: % Minorities (approximate)”. In addition, the “School Name” will be removed for confidentiality purposes. No further modifications are needed on the first page, and the wording of all the statements in the protocol will not be changed as they are clear and concise. However, the format in section 4, *Teacher Instruction/ Formative Assessment*, will be modified slightly. The last column will be removed since the meaning of rating (4) is not indicated. In addition, the statement 5f, *students participated in guided reading discussions*, in section 5, *Common Instructional Framework*¸ will be removed as the study does not focus on language integration and the researcher will not observe reading sessions.

3.3.2 Interviews

Three homeroom grade-3 teachers, three homeroom grade-4 teachers, one mathematics coordinator, one IB PYP coordinator, one technology integration coordinator and one director of ERC were interviewed. The interviews with the homeroom teachers were carried out to explore their perceptions and beliefs about integrated STEM education and their classroom teaching strategies, ways to promote their technological pedagogical content knowledge (TPACK), and the barriers that might hinder the implementation of STEM education. The interviews with the coordinators allowed the researcher to explore their perceptions and beliefs about integrated STEM education, investigate the ways they support elementary teachers to develop their TPACK, and the way the coordinators develop the curriculum materials, including the *Program of Inquiry (POI)* and S*cience Lab and Makerspace Program*. The interview with the director of ERC was conducted to explore his perceptions and beliefs about integrated STEM education and the professional development opportunities that the school offers to enhance the elementary teachers' TPACK.

The interviews took the form of semi-structured face-to-face interviews. Semi-structured interviews were selected to provide the interviewer with the flexibility in probing the respondents. Hence, the interviewer had the ability to respond to the situation at hand, clarify the question further and use probing questions when needed. The interviews were conducted in the free time of each participant, upon prior appointment with the interviewer.

The interviews were audio-recorded upon receiving the consent from the participants. In addition, an interview guide that lists the interview's main questions was used. Audio-recording was used to ensure that everything said is preserved for data analysis.

The interviewees were contacted in person to agree on the time and place of the interview. A consent form that states the purpose of the research, voluntary participation, and confidentiality of the information was given to the interviewees before conducting the interview. The time needed to finish each interview was 30 minutes. After conducting each interview, the interview recording was transcribed for analysis.

3.3.2.1 Interviewing instrument

Since the interviews are intended to be semi-structured, an interviewing guide, with the list of the main interview questions, were developed, including the main questions to be asked. The questions listed in the interview guide were derived from the reviewed literature, and they are specific to the research questions of the study, but open-ended.

Different interview guides were developed for the interviewees with different profiles. The first guide (Appendix C) included questions targeted to the homeroom teachers. The interview questions were divided into four categories: Background information, teaching strategies, technological pedagogical content knowledge, and challenges and barriers to implementing STEM education. The first section provided demographic information regarding the teachers’ educational background, career journey and years of teaching experience. The second section provided information regarding the teachers’ perceptions/ beliefs about the teaching strategies that should be used in classes and in the *Science Lab and Makerspace Program*, and their actual classroom teaching practices, which will attempt to answer the first and second research questions. The third section provided information regarding the support that teachers have to enhance their TPACK, which will attempt to answer the third research question. The fourth section provided information regarding the challenges and barriers that hinder the implementation of integrated STEM education, which will attempt to answer the fourth research question.

Another interview guide included questions targeted to the coordinators (Appendix D) and the director of ERC (Appendix E). The interview questions provided information regarding the support that they provide for the homeroom teachers to enhance their TPACK and the barriers that hinder the implementation of integrated STEM education. Therefore, they provided data for the third and fourth research questions to be answered.

3.3.3 Surveys

All the homeroom teachers, excluding the teachers that were interviewed, a total of 24 teachers, were invited to participate in an online survey. For convenience, the surveys were conducted online using Google Forms, thus the teachers were able to fill the surveys at any time convenient to them.

3.3.3.1 Survey instrument

A questionnaire (Appendix F) was used to conduct the online survey. A page was dedicated at the beginning of the questionnaire to present the participant with an overview of the research and ethical considerations, including voluntary participation, confidentiality and anonymity of the information.

The questionnaires were divided into four categories based on the study's research questions. In the first category, the questions seeked information regarding the teacher's background, such as, academic degree and years of teaching experience. In the second category, the teachers were asked questions about their adopted teaching practices and strategies. In the third category, the teachers were asked questions that are intended to uncover the support that they get to enhance their TPACK and the support that they would want to get. In the fourth category, the teachers were asked about the challenges and barriers they encounter in implementing integrated STEM education. The questionnaires were typed in English and French (Appendix G) as some teachers teach English sections, while others teach French sections. The English questionnaire was written first and then an online platform was used for translating it to French. Afterwards, the questionnaires were given to a French-educated expert who revised and modified the French questionnaire and compared it with the English questionnaire.

3.4 Data analysis method

The data that was analyzed was collected from the three instruments: STEM Classroom Observation Protocol, interviews and questionnaires. The data from the interviews were analyzed qualitatively, while the data from the observation protocol and questionnaires were analyzed quantitatively and qualitatively. Specifically, the level of indicators and the summary ratings from the observation protocol, and the close-ended questions from the questionnaires were analyzed quantitatively. The specific examples that were written in the observation protocol and the open-ended questions in the questionnaire were analyzed qualitatively.

The data from the interviews with the homeroom teachers, coordinators and director of ERC and the recorded specific examples from the STEM Classroom Observation Protocol were analyzed using the content analysis technique. First, the data were transformed into a written text, so the audio-recorded interviews were transcribed on the laptop. Then, coding categories were derived from the research questions and the text data, and they were color-coded according to the study's research questions. The coding detected the recurring themes and each set of recurrent themes were coded as one category. The categories were further divided into sub-categories.

The data from the level of indicators and summary ratings in the observation protocol and the data from questionnaires were entered into a spreadsheet and analyzed using descriptive statistics. Since the questionnaires were conducted online using Google Forms, the software automatically entered the data on a spreadsheet. The responses were analyzed into frequencies. Then, the mean wase examined for each subscale in the questionnaire and each level of indicator in the protocol.

3.5 Validity and reliability

The interview questions and the questionnaire items are derived from the research questions and the reviewed literature, thus the validity of the research study is increased. Content validity is enhanced when the instruments used cover the research questions properly, and reviewing the literature is considered one of the ways that contributes to content validity (Walonick, 2005). Therefore, the validity of the interviews and questionnaire are increased. In addition, the STEM classroom observation protocol was piloted to ensure the validity and reliability of the instrument in the context of the study. The protocol is modified in relation to the cultural/ language/ context/ system incompatibilities that will be encountered.

Furthermore, triangulation is used to increase the validity of the research study. Triangulation is established when multiple methods of data collection and multiple sources of data are used. In this study, three different procedures were carried out to collect data, which included observation, interviewing and surveying. By using different methods, the drawbacks of each method were minimized, and results were cross-verified, thus ensuring more validity of the results.

Moreover, data source triangulation was used as multiple sources of data are used in this study. Data were collected from different types of people to gain various perspectives and insights as well as data validity. In this study, the observations were conducted in different classes at different times in each class. The interview and questionnaire data were collected from different participants with different perspectives and positions.

Since it is a case study, the results cannot be generalized. However, generalizability (external validity) in qualitative research is thought in terms of the reader, thus the reader decides whether the results of the study are applicable to his/ her situation (Merriam, 2009). To make this possible, the researcher presented a detailed description of the context of the study and the procedures, to allow the reader to compare the findings with his/ her particular situation. Therefore, a holistic and richly descriptive presentation of the findings is provided.

The reliability of the study is thought in terms of the accuracy of information collected through using rigorous instruments and having the results consistent and comprehensive.

3.6 Researcher's bias and assumptions

In this study, it is assumed that the participants in the interviews and questionnaires answered the questions honestly. In addition, the researcher aimed to build rapport with the interviewee by listening carefully to what s/he is saying and acknowledging his/ her answers. As an observer, the researcher did not interact or talk with the students or instructor in the classroom and avoided eye contact.

3.7 Ethical considerations

In this study, ethical considerations, such as protection and safety of participants from harm, informed consent of the participants and right to privacy were taken into account upon conducting the study and collecting and analyzing the data. First, the researcher obtained the consent from the participants before collecting the data through an informed consent form that was given to each participant. The consent form will ensure the safety and security of the participants, confidentiality of the information provided and right to withdraw from the study anytime the participant feels uncomfortable. In addition, a brief consent introduction was included at the beginning of the interview and questionnaire scripts. The introduction informed the participants about the procedures (e.g. interview will be audio-recorded), confidentiality of information provided and anonymity (i.e. the real names will not be used) and right to withdraw at any time.

Furthermore, the researcher obtained approval from the authors who developed the *STEM Classroom Observation Protocol*, to use the instrument for the current study. The researcher indicated in the e-mail that the observation protocol will be used for research purposes, and will not be sold or used with curriculum development activities. Besides, a copyright statement on the instrument and in the thesis is included.

Moreover, the researcher observed extreme measures of honesty and accuracy in collecting and analyzing the data as any data that are relevant to the study were recorded and analyzed. The researcher did not exclude data that are contradictory to their views and that do not fit the purpose in the data analysis, hence all data were reported truthfully.

Table 1. Connecting procedures to research questions

	Observations (2 science units grade-3, 2 science units grade-4, Science lab and makerspace program)	Interview (three homeroom grade-3 teachers, three homeroom grade-4 teachers, math coordinator, IB PYP coordinator, technology integration coordinator and director of ERC)	Questionnaire (24 homeroom elementary teachers)
Research question 1: What are teachers' and administrators' perceptions and beliefs about integrated STEM education and relevant strategies?		X	

Research question 2: What are the strategies that homeroom teachers use within the elementary classes that reflect integrated STEM education?	X	X	X
Research question 3: What kind of support do homeroom teachers get to develop their technological pedagogical content knowledge for properly implementing STEM education?		X	X
Research question 4: What are the barriers that hinder proper implementation of integrated STEM education within elementary classes?		X	X

Chapter 4

Findings

The purpose of the study was to investigate the implementation of integrated STEM education by homeroom teachers in elementary classes in a private school in Beirut. The study adopted a mixed methods approach as qualitative and quantitative data were collected. The qualitative data were collected from the semi-structured interviews, observation notes and open-ended questions from the questionnaire. The quantitative data were collected from the observation ratings and close-ended questions in the questionnaires. This chapter presents, for each instrument, the data analysis method used and the results inferred from the analysis of the data provided by the instrument. The chapter will end with a summary of all the findings.

4.1 Analysis of Interviews

This section presents the analysis of interviews. First, the data analysis method used is explained, then the findings from the interviews are discussed in-depth.

4.1.2 Data Analysis Method

The interviews took the form of semi-structured interviews and each interview lasted between 25 to 35 minutes. Ten interviews were conducted with the grade-3 homeroom teachers, grade-4 homeroom teachers, math coordinator, IB-PYP coordinator, technology integration coordinator and the director of the ERC.

The audio-recorded interviews were transcribed and the following content analysis technique was used: the constant comparative method of data analysis, which was proposed primarily by Glaser and Strauss (as cited in Meriam, 2009). First, open coding was utilized by assigning codes that are relevant to answer the research questions. Then, axial coding was used to construct categories by grouping similar codes together. The process was repeated for each transcript, then the coding and primary categories were used to detect the recurring themes, and each set of recurrent theme was clustered into one category.

4.1.2 Findings from Interviews

A total of ten participants were interviewed in a semi-structured manner. The interviewees were three grade-3 homeroom teachers, three grade-4 homeroom teachers, one math coordinator, one IB-PYP coordinator, one technology integration coordinator and one director of ERC. An interviewing guide with the list of the main interview questions was used during the interviews. Depending on the interviewee's profile, a different guide was used. The first guide (Appendix C) included questions targeted to the homeroom teachers. The second guide (Appendix D) included questions targeted to the coordinators, whereas the third guide (Appendix E) included questions targeted to the director of ERC.

The names of the interviewees were letter-coded as follows: the director of ERC as D, the coordinators as C1, C2 and C3, and the teachers as T1, T2, T3, T4, T5 and T6. The categories and sub-categories that emerged from the analysis of the interviews are discussed below.

4.1.2.1 Director's perceptions and beliefs about integrated STEM education

When the director (D) was asked to define integrated STEM education, he defined the acronym "STEM" and added "arts" as part of the definition. He indicated that STEM requires the "integration" of the disciplines by stating that: "STEM as the integration of science, technology, engineering, arts and mathematics…I see it [as] making sense and finding connection points between these fields."

The belief held by the director of ERC about integrated STEM education is that it is needed for the future preparation for STEM-related jobs. He believes that the movement of STEM education makes sense for a certain purpose. D explains: "preparing kids for STEM field-related jobs [because] this whole movement is for the future [meaning] for the future preparation of the students, so yes it does make sense, but it makes sense for a purpose."

4.1.2.2 Coordinators' perceptions and beliefs about integrated STEM education

When the coordinators were asked to define integrated STEM education, two out three coordinators defined the acronym "STEM", exemplified in this response by C2: "I can tell you what the S, T, E and M stand for. The science, technology, engineering and math." C2 further elaborated on the definition and defined STEM education as the curriculum and framework for science, technology, engineering and math. Although one coordinator did not define the acronym "STEM", she explained how integrated STEM education is used in education by stating: "It is broadening the horizon and seeing how you can have it authentically integrated in different subjects and in different topics and seeing that STEM fits in so many of them" (C3).

Two coordinators, C1 and C3, said the word “integration” and one coordinator (C1) gave brief explanation of the word. C1 indicated: “integrated means that it’s not taught separately from the other subjects.”

The beliefs held by the coordinators about integrated STEM education is that it is a trend which started in the United States and gaining popularity worldwide. C2 stated: “this [STEM education] is something coming from the U.S…it’s whatever changes and trends they have in the States.” However, C1 believes that STEM education is a trend, but with a purpose. C1 explained:

> “the movement has grown in popularity for the last few years…there hasn’t been an emphasis on those fields and I also think that in education, they haven’t been connected…so kind of bringing those things [disciplines] together and looking at projects that can incorporate all of those different fields, so even integrating those together has been a rising trend.”

4.1.2.3 Teachers’ perceptions and beliefs about integrated STEM education

When the teachers were asked to define integrated STEM education, two out of six teachers defined the acronym “STEM”. One teacher (T4) elaborated on the vision of integrated STEM education, rather than defining it, by explaining: “the vision would be that it’s covering STEM topics and developing STEM thinking skills and concepts within the framework of the unit that incorporates other disciplines” (T4).

Two teachers (T5 and T6) indicated that they do not know the meaning of STEM, but reported that they are familiar with the term, either by having heard about it or by having read it somewhere. However, T6 related integrated STEM education to one of the units in the PYP POI after the interviewer defined the acronym “STEM”. Finally, one teacher gave a broad definition by stating: “it’s the learning, the background, the application, going back, it’s a circle…understanding all the concepts through whichever way” (T1).

Two teachers said the word “integration” and elaborated about it. They explained that integration means not teaching the disciplines as separate subjects, exemplified in this response by T3: “I read very briefly that it is integrating math, science, technology and engineering together, rather than teaching them as disciplines. They’re being taught in an interdisciplinary way.” However, the integration of disciplines does not always result in equal integration of all disciplines, as T4 explained: “I would just draw on all those disciplines, and just depending on the topic and engagement, maybe there was one traditional discipline that’s gona be more heavily emphasized than the others.”

The beliefs held by the teachers about integrated STEM education were grouped into two categories: 1) trend and 2) fluid process. One teacher indicated that STEM education is the “new trend”, but did not elaborate further about it. Another teacher indicated that STEM education is a fluid process and the teacher should always modify his/ her planning depending on the students’ needs.”

4.1.2.4 Director’s beliefs about relevant strategies for integrated STEM education

The director believes that “hands-on interdisciplinary projects” are the suitable teaching strategies or methods for applying STEM education. In addition, these projects should take place in the technology lab or the makerspace. D emphasized: “hands-on interdisciplinary projects taking place in the technology lab or in the makerspace. This is the best place and the successful integration that have been through was project-based and the makerspace."

4.1.2.5 Coordinator's beliefs about relevant strategies for integrated STEM education

The coordinators' beliefs about the relevant strategies for integrated STEM education were grouped into two categories: 1) PYP approach to learning and 2) project-based learning. The PYP approach to learning, which is inquiry-based, was indicated by two (C2 and C3) out three coordinators, and they stated that this approach goes hand in hand with STEM education. C2 emphasized: "STEM goes hand in hand with what we do. So our approach is inquiry-based." C3 indicated that the "PYP approach" provides opportunities for "trans-disciplinarity" and for "authentic integration". C3 indicated: "this is a way where the student will see how STEM fits and makes sense and makes connection authentically."

C1 believes that "project-based learning" is the suitable teaching strategy for applying STEM education. She elaborated: "immediately, I think of project-based learning…So projects; they [students] have a challenge, they have a problem that kids need to solve when they're building a bridge or moving an item from one place to another or these types of activities."

4.1.2.6 Teachers' beliefs about relevant strategies for integrated STEM education

The teachers were asked about the relevant strategies for applying STEM education and whether their teaching strategies are consistent with STEM. Diverse answers were obtained and the beliefs were grouped into five categories: 1) student-driven learning, 2) questioning, observing, modelling and applying, 3) inquiry-based learning, 4) using technology, and 4) lacking knowledge in strategies for STEM education.

Student-driven learning was indicated by one teacher, which requires students being engaged in the “real world, observing scientific processes and reflecting on what they saw” (T4). Questioning, observing, modelling and applying were stated by two (T1 and T6) out of six teachers without providing any further explanation.

Inquiry-based learning was indicated by one teacher (T3), who is a strong advocate for inquiry-based learning, and her beliefs are reflected in the teaching strategies used. T3 emphasized: “I am a strong advocate of inquiry-based learning and being an inquiry teacher, so I definitely believe in trying to find the connections between those disciplines and allowing students to draw on those connections.”

Using technology was stated by one teacher as a major strategy for applying STEM education. T5 highlighted: “you need to have technology. The tools should be available and up to date [meaning] having old materials that doesn’t work is not good.”

Lacking knowledge in strategies for STEM education was evident as one teacher did not answer the question due to lack of training in STEM education, hence not knowing what are the suitable teaching strategies for STEM education.

When the teachers were asked whether their teaching strategies are consistent with STEM education, mixed answers were obtained. Two out of six teachers stated that their strategies work for STEM education. T4 indicated: “definitely in a way, we could say that it is, what we do in PYP is following a program, the framework is trans-disciplinary, then this is common.” However, T5 indicated that the strategies work for strategies because they are trying to use technology, which implies that T5 equated STEM education with technology only.

One teacher (T1) indicated that the teaching strategies used are catered for the students' needs irrespective of STEM education. Three out of six teachers stated "I don't know" when they were asked the question, exemplified in this response by T4:

> "I don't know what principles you're setting or referring to. And I don't even know if there exists one set of framework or one set of principles, and if so I haven't seen it or it hasn't been talked about at school."

4.1.2.7 Instructional Strategies

The teachers were asked several questions about their teaching strategies in an attempt to answer the second research question (what are the strategies that homeroom teachers use within the elementary classes that reflect integrated STEM education?). Six categories were grouped in the theme of Instructional Strategies: 1) Student-centered approaches, 2) inquiry-based learning, 3) project-based learning, 4) constructing models, 5) technology integration and 6) integration of mathematics in the units. Each category will be discussed below.

Student-centered approaches

Various keywords mentioned were grouped into the category of "student-centered approaches." Three out of six teachers indicated that the learning is led by students and the teachers act as facilitators, exemplified in this response: "I very much take the role of the facilitator. I am not using direct instruction to a great deal…then the students are pretty much directing each other" (T2). Similarly, T5 stated: "They [students] are leading the learning in their inquiry and their questions and their way of thinking. I am just monitoring and guiding them.” T1 indicated that students have “assigned roles” and they “know what their role is”, hence students are responsible for their own learning as they take roles for different activities.

Engaging students in group work, pair work, class discussions, hands-on activities, making connections to real-life and building on background knowledge are other strategies that had been indicated by all teachers. Similar to other responses, T3 stated: “we work a lot on building on students’ backgrounds and through hands-on and experimenting and working together as a group, learning from each other and constructing on students’ learning and using scaffolding.” T3 further elaborated that the activities done in class should be “meaningful to them [students]”, “engaging”, “draw and make connections [to] what is happening around them” and having a “real-life context”.

Inquiry-based learning

All teachers reported “inquiry” as part of their teaching strategies, and five out of six teachers indicated “scientific process” or “scientific method” as part of inquiry learning. The teachers elaborated on the ways they involve their students in inquiry-based learning. The methods mentioned by teachers were observing, asking and writing questions, formulating hypothesis, predicting, researching, carrying out investigations, doing experiments, analyzing, drawing conclusions, reflecting on the conclusions and presenting their findings.

Project-based learning

When the teachers were asked to describe an instance when students worked on a project, they gave several examples of different projects that students usually work on throughout the year. Examples include building a city, where students have to think of the infrastructure and the city's systems, creating a well-being market at the school, and working on personal projects. In some projects, students are given the materials, while others, students have to plan the needed materials. In addition, the students are sometimes given ownership in the way they want to present their projects. Teachers indicated that students presented their projects through iMovies, rap songs, green screen, posters, PowerPoint presentations, paintings, documentaries and symbolic models.

Problem-based learning

When the teachers were asked to describe an instance when students worked on solving problems, they provided diverse answers. Two teachers (T5 and T6) gave examples on math word problems. Both teachers indicated that they direct the students with strategies to solve these word problems. T6 explained: "They [students] don't know how to make connections. So we teach them a strategy....use context clues…read it once, read it twice, break the word problem apart, translate the English words to math." Similarly, T5 emphasized that students should "go back to the rules that [they] learned about."

Furthermore, two teachers (T2 and T3) indicated that students solve problems related to the units. T2 stated that problem solving is included everyday, as stated in this response: "That [problem solving] happens all day. They [students] are always solving a problem. I present everything as a problem. Everything is something that needs to be worked out." However, one teacher (T4) stated that problem-based learning needs more work. T4 indicated: "I need to work more on problem-based learning, because I can't think of any in my classroom."

Constructing models

When the teachers were asked to describe an instance when students worked on constructing models, they gave few and limited examples of models. Two teachers pointed out that engineering design is not used frequently in the units, and they limited its application to one out of the six PYP units. The examples that were mentioned include art models and constructing an earthquake-proof model. One teacher indicated that when students are asked to construct a model, the process is structured and guided. Another teacher (T1) noted that students perform simulations rather than constructing models, where the materials are already provided.

However, one teacher indicated that students can create a model as a mean of showing their understanding and learning. T2 stated: "Students are always given options…For the last one [unit] that we did…some of them created dioramas, some of them created models."

The few learning experiences for constructing models can be explained with the limited experience of teachers with engineering design. One teacher indicated to have "very little experience with that [engineering design]" (T2). Another teacher queried "I am not quite sure what this is, if you would tell me a bit about that" (T3). After giving a brief description of engineering design, T3 was able to connect it to the inquiry model that they use in the PYP, which is taking action. However, T3 highlighted that the actions are self-initiated by the students, rather than imposed by the teacher, to solve significant local or global issues, as stated in this response: “students self-initiate it and students should not be forced…we definitely outline or advocate or highlight the issue, the significant issues, globally and locally…and this is where it leads to the action.”

Despite the few learning experiences in engineering design, the trial and error process was mentioned as one of the techniques that students use while testing the model regardless if the process was guided or no. T6 indicated: “they [students] were given the materials, then they put them together and then they realize that no it didn’t function….and they tried again and again. It went through several steps before they finally worked.”

Technology integration

When teachers were asked to explain if and how do they use technological literacy in the classroom, five out of six teachers gave examples on the technological tools that they use, such as iPads, iPad applications and laptops. However, only one teacher indicated that technological literacy could be strengthened, as stated in the following response: “technological literacy is present, but could be strengthened…I don’t explicitly teach any technology skills” (T4).

Based on the responses, technology is mostly being used as a tool. All teachers reported that students use different technological tools, such as iPad applications, to show their understanding and learning. For instance, T3 stated: “they [students] had to use technology in a creative way to show their understanding. So many of them used the iMovies or timemaps, and they posted it on their online portfolios.”

In addition, technology is used as a tool for communication and research. The e-portfolio, Seesaw, had been repeated several times by many teachers. It is used for students to post their work and few teachers reported that they use it for giving feedback to students. Besides, laptops and iPads are used for research, exemplified in this response: “they [students] use a lot of technology, well mostly iPads, computers with me when doing research or creating presentations of notes to reflect their learning” (T4).

Integration of mathematics in the units

Teachers reported that mathematics is integrated within the units when it can be authentically integrated. The math strands that are usually integrated within the units are measurement, geometry and data handling, whereas the number strands are usually taught as stand-alone. Teachers stated that they involve students in collecting data, graphing and/ or tabulating their data, analyzing the data and interpreting the results. Two teachers indicated that they focus on the strategies or procedures that students use to obtain the answer.

Summary on instructional strategies

All of the teachers use diverse student-centered approaches, including group work, hands-on activities and class discussions, and guide their students to construct their own learning. All of the teachers reported follow the inquiry process and rely on the scientific method when teaching science-based units. All of the teachers focus on asking questions, formulating hypothesis, doing experiments and drawing conclusions. Several teachers reported that they provide students with choices to present their findings. Similarly, group projects are most commonly used among teachers.

Although problem solving was indicated by several teachers, only one teacher indicated that problem-based learning is somehow absent in the classroom and requires more work. In addition, several teachers were not sure about the meaning of engineering design and reported having little experience with it. Besides, constructing models are not used frequently, rather the teachers rely on simulations more.

Finally, technology integration was indicated by all teachers, and they emphasized using various technological tools, particularly iPads and different applications. Similarly, teachers reported integrating mathematics in the units, whenever it can be integrated. However, the most common mathematical strand that is integrated is data handling. The table below summarizes the main categories of the instructional strategies that were reported by teachers.

Table 2. Summary of Instructional Strategies

Instructional Strategy	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Student-centered approaches	Guiding Hands-on Activities Discussing Cater for the needs	Facilitator Not using activities direct instruction Hands-on Student-driven	Constructivism Students working to construct their own Hands-on learning Group	Class discussions Group work Encourage them to talk	Guiding them Leading the learning	Guided them

	Make connections Assigned roles	Group work Working in groups Connecting to real life	learning Work in groups Small groups Scaffolding Building on students' background Engaging Making connections Real-life context			
Inquiry-based learning	Inquiry Scientific process Write questions Asking questions	Inquiry cycle Scientific process Scientific method Asking	Inquiry-based Inquiry teacher Inquiry process Scientific	Inquiry Asked questions Observed Experiments	Scientific method Ask questions Hypothesis Plan	Inquiry cycle Scientific method Ask a question Write

	Hypothesis Observer Doing research Experiments Present findings Presenting work Reflect Focus on background	questions Investigation Planning Conclusion Reflection	method Record questions Personal queries Formulating hypothesis Conduct experiments Drawing conclusions Getting materials	Predicting Drew diagrams	Experiment Instructions Materials Background information	questions Hypothesize Experiment Research List a procedure Materials Draw a conclusion
Project-based learning	Interesting projects Many projects Decided	Project Given options Given choices	Personal projects Creating a well-being market	Group projects Final product Poster	Big project Building a city	-

	Different forms of showing their work	Multiple of choices				
Problem-based learning	-	Present everything as a problem	Solving a problem	Problem-based learning Problem solving	Go back to rules Division problem	Follow strategies Use context clues Break the word problem
Constructing models	Not sure Simulation Steps to follow Constructed model Tried Build Reconstruct	Very little experience Created models Dioramas Model of an invention Creating Building Designing	Not quite sure Construct model to test Art models Take action Highlight issues Self-initiate	Model of water cycle Very guided	Design	Construct Simulated Build Engineer Model Rebuild Trial and error process

		Explain				
Technology integration	iPads Technology is highly integrated Technology is used in classroom Different applications Seesaw Book creator Movie iMovie Green screen Videotaping	iPads SeeSaw Video Slideshows Express using technology BrainPop YouTube	Integrated in almost everything Use technology in a creative way Different apps Online porfolio iMovies Popplet Timemaps Ddifferent media to present work	iPads Use a lot of technology Computers Creating presentations	Using technology in research Apps Presentations	Apps Seesaw iMovie Book creator Popplet Explain everything Videos Visual media

	Reading using YouTube Books on YouTube Links					
Integration of mathematics in the units	Collecting data	Gathering data Mathematical connection Measurement activity Expressing in graph form Analyzing graphs Interpreting graphs	Construct a 3D shape using 2D shape	Mathematical thinking tied to involve unit Involve math in science Measurement Volume units Converting Reading	Data handling Use math to build shapes Follow on maps Latitude Longitude Grids Coordinate points	Capacity in lab Read measurements Compare measurements

	beaker	
		Plotting
	Line graphs of plant growth	

4.1.2.8 Collaboration as a way to support teachers' TPACK

The way teachers collaborate was grouped into three categories: 1) sharing sessions, 2) assistance of subject experts and 3) teachers as curriculum writers.

Sharing sessions

The sharing sessions were indicated by one teacher and one coordinator. During these sessions, teachers and coordinators share their ideas and plan together the learning engagements for the unit. One teacher indicated: "we have done a lot of work as to sharing sessions with other classes. Each teacher is sharing what she does in her classroom, so this way, we learn from each other" (T5). Similarly, one coordinator indicated: "we have sessions…and we introduce those new updates into those departments" (C2).

Assistance of subject experts

The assistance of subject experts or school-wide coordinators was mentioned by the director (D) and one coordinator (C2). The teachers can schedule meetings with subject experts (i.e. school-wide coordinators), who would give their input regarding the units and provide support for teachers, specifically with the content knowledge. D explained: "we need to support this homeroom teacher with subject experts…we created an environment of collaboration….this is how the subject coordinators are filling the gaps and making sure that the homeroom teacher is able to deliver the message properly.” Alongside, C2 stated: “we have now the school-wide coordinators. They are providing sessions to back us up in the content.”

Teachers as curriculum writers

Another way for teachers to collaborate is through taking an active role in writing the curriculum. Two coordinators indicated that teachers are given the opportunity to “construct” the curriculum and be “curriculum writers”. The teachers who were interested in writing the curriculum had the chance to be part of a curriculum committee, as C3 indicated:

> “Teachers voice their interest, and they have been grouped according to their interests. So you have those teachers who are more interested in science in the curriculum, or social studies or mathematics…so they are working in groups. They are given a period of 2 months and a half to prepare and come up with a proposal.”

Then, the proposal submitted will be revised by the administrators and specific feedback will be provided.

4.1.2.9 Coaching as a way to support teachers’ TPACK

Coaching is another way to support teachers’ TPACK at the school. The ways that coaching is implemented are through one-on-one planning, co-teaching and conducting classroom observations followed by feedback on the teaching.

Teachers can plan their lessons with the coordinators on a one-on-one basis, as reported by one teacher and one coordinator. The coordinators go over the lesson plans, modifies it, provides ideas for the teaching practices and tools for the learning engagements, and support with the assessment. One teacher reported working closely with the technology coordinator and “co-planning” with her. T3 stated: “I worked with [name of technology coordinator], she supports us with passion hour. I have this time every week with the students where they work on developing their 21st century skills of creating and constructing things.”

In addition, sometimes, the technology coordinator co-teaches with the homeroom teacher and provides demo-lessons as a way to assist the homeroom teacher in her class. Occasionally, the principal and coordinators conduct classroom observations and provide teachers with feedback on their instructional practices.

4.1.2.10 Professional development opportunities

Various professional development opportunities have been stated in the interviews, including study groups, one-day workshops and multiple day workshops. The study groups were mentioned by one teacher. They are conducted once a month where one teacher is the moderator and facilitates the session regarding a certain topic. T6 stated: “Our study groups are also professional development…I think the study groups that I took for technology with [name of a teacher] really helped me.”

Furthermore, all ten interviewees indicated workshops as an important part of professional development. Workshops, whether one-day or multiple-day, are provided at the school, and these workshops are either given by a guest speaker or teachers or administrators from the school. An example of a one-day workshop that was repeated several times in the interviews is the “professional development sessions during faculty meetings”. One teacher indicated that during a faculty meeting, the teachers were actively involved in the different stages of the inquiry cycle, which enhanced their understanding of its stages.

As for the multiple-day workshops, the examples that were given and repeated often were the “in-service days” that are conducted three times a year, and the after-school workshops given by administrators or coordinators. Usually, these workshops actively involve teachers through hands-on activities. One of the after-school series that was mentioned several times was the empowering inquirers workshop, which exposed teachers to different research strategies and was tailored to increase the teachers’ digital citizenship. However, most of the professional development opportunities that were mentioned are not tailored towards STEM education, rather they are related to the IB training and PYP needs. The director indicated that STEM-related workshops will be more evident next year.

4.1.2.11 Resources available to support teachers’ TPACK

Several kinds of resources were mentioned by teachers, coordinators and the direcor in the interviews. They were classified into: 1) physical resources, 2) online resources, and 3) human resources. The physical resources that were repeated by all interviewees include: computer desktop in class, laptops, iPads, manipulatives, makerspace, textbooks, fiction and non-fiction books, coding resources (e.g. sphero robots and makey makey), drones, little bits, SMART board, 3D printers and microscopes.

Many electronic resources were indicated by the teachers and coordinators, such as reading through A to Z, science through A to Z, iPad applications, IXL, e-portfolio (Seesaw), encyclopedia Britannica online, RAZ kids, educational channels, links provided by the school, and shared math folder which includes websites, worksheets and text resources.

Furthermore, all teachers, one coordinator and the director mentioned some human resources that support teachers in their TPACK. These human resources are the coordinators and the co-teachers. The human resources act as a source of encouragement for teachers to grow professional and stay updated. Many teachers indicated that the technology coordinator assists them with technology and science and supports the teachers in facilitating a student-centered and creative environment. The director emphasized: "We appointed this year a technology integration coordinator…you will see her role more active next year because this year, she's just started…[she] takes care of technology and STEM and this person works with all the teachers closely to introduce STEM-related projects or ideas or training."

4.1.2.12 Common external barriers to STEM education

This section presents one external barrier to STEM education that was shared between the director, coordinators and teachers, which is the "lack of vision for STEM education."

Lack of vision for STEM education

Several keywords and phrases that were indicated by the director, one coordinator and two teachers were grouped into the category of "lack of vision for

STEM education”. These keywords and phrases include: “no clear policy”, “vision”, “don’t believe that we follow STEM here”, and “STEM is not a particular area that the school has addressed.” D said: “proper implementation…started with a vision that the leadership…should support…they should push for it to happen in the school…otherwise it will become an individual effort on the behalf of the teacher, and the teachers will not be supported with the proper environment.”

However, the director ensured that incorporating STEM education as part of the school’s vision is important, and the school is workings towards that goal. D indicated:

“So at this school for example, this was a top importance for us, so STEM education is now in our vision and mission and our guiding statements. So our guiding statements embed STEM in them, so it’s a serious thing that is now embedded in the guiding statements….it’s supported by the Board and by the president and by the directors. It’s not an individual effort...So, I encourage other school to put it also in their guiding statements, so they see it as a purposeful integration of STEM fields, rather than an individual effort in the science department or the math department.”

4.1.2.13 External barriers from the point of view of the director

This section presents the external barriers that were only mentioned by the director. These external barriers are grouped into three categories: 1) Lack of space, 2) financial barrier and 3) Time constraints in the upper grades.

Lack of space

Another issue that emerged is space allocation. Students need to have sufficient space to carry out STEM-related activities or projects. Although the elementary school has a science lab/ makerspace, the director indicated that a school needs at least 3 makerspaces, each caters for a different kind of STEM project. One is specific for coding/ robotics, one for projects that deal with metal and wood cutting and one for the "clean projects" that do not make a mess. D stated:

> "there are certain projects that are clean…and there are projects that are dirty *ya3ne* [meaning] whatever deals with metal cutting and wood cutting, you make a big mess, and we prefer this kind of activity to be taking place in another room from the room [where] you have robots and you have laptops…You cannot have one room and say I have a makerspace and am done…one is for robotics, one is for assembly for clean projects and one for cutting."

Financial barrier

The financial barrier was reported by the director as one of the major barriers that is always present. He stated:

"the financial barrier. This is always present. We always try our best to overcome this barrier by getting stuff from around us. But when it comes to buying machinery, you need the money. You need the money for the laptops, you need the money for the 3D printer you need the money for the robots, you need the money for the consumable *ya3ne* [meaning] the materials that you consume and that you put in the making of things."

However, the teachers and coordinators did not regard money as a barrier, exemplified in this response: "but we're really lucky at the school because I know a lot of schools face barriers of like equipment, budget…and so we don't have those barriers. We do have the funding if we wana go forward with different things" (C1).

Time constraints in the upper grades

The director regarded time as a major barrier in the upper grades due to a policy-related issue, which is the payment of teachers in the Lebanese law. Particularly, middle and secondary teachers are paid by the hour and any extra hour should be paid as per the Lebanese law. The director reported that the working hours are barely enough for teaching, hence it is difficult to find time for teachers to collaborate. D explained:

> "the third barrier is time…for STEM to happen, you need teachers to collaborate…unfortunately in Lebanon, we have a major issue which is the payment of the teachers. Any collaboration period needs to be a paid period for the teacher to do it because you pay them by the hour and in the Lebanese law, you pay 20 hours for the full-time and if the 20 are always used for teaching, any extra planning, that is extra collaboration between departments, that could reach up to 3 or 4 hours of collaboration per week and these need to be paid according to the law and if schools don't pay them, then this would impact the quality of the work and the projects and *ya3ne* [meaning] it's a major major financial burden. You need to find the time and you need to secure the funds for it, so it's different from the elementary level. At the elementary level, teachers are hired as full timers for their full day. In the middle and secondary, teachers follow the Lebanese law which is a load of 20 periods. 20 periods are barely enough for teaching. Most schools use them for contact hours *ya3ne* [meaning] for teaching."

4.1.2.14 External barriers from the points of view of coordinators and teachers

This section presents the external barriers that were mentioned by the coordinators and teachers. These external barriers are grouped into two categories: 1) Curricular issues and 2) limited coordinators' support.

Curricular issues

The categories that constitute the curricular issues include: 1) limited opportunities for authentically integrating STEM in the units, and 2) lack of in-depth science integration within the units. First, the curriculum does not have adequate opportunities for authentically integrating STEM-related activities within the units, and the PYP POI should be revised to make room for STEM education. C1 indicated: "coding doesn't have a place that it can be integrated authentically. It can be integrated superficially…it's like putting a squared peg in a circle hole…but it doesn't quite go."

Besides, the school is focused on language, as exemplified in this response: "the major focus is language, that the students have to learn Arabic, French and English and that takes a tremendous amount of time…And I think it is hard to attain STEM goals when you have that type of program" (T2).

Regarding the second category, the science scope and sequence is not rich and the science program is not rigorous. Therefore, the science content is not covered in-depth. Although some units in the PYP POI are science-based, they tend to lean towards social studies rather than science. C1 indicated:

> "the science scope and sequence that we're using in the PYP isn't very rich…we've been very social studies heading…and so yes you might have some

> couple of science experiments that you do within that unit, but it's not really going into concepts that you need to understand within the science."

One teacher emphasized: "students need to have a block of science at least several times a week and that doesn't exist right now at the school" (T2).

Lack of support

Various keywords that were clustered in the category of "lack of support" constitute: "support that we're giving", "more support", "more personnel", "proper support", "human support from the coordinator", and "coordinator needs to be more involved". Three out of six teachers stated that they need adequate coordinators' support, which is currently lacking in the school. Teachers indicated that they need more support, while one coordinator questioned whether teachers are given enough support to implement STEM and integrate it. Besides, the coordinator indicated that the elementary school lacks a science coordinator, which reduces the support given for teachers to enhance their content and pedagogical regarding in-depth science concepts and teaching practices.

4.1.2.14 External barriers from the points of view of teachers

This section presents the external barriers that were mentioned only by the teachers. These external barriers are grouped into four categories: 1) Time constraints, 2) high number of students in class, 3) limited technological advances and/ or resources, and 4) lack of professional development opportunities related to STEM education.

Time Constraints

Time constraints act as one of the major barriers to properly implement STEM education at the school. Teachers reported that they are overloaded and they do not have enough time to just finish the curriculum. In addition, the contact hours of the homeroom teacher with the kids are not enough. T2 indicated:

> "students really are not with their homeroom teacher that much. I only see my students 3 or 4 hours a day, which is very different from those set-up in the United States or Canada, where most homeroom teachers are with their students 5, 6 or 7 hours a day."

Moreover, planning is time consuming and teachers need to be given sufficient collaboration time to plan, implement, reflect and revise. The word "planning" has been repeated several times in the interviews and one interviewee reported: "I think if we thoughtfully planned ahead when to use which tools, when to do which activities, there would be a higher level of STEM education" (T4).

High number of students in class

One teacher pointed out that the number of students in the classroom is high. The average number of students in class per teacher is 27 and teachers need more support in the classroom to properly implement STEM education. T5 stated when answering the question on barriers: "the number of students in the classroom per teacher. I mean having 27 students in the classroom is a lot for one teacher to handle, and you need support."

Limited technological advances and/ or resources

Three out of six teachers indicated that there are inadequate technological resources, specifically iPads. iPads are not readily available to each student as each grade level is sharing one iPad cart. Hence, many teachers reported that each student should have one iPad. In addition, several teachers reported that there are limited technological upgrades and they cannot keep track of these updates. One teacher stated that the school doesn't keep up well with the technology upgrades and there could be better work with that.

Lack of professional development opportunities related to STEM education

Four teachers reported common keywords, such as "lack of workshops", "more workshops", "workshops…and training", "never been trained in STEM", and "ongoing PD". T6 emphasized: "I need a workshop just on this [points at the word STEM education]. workshops…and training."

4.1.2.13 Common internal barriers to STEM education

This section presents one internal barrier to STEM education that was shared between the director, coordinators and teachers, which is the "insufficient technological and content knowledge."

Insufficient technological and content knowledge

As for the category on "insufficient technological and content knowledge", the director, one coordinator and two teachers indicated that teachers might not have a strong background in a certain discipline like science as the subject is not their specialty area. One teacher reported: "science is definitely one of my weakest subject area" (T4).

In addition, D indicated: “all the elementary education students who come from universities, respectful universities, they lack completeness in the science skills, math skills and the university courses that they give them are not enough and could contain a lot of misconceptions.” Similarly, C3 explained:

> “most universities address them as elementary school teachers who specialize in math and science or language or social studies…Yet, when they come to work in a school like ours, they are homeroom teachers, which means they are responsible for all of this.”

Besides content knowledge, some teachers reported lack of familiarity with several technological applications, and they need support in knowing when and how to use them. T1 said:

> “some of them [iPad applications] am not familiar with…meaning the updates. I can’t just be updated…to get to understand…I have like 10, 20, 30, 40 applications on my iPad and am just using 2 or 3…the technology, the pact at which it’s changing…it’s way too much.”

4.1.2.14 Internal barriers to STEM education from the points of view of the coordinators and teachers

This section presents the internal barriers that were mentioned by the coordinators and teachers. These internal barriers are grouped into two categories: 1) personal challenges and 2) teacher understanding of STEM education.

Personal challenges

The keywords that were grouped into the category of “personal challenges” include: “resistance”, “people tend to resist change”, “require sometimes extra effort”, “more learning”, “much rather be handed”, “teachers don’t have…the motivation”, “fire up the motivation”, “trouble working…to try to get them teach more difficult content”, and “I didn’t really manage to get them to teach something more challenging”. One teacher and one coordinator indicated that some teachers exhibit resistance to teach more challenging content or to be curriculum writers due to different factors, including lack of motivation, prefer to be handed ready-made plans, insufficient time to learn more or requires additional effort.

Teacher understanding of STEM education

One teacher and three coordinators indicated that being familiar with the term STEM or understanding the meaning of it is lacking in the school as many teachers are not aware of STEM education. Besides, teachers need to be aware of the rationale behind STEM education and see how it fits into their curriculum or teaching practices. C1 stated: “most teachers either haven’t heard about it or don’t know about it or aren’t convinced, maybe it’s not important, or don’t see how it fits into the curriculum.” Similarly, C2 indicated:

> “Why do we need STEM. Why do I want STEM. Why are you marketing STEM…is it any better than what we are doing?...Will STEM help me move forward? Does it contradict to my PYP? These are all questions that need to be answered.”

4.1.2.15 Summary of the findings from interviews

To conclude, the director's, coordinators' and teachers' perceptions and beliefs about integrated STEM education varied. The director and the coordinators were familiar with the term STEM, unlike the teachers, who most of them did not know what the term stand for. The director believes that STEM education prepares the students for future STEM-related jobs, whereas the coordinators and teachers considered STEM as a trend that is gaining popularity worldwide.

Similarly, the director's, coordinators' and teachers' beliefs about the relevant strategies for STEM education varied as well. The director and coordinators held similar beliefs, by indicating that project-based learning is important for STEM. However, the teachers' beliefs were diverse, which could be explained by the lack of familiarity or training in STEM education.

When the interviewees were asked about the barriers for implementing STEM education at the school, various answers were obtained. The barriers that were commonly reported by the director, coordinators ad teachers include lack of vision for STEM education and insufficient technological and content knowledge. However, the director stated three barriers (lack of space, financial barrier and time constraints in the upper grades) that were not indicated by coordinators and teachers. Coordinators and teachers shared common barriers, including curricular issues, limited coordinators' support, personal challenges (e.g. resistance) and teacher understanding of STEM education. Additional barriers were reported by teachers only, which are time constraints, high number of students in class and limited technological advances and/or resources.

4.2 Analysis of Observations

This section presents the quantitative and qualitative data obtained from the STEM Classroom Observation Protocol. The observational data collected will answer the second research question: What are the strategies that homeroom teachers use within the elementary classes that reflect integrated STEM education? Based on the research question, seven dimensions from the observational protocol that reflect the strategies for STEM education are analyzed and discussed. The dimensions are: (a) Math and Science Content, (b) Student Cognitive Engagement in Meaningful Instruction, (c) Inquiry Learning, Project-based learning and Problem-based learning, (d) Teacher Instruction/ Formative Assessment, (e) Common Instructional Framework, (f) Student Engagement and (g) Use of Technology.

4.2.1 Data Analysis Method

The quantitative data from the observations were retrieved on Excel for analysis. Each Excel sheet referred to a session and it tabulated all the dimensions from the observation protocol along with their indicators. The dimensions were coded for the purpose of this research, as follows:

1. MSC: Math and Science Content
2. CEM: Student Cognitive Engagement in Meaningful Instruction
3. IBL: Inquiry Learning, Project-based learning and Problem-based learning
4. FA: Teacher Instruction/ Formative Assessment
5. CIF: Common Instructional Framework
6. SE: Student Engagement

7. UOT: Use of Technology

The indicators were also coded for the purpose of this research by numbering the codes of their corresponding dimensions. For example, the first indicator in MSC, *math and science content information was accurate*, was coded as MSC1, the second indicator in MSC, *teacher's presentation or clarification of mathematics or science content knowledge was clear*, was coded as MSC2, etc. In addition, the units were coded as follows:

1. HWOO(3): the classroom observations of the HWOO unit in grade-3
2. HTWW(3): the classroom observations of the HTWW unit in grade-3
3. WWA(4): the classroom observations of the WWA unit in grade-4
4. HTWW(4): the classroom observations of the HTWW unit in grade-4
5. HWOO(3)L: the lab observations of the HWOO unit in grade-3
6. HTWW(3)L: the lab observations of the HTWW unit in grade-3
7. HTWW(4)L: the lab observations of the HTWW unit in grade-4

The sessions that were observed in each unit of both grade levels were 45 minutes. During each observation session, the researcher filled the observation protocol over three slots of time (each slot covered a 15-minute period). The rating that was given in every slot (every 15 minutes) was inserted for each indicator. Then, the mean scores across the slots of the sessions were calculated for each indicator.

However, some indicators in some dimensions are more important than the other indicators in the same dimension. Therefore, the weighted average was calculated for some of the dimensions (i.e. Math and Science Content; Student Cognitive Engagement in Meaningful Instruction; Inquiry Learning, Project-Based Learning and Problem-Based Learning; Teacher Instruction and Formative Assessment). The more important indicators were given a coefficient of 2 whereas the less important indicators were given a coefficient of 1. Then, the mean was calculated for each summary rating across the slots of the session.

Besides, each session had an “average score for the session”, which was obtained by calculating the mean scores for all the summary ratings.

Then, the global observation mean scores were calculated across all the indicators of the sessions, and the “average score for the sessions” was calculated across all the sessions. Moreover, another Excel workbook compiled all the global mean scores of all the dimensions and indicators for all of the units (HWOO(3), HTWW(3), WWA(4), HTWW(4)). One sheet included the global mean scores for the classroom observations and another sheet included the global mean scores for the lab/ makerspace observations. Then, the global means were calculated for each indicator.

The global mean scores were conditionally formatted. The mean scores between 0 and 1 were highlighted in red, which indicate that the sessions were not STEMy. The mean scores between 1.01 and 2 were highlighted in yellow, which indicate that the sessions were moderately STEMy. The mean scores between 2.01 and 3 were highlighted in green, which indicate that the sessions were highly STEMy.

Besides the quantitative data, qualitative data were collected by recording examples and notes that are specific for the indicators. The qualitative data will be used to support the quantitative findings through giving examples.

4.2.2 Findings from Observations

Seven observation sessions were carried out in one grade-3 section on the technology unit about How We Organize Ourselves (HWOO); 11 observation sessions were carried out in another grade-3 section on the science unit about How the World Works (HTWW); 8 observation sessions were carried out in one grade-4 section on the science unit about Who We Are (WWA); 9 observation sessions were conducted in another grade-4 section on the science unit about How the World Works.

Additional observations were conducted in the Science Lab and Makerspace in parallel with the class observations. The sessions carried out in the lab/ makerspace were connected with the corresponding units. In the grade-3 unit on HWOO, 7 observation sessions were carried out in the lab and makerspace. In the grade-3 unit on HTWW, 2 observation sessions were carried out. Similarly, 2 observation sessions were conducted for the grade-4 unit on HTWW. The latter observation sessions were few as several lab sessions were carried out in the classroom. Each unit's central idea and lines of inquiry are presented in table 3 below.

Table 3. Central idea and lines of inquiry for each unit

Unit and grade level	Central idea	Lines of inquiry
HWOO(3)	Cities develop systems that have a function and structure designed to meet people's needs	1. The structure of cities 2. The function of networks 3. Interconnectedness of networks within a city
HTWW(3)	Natural hazards alter the environment	1. What natural hazards are 2. How natural hazards alter the environment 3. Human responses to

		natural hazards
WWA(4)	Health is affected by the choices we make	1. How body systems are interconnected 2. How to maintain a balance 3. Consequences in making choices
HTWW(4)	Innovative thinking can lead to change	1. How creativity helps solve problems & develop passions 2. Evolution of ideas 3. Impact of technology on everyday life (negative & positive)

The findings from observations will be discussed based on the dimensions of the observation protocol, separating the analysis of the classroom observations from the analysis of the lab/ makerspace observations. Under each dimension, a global descriptive analysis of grade-3 and grade-4 will be provided. Then, the main differences between the units of each grade level will be analyzed descriptively. Interpretations will be given for the patterns that are found in the numerical tables and these interpretations will be supported by the qualitative notes taken.

4.2.3 Analysis of MSC: Classroom Observations

Global Descriptive Analysis

Table 4. MSC classroom observation global mean scores across the grade levels

Math and Science Content	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
MSC1	1.29	1.30	1.08	0.37	1.01	MSC1
MSC2	0.57	1.18	0.96	0.00	0.68	MSC2
MSC3	1.00	1.82	1.17	0.00	1.00	MSC3
MSC4	1.00	0.52	0.5	0.00	0.50	MSC4
MSC5	0.24	0.15	0.38	0.22	0.25	MSC5
MSC6	0.67	1.24	0.5	0.22	0.66	MSC6
MSC7	0.95	0.18	0.08	0.37	0.40	MSC7
MSC8	1.38	0.39	0.17	0.81	0.69	MSC8
MSC9	2.52	0.85	0.96	1.15	1.37	MSC9
MSC10	0.96	0.94	0.73	0.27	0.73	MSC10

Table 4 displays the classroom observation global mean scores across the grade levels. As shown in Table 4, most of the indicators obtained low mean scores over the grade levels, MSC5, *student mistakes or misconceptions were clearly addressed (emphasis on correct content here),* being the lowest with 0.25, while MSC3, *teacher used accurate and appropriate mathematics or science vocabulary,* was closer to the moderate (1.00). Two indicators obtained moderate mean scores, MSC1, *math and science content information was accurate*, and MSC9, *appropriate connections were made to real-world contexts*, with 1.01 and 1.37, respectively.

However, in HWOO(3), MSC8, *appropriate connections were made to other areas of mathematics/science or to other disciplines*, was moderate with a mean score of 1.38 and MSC9, *appropriate connections were made to real-world contexts*, was high with a mean score of 2.52 as opposed to other units.

However, MSC9, *appropriate connections were made to real-world contexts,* was moderate in HTWW(4) with a mean score of 1.15. Although MSC9 was low in WWA(4), its mean score (0.96) was closer to the moderate.

The mean scores for MSC10, *summary: Quality of Mathematics and Science Content*, indicates that the quality of math and science content is poor in grade-3 and grade-4. However, MSC10 for HWOO(3) and HTWW(3) were closer to the moderate with mean scores of 0.96 and 0.94, respectively as opposed to WWA(4) and HTWW(4) with mean scores of 0.73 and 0.27, respectively.

Grade-3 Descriptive Analysis

Table 5. MSC Classroom Observation mean scores for HWOO(3) across the sessions

Math and Science Content	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
MSC1	0.67	0.67	0	2	1	2.67	2	1.29	MSC1
MSC2	0.67	0.00	0.00	0.33	0.00	3.00	0.00	0.57	MSC2
MSC3	0.67	0.67	0	0.33	0.67	2.67	2	1.00	MSC3
MSC4	0.67	0.67	0.33	1.33	0	2	2	1.00	MSC4
MSC5	0	0	0	0	0	0.67	1	0.24	MSC5
MSC6	0	0	0.67	0.33	0	1	2.67	0.67	MSC6
MSC7	0.67	0	0	0	1	2	3	0.95	MSC7

MSC8	0	0	1.33	2	2.33	1	3	1.38	MSC8
MSC9	2.67	1.33	1.67	3	3	3	3	2.52	MSC9
MSC10	0.67	0.41	0.33	1.03	0.74	2.18	1.38	0.96	MSC10

Table 6. MSC Classroom Observation mean scores for HTWW(3) across the sessions

Math and Science Content	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
MSC1	1.67	2.00	3	2.667	3	2.00	0	0	0	0	0	1.30	MSC1
MSC2	1.00	1.00	3.00	3.00	3.00	2.00	0.00	0.00	0.00	0.00	0.00	1.18	MSC2
MSC3	3.00	3.00	3	3.00	3.00	2.00	3	0	0	0	0	1.82	MSC3
MSC4	1.67	2.00	0.00	2.00	0	0	0	0	0	0	0	0.52	MSC4
MSC5	0	0	1	0.667	0	0.00	0	0	0	0	0	0.15	MSC5
MSC6	1.67	2	3.00	2.67	2.333	2	0.00	0.00	0.00	0.00	0.00	1.24	MSC6
MSC7	1.00	0	0	0	1	0	0	0	0	0	0	0.18	MSC7
MSC8	0	0	1.00	2	0.67	0.667	0	0	0	0	0	0.39	MSC8
MSC9	3.00	3.00	1.33	1	0	1	0	0	0	0	0	0.85	MSC9
MSC10	1.56	1.62	1.87	2.13	1.69	1.21	0.31	0.00	0.00	0.00	0.00	0.94	MSC10

Tables 5 and 6 show the classroom observations' mean scores for HWOO(3) and HTWW(3) across the sessions. When comparing the MSC for both units in grade-3, one may notice that in HWOO(3), the MSC was more evident by the end of the unit, whereas in HTWW(3), MSC was more evident in the beginning of the unit. In both units, MSC1, *math and science content information was accurate*, was moderate with mean scores of 1.29 for HWOO(3) and 1.30 for HTWW(3).

As shown in Table 5, MSC9, unlike other indicators, was highly respected in all the sessions in HWOO(3). However, MSC8 and MSC9 obtained low mean scores in

HTWW(3) with values of 0.39 and 0.85, respectively. In HTWW(3), MSC6, *teacher and students discussed key mathematical or science ideas and concepts in depth*, got a moderate mean score of 1.24 as opposed to the low mean score (0.67) in HWOO(3), indicating that science-based units cover science content in more depth than technology-based units.

As shown in Table 6, in HTWW(3), MSC1, *math and science content information was accurate,* MSC2, *teacher's presentation or clarification of mathematics or science content knowledge was clear*, MSC3, *teacher used accurate and appropriate mathematics or science vocabulary*, and MSC6, *teacher and students discussed key mathematical or science ideas and concepts in depth*, had moderate to high mean scores across the sessions in the beginning of the unit as opposed to HWOO(3), indicating that the math and science content was emphasized by the teacher.

Grade-3 Interpretive Analysis

In HTWW(3), the unit was about natural hazards (see Table 3), and the teacher modelled one natural hazard and explained it in-depth in the beginning of the unit. For instance, the teacher discussed "tectonic plates", "how mountains are formed", "Pangea-separation of continents", and "Earth's layers". In addition, various science vocabulary were used, such as "collide", "fossils", "tectonic plates", "fault line", "hypocenter", and "epicenter". But when the students started their own research, the teacher didn't discuss the science concepts in-depth, hence explaining why the science content, particularly MSC1, MSC2, MSC3 and MSC6, were more evident in the beginning of the unit.

However, in HWOO(3), the science content was more evident by the end of the unit when the teacher discussed the city's networks in-depth. For example, when explaining about the water system, the teacher discussed about "compositing toilets" and how "dry toilets use lime or ash to cover and break apart stool and urine."

Although, the science content was not rich in this unit, there were many connections to real-world contexts and to other disciplines. For example, students named many systems in a city and gave examples; teacher requested students to write functions of 3 city networks; the unit was connected to environmental science as the students read a comic about one sustainable development goal which was sustainable cities and communities, and discussed scientific words, such as sustainable, air quality and waste management.

Grade-4 Descriptive Analysis

Table 7. MSC classroom observation mean scores for WWA(4) across the sessions

Math and Science Content	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
MSC1	0	0	3	2	1	0.67	0.67	1.33	1.08	MSC1
MSC2	0.67	0.00	1.00	2.00	1.00	0.67	0.67	1.67	0.96	MSC2
MSC3	0	1	2	2	1	0.67	0.67	2	1.17	MSC3
MSC4	0	0	0	2	0	0.67	0.67	0.67	0.5	MSC4
MSC5	0	0	1	1.33	0.67	0	0	0	0.38	MSC5
MSC6	0	0	1	1.67	0.67	0	0	0.67	0.5	MSC6
MSC7	0	0	0	0	0	0	0	0.67	0.08	MSC7
MSC8	0	0	0	1.33	0	0	0	0	0.17	MSC8
MSC9	1	0	0	2	0	1.33	1.33	2	0.96	MSC9
MSC10	0.18	0.15	1.08	1.72	0.56	0.51	0.51	1.13	0.73	MSC10

Table 8. MSC classroom observation mean scores for HTWW(4) across the sessions

Math and Science Content	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
MSC1	1.00	0	0	1.33	0.67	0.33	0	0	0	0.37	MSC1
MSC2	0	0	0	0	0	0	0	0	0	0	MSC2
MSC3	0	0	0	0	0	0	0	0	0	0	MSC3
MSC4	0	0	0	0	0	0	0	0	0	0	MSC4
MSC5	1	0	0	0	0	0	0	0	1	0.22	MSC5
MSC6	1	0	0.00	1.00	0	0	0	0	0	0.22	MSC6
MSC7	2.33	1	0	0	0	0	0	0	0	0.37	MSC7
MSC8	0.67	3	0	2	1.00	0.67	0	0	0	0.81	MSC8
MSC9	1.00	3	3	2	1	0.33	0	0	0	1.15	MSC9
MSC10	0.62	0.54	0.23	0.59	0.26	0.13	0	0	0.08	0.27	MSC10

Tables 7 and 8 show the MSC classroom observation mean scores for WWA(4) and HTWW(4). In both units, most of the indicators obtained low mean scores, indicating that the content was poorly covered. However, the science content was more evident in the WWA(4) than in HTWW(4) as evidenced by MSC10's, *summary: Quality of Math and Science Content,* mean score of 0.73 in WWA(4) compared to 0.27 in HTWW(4).

Only session 4 in WWA(4) covered the science content moderately as evidenced by the moderate mean scores of almost all of its indicators (see Table 7). In addition, MSC1, *math and science content information was accurate,* MSC2, *teacher's presentation or clarification of mathematics or science content knowledge was clear*, MSC3, *teacher used accurate and appropriate mathematics or science vocabulary*, and MSC4, *teacher/students emphasized meaningful relationships among different facts,* *skills, and concepts*, and MSC9, *appropriate connections were made to real-world contexts,* had mean scores of 2, which were closer to the high range.

As shown in Table 7, MSC2, *teacher's presentation or clarification of mathematics or science content knowledge was clear*, MSC3, *teacher used accurate and appropriate mathematics or science vocabulary,* and MSC4, *teacher/students emphasized meaningful relationships among different facts, skills, and concepts*, were completely absent in HTWW(4) (mean score = 0).

Grade-4 Interpretive Analysis

More science content was covered in WWA(4) than in HTWW(4) as the former unit covered the body systems and their functions. However, the content was not covered in-depth. For example, the teacher explained about the two types of blood cells and their functions, discussed the function of the heart and used science vocabulary (e.g. atrium, ventricle…) and clarified the function of the blood vessels. The information presented were frequently related to real-life as the teacher related the functions of certain body systems to the conditions of the person (e.g. how does the circulatory system function when doing physical activity, what happens to the white blood cells when a person is sick…).

Although the science content was not covered adequately in HTWW(4), the teacher made connections to real-world contexts and to other disciplines (technology and science) in the beginning of the unit when there were class discussions. For example, when students were asked to differentiate between a discovery and an invention, one student gave glass as an example of an invention. Then, the teacher gave the students time to think about the example, and asked them about fire: "How many think that this is a discovery?”. Then the teacher counted: 26 out of 27 students said it is a discovery. The teacher made a connection to math by asking students to provide the fraction. Then, the students were justifying their answers to the question about fire. Teacher scaffolded on students’ answers and explained that because fire is present, all you need to do is to light it, whereas an invention is something that is human-made.

As the unit progressed, the students were working independently on their inventions, and there was more one-on-one discussions with the teacher. Hence, no science or math content was explained as a whole class.

4.2.4 Analysis of CEM: Classroom Observations

Global Descriptive Analysis

Table 9. CEM classroom observation global mean scores across the grade levels

Student Cognitive Engagement in Meaningful Instruction	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
CEM1	2.43	1.91	1.29	1.74	1.84	CEM1
CEM2	1.67	1.12	1.00	1.26	1.26	CEM2
CEM3	1.52	2.33	0.63	1.30	1.44	CEM3
CEM4	1.10	0.36	1.33	1.07	0.97	CEM4
CEM5	0.52	0.00	0.58	0.96	0.52	CEM5
CEM6	0.62	0.15	0.00	1.00	0.44	CEM6
CEM7	1.50	1.25	0.86	1.29	1.22	CEM7

Table 9 displays the CEM classroom observation global mean scores across all the grade levels. CEM7, *Summary: Quality of Student Cognitive Engagement in Meaningful Instruction,* obtained a mean score of 1.22, indicating that the quality of CEM was moderate across the grade levels. WWA(4) was the unit with the least CEM as most of its indicators obtained low mean scores, while HWOO(3) was the unit with the most CEM as most of its indicators obtained moderate and high mean scores.

Most of the indicators obtained moderate mean scores over the grade levels, with CEM6, *students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena,* being the lowest with a mean score of 0.44, and CEM1, *students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.* , being the highest with a mean score of 1.84.

CEM5, *students were asked to apply knowledge to a novel situation*, and CEM6, *students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena*, were poorly implemented across all the grade levels, whereas CEM1 was highly respected across the grade levels. Although CEM4, *students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena*, obtained a low mean score of 0.97, it was closer to the moderate.

Grade-3 Descriptive Analysis

Table 10. CEM classroom observation mean scores for HWOO(3) across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
CEM1	3.00	2.00	1.67	2.33	2.00	3.00	3.00	2.43	CEM1
CEM2	2	1	1.67	0.67	1	2.33	3	1.67	CEM2
CEM3	0	1.67	2.33	0.67	1.67	1.33	3	1.52	CEM3
CEM4	2	1.33	0.33	0.33	0.67	1	2	1.10	CEM4
CEM5	0	0.67	0	0	0	0	3	0.52	CEM5
CEM6	0	0.33	1.33	0.33	0	1.33	1	0.62	CEM6
CEM7	1.33	1.30	1.44	0.89	1.11	1.74	2.67	1.50	CEM7

Table 11. CEM classroom observation mean scores for HTWW(3) across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
CEM1	3.00	3.00	1.67	1.67	2.00	1.67	1.33	3.00	2.00	0.67	1.00	1.91	CEM1
CEM2	3	3	2.00	0.67	0.667	1.33	1.667	0	0	0	0	1.12	CEM2
CEM3	2.67	3.00	2.00	0.67	2.00	2.67	2.667	3	2	2	3	2.33	CEM3
CEM4	1	1.00	0.00	0.00	0.00	0	2	0	0	0	0	0.36	CEM4
CEM5	0	0.00	0	0	0	0	0	0	0	0	0	0.00	CEM5
CEM6	0.67	0.00	0.00	1.00	0	0.00	0	0	0	0	0	0.15	CEM6
CEM7	2.11	2.11	1.26	0.78	1.04	1.26	1.48	1.33	0.89	0.59	0.89	1.25	CEM7

Tables 10 and 11 display the CEM classroom observation mean scores for HWOO(3) and HTWW(3) across the sessions. CEM7, *summary: Quality of Student Cognitive Engagement in Meaningful Instruction*, was moderate in both units, and most of the indicators got moderate to high mean scores. When comparing CEM7 in both units, CEM was more evident in HWOO(3) (1.50) than in HTWW(3) (1.25).

In HWOO(3), CEM1, *students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.*, obtained a high mean score of 2.43 and the indicator was highly respected across the sessions. However, CEM1 was moderate in HTWW(3) with a mean score of 1.91, which is closer to the high range. In both units, CEM1 was evident by the end of the units.

In HTWW(3), CEM3, *students were given opportunities to summarize, synthesize, and generalize*, was high with a mean score of 2.33 and the indicator was highly respected throughout the whole unit (see Table 11). However, CEM3 was moderate in HWOO(3) with a mean score of 1.52 and it was more evident by the end of the unit (see Table 10).

CEM4, *students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena*, was moderate in HWOO(3) with a mean score of 1.10, but it was low in HTWW(3) with a mean score of 0.36, indicating that the teacher in HTWW(3) determined the means of representation.

Grade-3 Interpretive Analysis

In HWOO(3), there were several instances where students were engaged in high cognitive activities, which contributed to the high CEM1 indicator across the sessions. For example, at the beginning of the session 1, the teacher asked a question: “how can we build a circuit to make the lightbulb turn on?”, and students had to answer without the help of the teacher. Other ways that the teacher engaged students were through asking each other questions and providing answers without the teacher’s help, and engaging them in rewriting a comic for second graders using age-appropriate words.

Similarly, in HTWW(3), some of the high cognitive activities that the teacher engaged students were through making predictions, providing reasonable explanations, and researching about natural hazards, which was evident in several sessions by the end of the unit. However, students were always given opportunities to summarize and synthesize through their research and explanations, rendering the high mean score for CEM3.

Students were given limited opportunities to represent phenomena using various means in HTWW(3) as the teacher determined the mean of representations, which was PowerPoint presentations, thus rendering the absence of CEM4.

Grade-4 Descriptive Analysis

Table 12. CEM classroom observation mean scores for WWA(4) across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
CEM1	1.67	0.00	0.33	1.33	1.00	2.00	2.33	1.67	1.29	CEM1
CEM2	0	1.33	1	1.67	1	0.67	1	1.33	1.00	CEM2
CEM3	0	0	0	0.33	2	0.67	0.67	1.33	0.63	CEM3
CEM4	1	1.33	0.67	1	2	2	2	0.67	1.33	CEM4
CEM5	0	0	0	0	0	2	2	0.67	0.58	CEM5
CEM6	0	0	0	0	0	0	0	0	0.00	CEM6
CEM7	0.48	0.44	0.37	0.85	1.11	1.19	1.33	1.11	0.86	CEM7

Table 13. CEM classroom observation mean scores for HTWW(4) across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
CEM1	0.33	3.00	2.33	2.00	1.67	0.00	2.67	2.00	1.67	1.74	CEM1
CEM2	0.667	2.333	3.00	0.67	0.667	0.00	2.67	0.00	1.333	1.26	CEM2
CEM3	0.667	3.00	3.00	2.00	1.00	2.00	0	0	0	1.30	CEM3
CEM4	0	3.00	2.33	0.00	0.00	1.333	1	0.667	1.333	1.07	CEM4
CEM5	0	3.00	2.33	0	0	0	0	2	1.33	0.9	CEM5

			3						3	6	
CEM6	0	3.00	2.67	0.00	0	2.00	1.33	0.00	0	1.00	CEM6
CEM7	0.37	2.85	2.67	1.04	0.74	0.81	1.44	0.74	0.96	1.29	CEM7

Tables 12 and 13 show the CEM classroom observation mean scores for WWA(4) and HTWW(4) across the sessions. CEM7, *summary: Quality of Student Cognitive Engagement in Meaningful Instruction*, was moderate in HTWW(4) with a mean score of 1.29, but low in WWA(4) with a mean score of 0.86, indicating that the quality of CEM was better in HTWW(4) than in WWA(4). Most of the indicators in HTWW(4) obtained moderate mean scores as opposed to WWA(4).

CEM1, *students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.*, and CEM4, *students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena*, were moderate in both units. However, CEM2, *students were asked to explain or justify their thinking*, and CEM3, *students were given opportunities to summarize, synthesize, and generalize*, were moderate in HTWW(4), but low in WWA(4).

As shown in Table 13, sessions 2 and 3 in HTWW(4) were characterized with high CEM, indicating that these sessions were highly implementing STEM approaches as students were highly engaged in all the CEM indicators.

Grade-4 Interpretive Analysis

The HTWW(4) unit had more opportunities for students to engage in CEM indicators than WWA(4). For example, the students were involved in the engineering design process throughout the whole unit. In sessions 2 and 3, which had high CEM mean scores, the students were interviewing each other twice to obtain in-depth notes about a certain problem (empathize with their partners) in order to think of a solution based on their partner's needs. Then, they had to write about the user's needs (things that they are trying to do) and insights (new learnings about their partner's feelings/ worldview to leverage in their designs and make inferences from what they heard). Then, the students had to define the problem statement by writing "(partner name) needs a way to (user's need)….Surprisingly// because// but [circle one] (insight)". Afterwards, students had to sketch at least 5 radical ways to meet their user's needs.

In other sessions, students were researching, synthesizing and sharing their research on inventions. By the end of the unit, the students had to come up with different solutions for their problem, and they had to compare these solutions and choose the most feasible one.

However, in WWA(4), the students were mostly engaged in a carousel activity, through which they had to rotate between tables (centers) and write examples and draw and label the body systems. The carousel activity was done for each body system (e.g. respiratory, circulatory, digestive…).

4.2.5 Analysis of IBL: Classroom Observations

Global Descriptive Analysis

Table 14. IBL classroom observation global mean scores across the grade levels

Inquiry Learning, PjBL & PBL	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
IBL1	2.81	2.27	1.46	2.00	2.14	IBL1
IBL2	1.19	0.61	1.29	1.41	1.12	IBL2
IBL3	0.29	0.97	0.25	0.70	0.55	IBL3
IBL4	0.90	0.79	0.33	1.19	0.80	IBL4
IBL5	0.67	0.00	0.33	0.96	0.49	IBL5
IBL6	0.76	0.45	0.21	1.11	0.63	IBL6
IBL7	0.52	0.15	0.63	1.30	0.65	IBL7
IBL8	0.05	0.00	0.00	0.15	0.05	IBL8
IBL9	0.43	0.00	0.33	1.30	0.51	IBL9
IBL10	0.96	0.71	0.61	1.17	0.86	IBL10

Table 14 displays the IBL classroom observation global means scores across the grade levels. Most of the indicators had low mean scores over the grade levels, with IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process*, being the lowest with a mean score of 0.05. Project-based learning, scientific inquiry and engineering design were poorly implemented as evidenced by the low mean scores of IBL3 (0.55), *students developed their own questions and/or hypotheses to explore or test*, IBL4 (0.80), *students engaged in scientific inquiry process (tested hypotheses and made inferences)*, IBL5 (0.49), *students determined which problem-solving strategies to use*, IBL6 (0.63), *students had to* *present or explain results of project*, IBL7 (0.65), *students worked on a project requiring creativity*, IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process*, and IBL9 (0.51), *there was an explicit evidence of students using engineering (or reverse engineering) design process.* However, HTWW(4) was the unit that implemented IBL moderately as most of its indicators had moderate mean scores, indicating that the unit was closest to STEM as opposed to the other units.

Conversely, IBL1, *students were engaged in open-ended tasks or questions*, had the highest mean score of 2.14, and it was highly respected across all the units, indicating that teachers frequently engage students in open-ended tasks or questions.

Furthermore, IBL2, *students engaged in hands-on or real-life problem solving activities or a lab experiment*, had moderate mean score of 1.12. All the units obtained moderate mean scores of IBL2, except for HTWW(3), with a low mean score of 0.61.

Grade-3 Descriptive Analysis

Table 15. IBL classroom observation mean scores for HWOO(3) across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
IBL1	3.00	2.67	2.00	3.00	3.00	3.00	3.00	2.81	IBL1
IBL2	2	0	1.33	0	0	2	3	1.19	IBL2
IBL3	1.33	0	0	0	0	0.67	0	0.29	IBL3
IBL4	1.33	0.33	0	0.67	0	2	2	0.90	IBL4
IBL5	1.67	0	0	0	0	0	3	0.67	IBL5
IBL6	0.67	1.33	0.00	0.33	0.00	0.00	3.00	0.76	IBL6
IBL7	0.00	0.00	0.00	0.67	0.00	0.00	3.00	0.52	IBL7

IBL8	0	0	0	0	0	0	0.33	0.05	IBL8
IBL9	0	0	0	0	0	0	3	0.43	IBL9
IBL10	1.38	0.52	0.48	0.60	0.43	1.10	2.24	0.96	IBL10

Table 16. IBL classroom observation mean scores for HTWW(3) across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
IBL1	3.00	3.00	2.00	1.33	2.00	1.00	2.67	3.00	2.00	2.00	3.00	2.27	IBL1
IBL2	2.33	3	0.00	0	0	0	0	0	1.33	0	0	0.61	IBL2
IBL3	2.00	3	0.33	0.667	0	0.00	1	3	0.67	0	0	0.97	IBL3
IBL4	1.67	2.00	1	1.00	0	0	1	2	0	0	0	0.79	IBL4
IBL5	0.00	0	0	0	0	0	0	0	0	0	0	0.00	IBL5
IBL6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	3.00	0.45	IBL6
IBL7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	1.00	0.15	IBL7
IBL8	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	IBL8
IBL9	0	0	0	0	0	0	0	0	0	0	0	0.00	IBL9
IBL10	1.29	1.57	0.48	0.43	0.29	0.14	0.67	1.14	0.57	0.48	0.71	0.71	IBL10

Tables 15 and 16 show the IBL classroom observation mean scores for HWOO(3) and HTWW(3) across the sessions. Most of the indicators obtained low mean scores, indicating a poor implementation of inquiry-based learning, problem-based learning and project-based learning. In both units, IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process*, had the lowest mean score of 0.05 in HWOO(3) and 0 in HTWW(3), while IBL1, *students were engaged in open-ended tasks or questions*, had the highest mean score of 2.81 in HWOO(3) and 2.27 in HTWW(4). In addition, IBL1 was highly respected across all the sessions in both units. However, IBL2, *students engaged in hands-on or real-life* *problem solving activities or a lab experiment*, was moderate in HWOO(3) with a mean score of 1.19, while it was low in HTWW(3) with a mean score of 0.61.

Despite the low mean scores, the IBL indicators got higher mean scores in HWOO(3) than in HTWW(3), where three indicators (IBL5, IBL8 and IBL9) were totally absent in HTWW(3). Moreover, session 7 in HWOO(3) was characterized with a high mean score of 2.24 as shown in table 14.

Grade-3 Interpretive Analysis

Inquiry learning was confined to asking open-ended questions and engaging students in hands-on activities as evidenced by the patterns discussed above. The hands-on activities were evident in the beginning of the HTWW(3) unit as a way of exploring the unit. For example, at the beginning of the unit, the students were engaged in the “see/ think/ wonder” activity, where they had to describe what they see, write what do they think about this picture and give their guesses, and wonder through asking questions (what, why, where, how).

Moreover, project-based learning and engineering design were absent in the HTWW(3) unit as students researched their natural hazards and presented their findings without creating a project or constructing models. However, PjBL and engineering design were evident in HWOO(3) unit, particularly by the end of the unit, because students had to build a city. The students were engaged in the engineering design process as they drew their blueprints of the city model and planned how to make one city network more sustainable.

Grade-4 Descriptive Analysis

Table 17. IBL classroom observation mean scores for WWA(4) across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
IBL1	0.67	0.67	0.67	2.00	1.67	2.00	2.00	2.00	1.46	IBL1
IBL2	1	1.33	0	0.33	1.67	2	2	2	1.29	IBL2
IBL3	0	0	0	0	2	0	0	0	0.25	IBL3
IBL4	0	0	0	0	0.67	0.67	0.67	0.67	0.33	IBL4
IBL5	0	0	0	0	0	1.33	1.33	0	0.33	IBL5
IBL6	0.33	0.00	0.00	0.00	0.33	0.33	0.67	0.00	0.21	IBL6
IBL7	0.33	0.00	0.00	0.33	0.33	2.00	2.00	0.00	0.63	IBL7
IBL8	0	0	0	0	0	0	0	0	0.00	IBL8
IBL9	0	0	0	0	0	1.33	1.33	0	0.33	IBL9
IBL10	0.29	0.29	0.10	0.36	0.90	1.12	1.14	0.67	0.61	IBL10

Table 18. IBL classroom observation mean scores for HTWW(4) across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
IBL1	2.00	3.00	3.00	2.00	1.67	0.00	2.67	2.00	1.67	2.00	IBL1
IBL2	0	3	2.33	2	1	0	2.67	0.00	1.67	1.41	IBL2
IBL3	0.00	2	0	0	0	0.00	2.67	0.00	1.67	0.70	IBL3
IBL4	0.00	3.00	2.333	0.67	0.333	0	2.67	0.00	1.67	1.19	IBL4
IBL5	0.00	2.333	1.667	0	0	0	2.67	2.00	0.00	0.96	IBL5
IBL6	0.00	2.00	2.00	1.00	1.00	1.33	2.67	0.00	0.00	1.11	IBL6
IBL7	0.00	3.00	2.33	0.00	0.00	0.00	2.67	2.00	1.67	1.30	IBL7
IBL8	0	0.667	0.667	0	0	0	0.00	0.00	0.00	0.15	IBL8
IBL9	0	3	2.333	0	0	0	2.67	2.00	1.67	1.30	IBL9
IBL10	0.29	2.52	1.86	0.74	0.50	0.10	2.48	0.86	1.19	1.17	IBL10

Tables 17 and 18 display the IBL classroom observation mean scores for WWA(4) and HTWW(4) across the sessions. There were significant differences between the two units in implementing IBL. HTWW(4) displayed more instances of IBL compared to WWA(4) as HTWW(4) had more opportunities for project-based learning, scientific inquiry and engineering design.

As shown in Table 18, in HTWW(4), most of the indicators obtained moderate mean scores, with IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process*, being the lowest with a mean score of 0.15 and IBL1, *students were engaged in open-ended tasks or questions,* being the highest with a mean score of 2. Most of the inquiry learning occurred in the beginning and the end of the unit, and two sessions (sessions 2 and 7) displayed high IBL instances compared to the other sessions.

Grade-4 Interpretive Analyis

HTWW(4) was characterized with better implementation of inquiry-based learning as it engaged students in scientific inquiry, project-based learning and engineering design challenges. For example, many sessions in HTWW(4) were dedicated for the steps of the engineering design process (step 1: identify a problem; step 2: develop solutions; step 3: choose a solution; step 4: build a prototype; step 5: test the prototype; step 6: communicate your results). First, the students were engaged in a quick design challenge, where they had to create an invention or improve a certain technology in a limited period of time. The students went over all the engineering-design process steps as they worked on building their prototypes, testing them, sharing them and getting feedback on their designs. Some students had the chance to improve their designs based on the oral feedback provided. Then, the teacher wrapped the design process and asked questions about each step (e.g. “what does empathy mean have to do with designing?”, “why should we start empathizing with our partner?”, “what does ideate mean”, etc.).

Subsequent sessions were dedicated for the steps in the engineering design process. The students identified several problems through asking questions to identify the user’s needs. Then, they had to ideate and generate solutions to meet the user’s needs and share the solutions and receive feedback. Afterwards, they had to choose one problem that they want to address and discuss it with the teacher for the feasibility before proceeding to step 3 (choosing a solution). After receiving the teacher’s feedback, the students planned the materials needed and the procedure for building the prototype, and drew sketches of their designs. Finally, the students built their prototypes and presented their prototypes to third graders.

In addition, the teacher engaged students in reading certain texts related to various inventions (e.g. robots, vacuum cleaners, compact discs, air conditioners, cell phones, lasers, x-rays, copying machines, antibiotics, computers, TVs, rockets and airplanes), and asked them to answer the following questions, that were related to the unit’s lines of inquiry:

1. How technology evolved through time?
2. What are the positive and negative impacts of technology on our everyday lives?
3. How the invention helped us solve problems?

However, in WWA(4), inquiry learning was mostly confined to asking open-ended questions, such as “what happens to our body if one system gets hurt?”, ““why there was a piece of a gum in the large intestine?”, “why the boy in the video had more white blood cells than usual?”, “What other recommendations do you suggest other than the inhaler?”, etc. Two sessions were dedicated for hands-on activities, where each table was a center for a different activity (e.g. puzzles, simulations, iPad applications). The center for simulations allowed students to simulate one body system using the materials provided without being involved in solving a certain problem.

4.2.5 Analysis of FA: Classroom Observations

Global Descriptive Analysis

Table 19. FA classroom observation global mean scores across the grade levels

Teacher Instruction/ Formative Assessment	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
FD	0.43	0.12	1.042	0.26	0.46	FD
FA2	0.95	0.55	0.667	0.78	0.74	FA2
FA3	1.48	1.21	0.75	1.07	1.13	FA3
FA4	2.05	0.91	1.083	1.93	1.49	FA4
FA5	0.29	0.03	0	0.48	0.20	FA5
FA6	1.29	0.70	0.375	0.30	0.66	FA6
FA7	1.10	0.52	0.208	0.41	0.56	FA7
FA8	1.04	0.59	0.658	0.73	0.76	FA8

Table 19 shows the FA classroom observation global mean scores across the grade levels. Most of the indicators obtained low mean scores, with FA5, *students were* *engaged in self- and/or peer-assessment,* being the lowest with a mean score of 0.20. FA4, *teacher provided specific feedback to students*, was the highest with a moderate mean score of 1.49. FA3, *teacher used a variety of strategies to monitor student learning and understanding throughout the lesson*, and FA4 were moderately respected across all the units.

In addition, HWOO(3) was characterized with the most unit that implemented FA, as it was the only unit that obtained a moderate mean score of 1.04. Most of the unit's indicators had moderate to high mean scores. FA3, *teacher used a variety of strategies to monitor student learning and understanding throughout the lesson*, had a mean score of 1.48 (moderate), FA4, *teacher provided specific feedback to students,* had a mean score of 2.05 (high), FA6, *teacher adjusted or differentiated instruction based on evidence of student learning*, had a mean score of 1.29 (moderate) and FA7*, students were given opportunities to reflect on their own learning,* had a mean score of 1.10 (moderate). Although FA2*, teacher provided clear criteria for success/examples of good work to students*, had a low mean score of 0.95, it was closer to the moderate.

Grade-3 Descriptive Analysis

Table 20. FA classroom observation mean scores for HWOO(3) across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
FD	0.33	0.33	0.33	0.67	0.33	0.67	0.33	0.43	FD
FA2	1.33	0	1	1.33	1.33	0.67	1	0.95	FA2
FA3	0.33	1.33	1.33	1.33	2.33	1.67	2.00	1.48	FA3
FA4	2	1.67	2	2	2	1.67	3	2.05	FA4
FA5	1	0	1	0	0	0	0	0.29	FA5
FA6	0	1.33	1	2	1	2	1.67	1.29	FA6
FA7	2	3	0.67	0	1	1	0	1.10	FA7
FA8	0.90	0.93	1.00	1.07	1.20	1.07	1.13	1.04	FA8

Table 21. FA classroom observation mean scores for HTWW(3) across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
FD	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.33	0.00	0.12	FD
FA2	1.33	0	0	0.00	0.33	0.67	0	0	0.33	1.33	2	0.55	FA2
FA3	2.33	3.00	1.00	1.67	1.00	1.33	3.00	0.00	0.00	0.00	0.00	1.21	FA3
FA4	1	1.00	1.33	2	0.333	0.67	0	0	0	1.33	2.33	0.91	FA4
FA5	0	0	0	0	0	0	0	0	0	0.33	0	0.03	FA5
FA6	1.33	2.00	0.67	1	0.667	1.333	0.67	0.00	0.00	0.00	0.00	0.70	FA6
FA7	0.67	2	0.33	1.333	0	1.333	0	0	0	0	0	0.52	FA7
FA8	1.10	1.10	0.43	0.77	0.37	0.73	0.73	0.00	0.13	0.50	0.63	0.59	FA8

Tables 20 and 21 show the FA classroom observation mean scores for HWOO(3) and HTWW(3) across the sessions. HWOO(3) had better mean scores across the sessions for FA3, FA4 and FA6 than HTWW(3). As shown in table 21, in HTWW(3), the indicators were more evident in the beginning of the unit, and many indicators were totally absent (FD, FA2, FA5, FA6 and FA7) across the sessions by the end of the unit.

Grade-3 Interpretive Analysis

In HWOO(3), there were several instances where the teacher provided specific feedback for the students. For example, when the students were trying to build a circuit in the beginning of the unit, the teacher went to each pair and gave constructive feedback. The teacher always circulated between the students and provided feedback through prompts, asking questions or guided instructions. In addition, the teacher varied the strategies to monitor students' learning, such as asking questions and giving sheets of paper to fill.

Furthermore, in HWOO(3), the students were given more opportunities to reflect on their learning than in HTWW(3). For example, after re-writing the comic on sustainable cities, the teacher requested students to reflect by answering two questions on post-its (Q1: what does it mean for a city to be sustainable? Q2: choose one network and describe how could it work sustainable).

In HTWW(3), the formative assessment techniques were limited to asking questions to the whole class and providing feedback on the answers given. However, in one session, the teacher gave a quiz to check for the students' understanding on earthquakes. In the quiz, some questions were open-ended, such as "describe how the plates are moving.", "tell where this kind of movement usually occurs and what are the results”, “name at least 5 items you would include in the emergency kit in case of an earthquake. Explain why you have these items in your kit”, “explain the theory of continental drift and what evidence scientists used to prove the truth of the theory.”

Grade-4 Descriptive Analysis

Table 22. FA classroom observation mean scores for WWA(4) across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
FD	3	1	1.33	0.33	2	0	0	0.67	1.04	FD
FA2	1	1	0.33	0	2	0	0	1	0.67	FA2
FA3	0.67	0.33	0.33	0.67	1.33	0.67	0.67	1.33	0.75	FA3
FA4	2	2	0.33	0.67	1.67	0.67	0.67	0.67	1.08	FA4
FA5	0	0	0	0	0	0	0	0	0	FA5
FA6	0	0	0	1.33	1	0	0	0.67	0.38	FA6
FA7	0	0	0	0.67	1	0	0	0	0.21	FA7
FA8	1.13	0.67	0.43	0.47	1.43	0.20	0.20	0.73	0.66	FA8

Table 23. FA classroom observation mean scores for HTWW(4) across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
FA1	1.00	0.33	0.00	0.33	0.00	0.00	0.00	0.33	0.33	0.26	FA1
FA2	1.00	1	0.667	1.67	0.00	0.00	2	0	0.667	0.78	FA2
FA3	0.67	2.00	2.00	0.67	2.00	0.33	2.00	0.00	0.00	1.07	FA3
FA4	0.667	2.67	3	1	3	2.00	2.667	1.667	0.667	1.93	FA4
FA5	0	2	2.333	0	0	0	0	0	0	0.48	FA5
FA6	0	0.00	1	0.667	0.667	0.333	0.00	0.00	0.00	0.30	FA6
FA7	1	0	2.67	0	0	0	0	0	0	0.41	FA7
FA8	0.70	1.13	1.43	0.70	0.77	0.30	1.07	0.23	0.27	0.73	FA8

Tables 22 and 23 show the FA classroom observation mean scores for WWA(4) and HTWW(4) across the sessions. Most of the indicators in both units had low mean scores, and the FA indicators were poorly implemented across the sessions. FA4, *teacher provided specific feedback to students*, had moderate mean scores with 1.08 in WWA(4) and 1.93 in HTWW(4). FA4 in HTWW(4) was close to the high range.

Grade-4 Interpretive Analysis

Providing specific feedback was higher in HTWW(4) than in WWA(4) as students were working on creating or improving an invention, so the teacher was providing more specific feedback on a one-on-one basis regarding their proposed problems, solutions and procedures that they will follow. For instance, the teacher emphasized to one student to build background of content knowledge before proceeding with building the prototype.

In only two sessions, the students were engaged in peer-assessment as they provided feedback on their peer's drawings and proposed solutions in the quick design challenge.

In WWA(4), the teacher used few of the carousel activities as a formative assessment. For instance, the teacher asked students to write their questions about certain ideas, which were distributed on every table. The students had to write questions about: "becoming an adult, interconnectedness, circulatory system, respiratory system, digestive system, and questions about my body."

4.2.6 Analysis of CIF: Classroom Observations

Global Descriptive Analysis

Table 24. CIF classroom observation global mean scores across the grade levels

Common Instructional Framework	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
CIF1	1.86	1.18	1.25	1.15	1.36	CIF1
CIF2	2.00	2.09	1.04	1.37	1.63	CIF2
CIF3	2.48	1.18	1.21	1.52	1.60	CIF3
CIF4	1.76	0.88	0.96	1.19	1.20	CIF4
CIF5	2.19	0.67	1.13	1.22	1.30	CIF5
CIF6	2.06	1.20	1.12	1.29	1.42	CIF6

Table 24 shows the CIF classroom observation global mean scores across the grade levels. CIF6, *Summary: Overall rating of Quality of Common Instructional Framework implementation*, had a mean score of 1.42, indicating that the overall quality of CIF was moderate across the grade levels. All other indicators obtained had moderate mean scores with CIF4, *teachers provided assistance/scaffolding when students struggled*, being the lowest with a mean score of 1.20 and CIF2, *students used writing to communicate what they had learned*, being the highest with a mean score of 1.63.

CIF1, *students worked collaboratively in teams or groups*, CIF2, *students used writing to communicate what they had learned*, and CIF3, *teachers asked open-ended questions that required higher level thinking*, were highly respected across the units, indicating that these indicators were most commonly implemented in the units.

Furthermore, HWOO(3) is characterized by a high application of STEM when compared to the other units as its summary rating (CIF6) had a mean score of 2.06. In addition, CIF3, *teachers asked open-ended questions that required higher level thinking*, and CIF5, *students engaged in discussion with each other,* had high mean scores of 2.48 and 2.19, respectively. CIF2, *students used writing to communicate what they had learned*, had a mean score of 2.00 that is close to the high range.

Grade-3 Descriptive Analysis

Table 25. CIF classroom observation mean scores for HWOO(3) across the sessions

Common Instructional Framework	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
CIF1	2	1.67	3	1	0.33	2	3	1.86	CIF1
CIF2	1.67	1.67	1.67	2	3	3	1	2.00	CIF2
CIF3	2.00	2.67	1.00	2.67	3.00	3.00	3.00	2.48	CIF3
CIF4	1.67	2.00	0.67	1.67	1.33	2.00	3.00	1.76	CIF4
CIF5	2.33	2.67	2	1	1.33	3	3	2.19	CIF5
CIF6	1.93	2.13	1.67	1.67	1.80	2.60	2.60	2.06	CIF6

Table 26. CIF classroom observation mean scores for HTWW(3) across the sessions

Common Instructional Framework	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
CIF1	2	3.00	1	1	0.67	0	0	0	0	2.33	3	1.18	CIF1
CIF2	3.00	3.00	0.00	0	2	2	3	3	2	2	3	2.09	CIF2
CIF3	3.00	3.00	1.67	1.67	1.33	0.33	2.00	0.00	0.00	0.00	0.00	1.18	CIF3
CIF4	1.67	2.00	1.33	1.33	0.67	0.67	0.00	1.00	1.00	0.00	0.00	0.88	CIF4
CIF5	2.00	3.00	1	1	0.33	0	0	0	0	0	0	0.67	CIF5
CIF6	2.33	2.80	1.00	1.00	1.00	0.60	1.00	0.80	0.60	0.87	1.20	1.20	CIF6

Tables 25 and 26 show the CIF classroom observation mean scores for HWOO(3) and HTWW(3) across the sessions. HWOO(3) was characterized with high CIF implementation as most of the indicators obtained moderate to high mean scores across the sessions. In addition, the sessions that were observed by the end of the unit displayed higher application of CIF than the sessions at the beginning of the unit, indicating a better STEM application (see Table 25). Particularly, sessions 6 and 7 were characterized with high CIF implementation as almost all of the indicators obtained high mean scores as shown in Table 25.

However, HTWW(3) was characterized with moderate CIF implementation, and the CIF indicators were more evident in the beginning of the unit, particularly sessions 1 and 2 (see Table 26). The first two sessions were characterized with high STEM application as most of the indicators obtained high mean scores. CIF4, *teachers provided assistance/scaffolding when students struggled,* and CIF5, *students engaged in discussion with each other,* had low mean scores of 0.88 and 0.67, respectively, and they were absent towards the end of the unit.

Grade-3 Interpretive Analysis

In HWOO(3), there were several instances that engaged students in the CIF indicators throughout the whole unit. For example, students worked in pairs or groups, engaged in group and class discussions, wrote their notes on their journals/ post-its and shared them with the whole class, were asked open-ended questions (e.g. “how did your understanding of sustainability change?”, “why do you think the houses are next to bus stop?”, “why do you think they made spaces in houses for office work?”, “how do the laws in these countries help in maintaining sustainability?”).

As for HTWW(3), class discussions were mostly used in the beginning of the unit, where the teacher was explaining about earthquakes. Group work was more evident in the beginning of the unit, when the students were engaged in an exploration activity, and in the end of the unit, when the students worked together on their PowerPoint presentations.

However, writing was most frequently used throughout the whole unit, as the students were taking notes, especially because they were researching about natural hazards. For example, each student was given a “Natural Hazard” booklet, and s/he had to research and record the following information: “what (definition of a specific natural hazard); where does it happen; why does it happen; its potential effects and damages on ecosystems (plant, people, land and animals) and on construction and buildings; proactive, safety and preventive measures (before, during and after a natural hazard)”. In addition, students took notes on their booklets about other natural hazards while other groups were presenting.

Grade-4 Descriptive Analysis

Table 27. CIF classroom observation mean scores for WWA(4) across the sessions

Common Instructional Framework	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
CIF1	2	2	0.33	0	1.67	2	2	0	1.25	CIF1
CIF2	2	0.67	0	1.67	2	0	0	2	1.04	CIF2
CIF3	1.33	0.67	1.33	1.67	1.33	0.67	0.67	2.00	1.21	CIF3
CIF4	0.33	0.00	0.67	1.33	1.00	1.33	1.33	1.67	0.96	CIF4
CIF5	2	2	0.33	0	0.67	2	2	0	1.13	CIF5
CIF6	1.53	1.07	0.53	0.93	1.33	1.20	1.20	1.13	1.12	CIF6

Table 28. CIF classroom observation mean scores for HTWW(4) across the sessions

Common Instructional Framework	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
CIF1	0.667	3.00	2.333	2	1.33	0	0	0	1	1.15	CIF1
CIF2	0.00	3.00	1.33	2	1.333	0	2.667	2	0	1.37	CIF2
CIF3	2.00	3.00	3.00	1.33	0.67	1.00	2.00	0.00	0.67	1.52	CIF3
CIF4	0.67	1.33	3.00	1.33	1.00	0.00	2.67	0.00	0.67	1.19	CIF4
CIF5	0.00	3.00	3	2	1.33	0	0	0.67	1	1.22	CIF5
CIF6	0.67	2.67	2.53	1.73	1.13	0.20	1.47	0.53	0.67	1.29	CIF6

Tables 27 and 28 display the CIF classroom observation mean scores for WWA(4) and HTWW(4) across the sessions. In WWA(4), the CIF implementation was dispersed across the sessions and it was less evident in the middle of the unit (see Table 27). However, in HTWW(4), the CIF implementation was more evident in the beginning of the unit, and sessions 2 and 3 were characterized with high mean scores, indicating more STEM approaches when compared to other sessions (see Table 28).

Grade-4 Interpretive Analysis

Group work, discussions and writing were used frequently in both units. However, in HTWW(4), they were more evident in the beginning of the unit as students were working in pairs in the first steps of the engineering design process. They had to interview each other to identify the user’s needs and several problems that need to be solved. In addition, the students had to discuss the reading texts on inventions and synthesize the information together. However, by the end of the unit, the students were more working independently on their inventions.

In WWA(4), students were engaged in group discussions and whole class discussions along, and many of the carousel activities were done in groups. For example, students, in groups, had to discuss the meaning of the word “sytems”, write the definition on a poster and come up with examples on systems in the world. Similar engagements were done throughout several sessions in this unit.

4.2.7 Analysis of SE: Classroom Observations

Global Descriptive Analysis

Table 29. SE classroom observation global mean scores across the grade levels

Student Engagement	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
SE1	2.81	2.67	2.75	2.37	2.65	SE1
SE2	2.86	2.45	2.46	2.11	2.47	SE2
SE3	2.95	1.24	2.54	1.89	2.16	SE3
SE4	2.62	1.97	1.38	2.00	1.99	SE4
SE5	0.71	0.24	0.17	0.33	0.36	SE5
SE6	2.39	1.72	1.86	1.74	1.93	SE6

Table 29 shows the SE classroom observation global mean scores across the grade levels. SE6, *summary: Student Engagement*, obtained a mean score of 1.93, which is close to the high range, indicating a moderate overall student engagement across the units. Most of the indicators obtained high mean scores, with SE1, *students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions)*, being the highest with a mean score of 2.65, and SE5, *students showed perseverance when solving math/science problems*, being the lowest with a mean score of 0.36. SE1, *students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions),* SE2, *the time in class was spent productively on meaningful tasks,* and SE3, *teacher pursued the active engagement of all students*, were highly respected across the units. Although SE4, *students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem)*, obtained a moderate mean score of 1.99, it is closer to the high range.

HWOO(3) was the unit with the most student engagement as all of its indicators, except SE5, had high mean scores as shown in Table 29. HTWW(3) and HTWW(4) were close in terms of student engagement as evidenced by their summary ratings (SE6) of 1.72 and 1.74, respectively.

Grade-3 Descriptive Analysis

Table 30. SE classroom observation mean scores for HWOO(3) across the sessions

Student Engagement	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
SE1	3.00	2.67	3.00	2.00	3.00	3.00	3.00	2.81	SE1
SE2	3.00	2.67	3.00	2.33	3.00	3.00	3.00	2.86	SE2
SE3	3	3	3	2.67	3	3	3	2.95	SE3
SE4	3	3	2.33	1.67	2.33	3	3	2.62	SE4
SE5	1.67	1.33	0	0	0	0	2	0.71	SE5
SE6	2.73	2.53	2.27	1.73	2.27	2.4	2.8	2.39	SE6

Table 31. SE classroom observation mean scores for HTWW(3) across the sessions

Student Engagement	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
SE1	3.00	3.00	2.00	1.67	2.67	2.33	3.00	3.00	3.00	2.67	3.00	2.67	SE1
SE2	3.00	3.00	2.00	1.67	2.00	1.67	3.00	3.00	2.33	2.33	3.00	2.45	SE2
SE3	3	3	1.67	1.33	1.333	1	1.33	1	0	0	0	1.24	SE3
SE4	3	3	1.33	1.00	1.00	1	3	3	2	1.33	2	1.97	SE4
SE5	0.67	0.00	0	0	0	0	2	0	0	0	0	0.24	SE5
SE6	2.53	2.40	1.40	1.13	1.40	1.2	2.47	2	1.47	1.27	1.6	1.72	SE6

Tables 30 and 31 show the SE classroom observation mean scores for HWOO(3) and HTWW(3) across the sessions. HWOO(3) was characterized with higher student engagement than HTWW(3) as evidenced by the high mean scores of the indicators in HWOO(3) across the sessions. As shown in Table 30, all indicators, except SE5, were highly respected across the sessions in HWOO(3).

Grade-3 Interpretive Analysis

Although in both units, the students were behaviorally engaged, the students appeared more cognitively engaged in HWOO(3) than in HTWW(3) for two reasons. First, students were engaged in more group and pair discussions in HWOO(3) than in HTWW(3). Second, the students were engaged in more challenges in HWOO(3) (e.g. building a circuit and connecting its parts, reflecting how the circuit activity is related to the city networks, rewriting a comic, drawing blueprints and building a city model). In HTWW(3), students appeared cognitively engaged the most when they were researching and asking questions.

Grade-4 Descriptive Analysis

Table 32. SE classroom observation mean scores for WWA(4) across the sessions

Student Engagement	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
SE1	2.33	3.00	3.00	3.00	3.00	2.67	2.00	3.00	2.75	SE1
SE2	2.33	2.00	2.67	2.33	3.00	2.67	2.33	2.33	2.46	SE2
SE3	3	0.67	3	3	3	2.67	2	3	2.54	SE3
SE4	1	0.67	1.33	1.67	2.33	1.33	1.33	1.33	1.38	SE4
SE5	0	0	0	0	0	0	0	1.33	0.17	SE5
SE6	1.73	1.27	2	2.00	2.27	1.87	1.53	2.20	1.86	SE6

Table 33. SE classroom observation mean scores for HTWW(4) across the sessions

Student Engagement	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
SE1	3.00	3.00	3.00	3.00	1.67	1.67	2.00	1.67	2.33	2.37	SE1
SE2	1.33	3.00	3.00	2.33	1.67	1.33	2.33	2.00	2.00	2.11	SE2
SE3	2	3	3	3.00	3	0.667	0	1	1.333	1.89	SE3
SE4	2	3	3.00	2.00	1.67	0.333	2	2	2	2.00	SE4
SE5	0.00	1.00	2	0	0	0	0	0	0	0.33	SE5
SE6	1.67	2.60	2.80	2.07	1.60	0.8	1.267	1.333	1.533	1.74	SE6

Tables 32 and 33 show the SE classroom observation mean scores for WWA(4) and HTWW(4) across the sessions. In both units, SE1, *students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions),* and SE2, *the time in class was spent productively on meaningful tasks*, were highly respected across the sessions. However, SE4, *students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem),* had a higher mean score in HTWW(4) (2.00), that was close to the high range, than in WWA(4) (1.38).

Grade-4 Interpretive Analysis

Although in both units the students were behaviorally engaged, HTWW(4) had more opportunities for students to be cognitively engaged. A possible interpretation for this difference is that students were engaged in an engineering design challenge that required them to create or improve an invention by the end of the unit. Hence, students were thinking hard on meaningful problems that they are interested in solving.

4.2.8 Analysis of UOT: Classroom Observations

Global Descriptive Analysis

Table 34. UOT classroom observation global mean scores across the grade levels

Use of Technology	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean	
UOT1	1.43	1.48	1.79	0.81	1.38	UOT1
UOT2	0.71	1.58	1.29	0.41	1.00	UOT2
UOT3	0.81	0.88	1.33	0.41	0.86	UOT3
UOT4	0.14	0.00	0.33	0.00	0.12	UOT4
UOT5	0.33	0.18	1.08	0.00	0.40	UOT5
UOT6	0.00	0.36	0.04	0.52	0.23	UOT6
UOT7	0.33	0.64	0.38	0.33	0.42	UOT7
UOT8	0.54	0.73	0.89	0.35	0.63	UOT8

Table 34 displays the UOT classroom observation mean scores across the grade levels. Most of the indicators had low mean scores with UOT4, *students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective)*, being the lowest with a mean score of 0.14 and UOT1, *technology was used to a high extent (as a proportion of time of the lesson and intensity of use)*, being the highest with a mean score of 1.38. UOT1, *technology was used to a high extent (as a proportion of time of the lesson and intensity of use)*, UOT2, *students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding*, UOT3, *students used technology to generate or manipulate one or more representations of a given concept or idea*, UOT4, *students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective)*, and UOT5, *students used technology to practice skills or reinforce knowledge*, indicate an effective use of technology. However, UOT6, *technology was used but did not appear to provide any added benefit*, and UOT7, *teacher used technology to achieve instructional goals. (Emphasis on the "teacher" here),* indicate that technology was not used effectively.

UOT1 had a mean score of 1.38, indicating that the extent of which technology was used was moderate. However, the way technology was used varied with UOT2, *students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding*, and UOT3, *students used technology to generate or manipulate one or more representations of a given concept or idea*, were the most frequently used across the units. Although these two indicators had low mean scores of 1.00 and 0.86, they were closer to the moderate.

WWA(4) was the most unit which made use of technology in various ways, as evidenced by the moderate mean scores of UOT1 (1.79), UOT2 (1.29), UOT3 (1.33) and UOT5 (1.08). HTWW(4) was the least unit which made use of technology in various ways, as evidenced by the low mean scores of all of its indicators.

Grade-3 Descriptive Analysis

Table 35. UOT classroom observation mean scores for HWOO(3) across the sessions

Use of Technology	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
UOT1	2.67	0.33	1.00	2.33	0.67	1.00	2.00	1.43	UOT1
UOT2	1.67	0	0.67	2	0.67	0	0	0.71	UOT2
UOT3	1.67	0.33	0.33	0.33	0.00	0.00	3.00	0.81	UOT3
UOT4	0	0.00	0.00	0.33	0.67	0	0	0.14	UOT4
UOT5	0	0.00	0.33	0.67	1.33	0	0	0.33	UOT5
UOT6	0	0.00	0.00	0	0	0	0	0.00	UOT6
UOT7	0	0.00	0.00	0.33	0	2	0	0.33	UOT7
UOT8	0.86	0.10	0.33	0.86	0.48	0.43	0.71	0.54	UOT8

Table 36. UOT classroom observation mean scores for HTWW(3) across the sessions

Use of Technology	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean	
UOT1	2.33	3.00	1.00	1.00	2.00	1.00	1.00	3.00	2.00	0.00	0.00	1.48	UOT1
UOT2	2.33	3	2.00	1.333	2.00	0.667	1	3	2	0	0	1.58	UOT2
UOT3	2.00	3.00	2.00	1.67	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	UOT3
UOT4	0	0	0	0.00	0.00	0	0	0	0	0	0	0.00	UOT4
UOT5	0	0	0.00	0.00	0	2	0	0	0	0	0	0.18	UOT5
UOT6	0	0	1	1	0	0	2	0	0	0	0	0.36	UOT6
UOT7	0	0	2	2.00	3	0	0	0	0	0	0	0.64	UOT7
UOT8	0.95	1.29	1.14	1.00	1.14	0.52	0.57	0.86	0.57	0.00	0.00	0.73	UOT8

Tables 35 and 36 show the UOT classroom observation mean scores for HWOO(3) and HTWW(3) across the sessions. As shown in Table 36, HTWW(3) displayed higher use of technology in the beginning of the sessions, particularly for UOT1, UOT2 and UOT3, whose mean scores ranged between moderate to high. However, HWOO(3) displayed poor use of technology as evidenced by the frequent low mean scores across the sessions (see Table 35).

Grade-3 Interpretive Analysis

In HTWW(3), the first two sessions were dedicated for exploring the unit, which was co-taught with the technology coordinator. In these sessions, the students explored the unit through Nearpod, an interactive classroom application. The unit's central idea, *natural hazards alter the environment*, was shared on Nearpod and students had to paraphrase it in their own words and submit it on Nearpod. Also, various images of natural hazards were shown as 360 degrees images, and the students were engaged in the "see/think/wonder" activity. In addition, the teacher used videos explaining the continental drift and plate tectonics' theory and BrainPop Jr. video on "The Mysteries of Life". Besides, the teacher showed students a 3D model of Earth's structure and explained it using the model.

However, in HWOO(3), the technology used were more hands-on tools. For example, the first two sessions engaged students in building a circuit using materials provided by the teacher.

In both units, teachers used the SMART board to display information related to the unit and allowed students to use iPads and laptops occasionally, and books frequently.

Grade-4 Descriptive Analysis

Table 37. UOT classroom observation mean scores for WWA(4) across the sessions

Use of Technology	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean	
UOT1	0.67	0.67	3.00	2.33	2.00	2.33	2.33	1.00	1.79	UOT1
UOT2	0	0.33	2.33	2	1.67	2	2	0	1.29	UOT2
UOT3	1.33	1.33	0.00	2.00	2.00	2.00	2.00	0.00	1.33	UOT3
UOT4	0	0	0.67	0	0	0	0	2	0.33	UOT4
UOT5	0	0	0	1	1.67	2.67	2.67	0.67	1.08	UOT5
UOT6	0	0	0	0	0	0	0.33	0	0.04	UOT6
UOT7	1	1.33	0.33	0.33	0	0	0	0	0.38	UOT7
UOT8	0.38	0.52	0.90	1.10	1.05	1.29	1.33	0.52	0.89	UOT8

Table 38. UOT classroom observation mean scores for HTWW(4) across the sessions

Use of Technology	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean	
UOT1	1.33	1.33	2.33	0.00	0.00	0.00	0.00	0.67	1.67	0.81	UOT1
UOT2	0.00	1	2.00	0	0.00	0	0	0.667	0	0.41	UOT2
UOT3	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.67	0.41	UOT3
UOT4	0	0	0	0.00	0.00	0	0	0	0	0.00	UOT4
UOT5	0	0	0.00	0.00	0	0	0	0	0	0.00	UOT5
UOT6	2	0	0	1.667	0	1	0	0	0	0.52	UOT6
UOT7	2	1	0	0.00	0	0	0	0	0	0.33	UOT7
UOT8	0.76	0.48	0.90	0.24	0.00	0.14	0.00	0.19	0.48	0.35	UOT8

Tables 37 and 38 show the UOT classroom observation mean scores for WWA(4) and HTWW(4) across the sessions. As shown in Table 37, WWA(4) was characterized with effective use of technology in the middle of the sessions as evidenced by the moderate to high mean scores of UOT1, UOT2, UOT3 and UOT8. Conversely, HTWW(4) was characterized with poor use of technology as almost all indicators had low mean scores across the sessions.

Grade-4 Interpretive Analysis

The use of technology was more evident in WWA(4) than in HTWW(4) as the teacher involved students in watching videos, showing animations/ simulations, writing on posters, and using different iPad applications. Some of these applications were *Mr. Body* application and *merge cube* for augmented reality. The *merge cube* gets synced to many applications and one of these applications is *Mr. Body*. Another application was the *Human Body* application, which has only sound, and shows the different body systems. Hence, the students can see how different factors/ events can affect the body systems. Another technological tool used was the *virtual t-shirt,* which showed the organs of the person wearing it on the iPad(circulatory system, digestive system, respiratory system). However, these centers' activities were done at the end of the unit. It would have been better if they were done at the beginning of the unit as an exploration activity, because students seemed to have fun with these iPad applications without inquiring further into them.

However, in HTWW(4), the use of technology was limited to the concrete materials that were used in the quick design challenge and while building their prototypes. In one session, the teacher showed students a video as a way to inspire them ("Kids and Adults Design New Tech Tools"). The teacher paused the video and asked students questions about the video. She related the video to the design process that students are following (for example: which stage one student is now in?). In both units, the teachers used the SMART board to display information.

4.2.9 Analysis of the average scores of the units

Global Descriptive Analysis of the overall STEMiness of the units

Table 39. Mean scores of the units

	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	Mean
Average Score of the units	1.48	1.14	1.11	1.12	1.21

Table 39 shows the average scores of all the units that indicate the overall STEMiness of these units. All of the units obtained moderate mean scores with HWOO(3) being the highest with a mean score of 1.48, and WWA(4) being the lowest with a mean score of 1.11. WWA(4), HTWW(4), and HTWW(3) had mean scores that were close to each other.

Grade-3 Descriptive Analysis of the overall STEMiness of the sessions

Table 40. HWOO(3) mean scores across the sessions

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean
Average Scores for the sessions	1.50	1.25	1.19	1.23	1.29	1.81	2.07	1.48

Table 41. HTWW(3) mean scores across the sessions

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session10	Session 11	Mean
Average Scores for the sessions	1.82	1.96	1.20	1.18	1.12	0.90	1.10	1.04	0.76	0.66	0.82	1.14

Tables 40 and 41 show the average scores of the sessions of HWOO(3) and HTWW(3). As shown in table 40, the STEMiness of the sessions in HWOO(3) was highly respected as all of the sessions were moderately STEMy, except for the last session, which was highly STEMy. However, in HTWW(3), the STEMiness of the sessions varied throughout the unit. The sessions that were at the beginning of the unit were moderately STEMy as opposed to the sessions that were done by the end of the unit (not STEMy).

Grade-4 Descriptive Analysis of the overall STEMiness of the sessions

Table 42. WWA(4) mean scores across the sessions

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Mean
Average Scores for the sessions	0.95	0.77	0.95	1.15	1.42	1.20	1.18	1.22	1.11

Table 43. HTWW(4) mean scores across the sessions

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Mean
Average Scores for the sessions	0.91	1.93	1.90	1.19	0.79	0.52	1.24	0.69	0.89	1.12

Tables 42 and 43 show the average scores of the sessions for WWA(4) and HTWW(4). As shown in table 42, the last sessions were moderately STEMy as opposed to the first three sessions. However, sessions 1 and 2 had mean scores of 0.95, which were close to the moderate.

As shown in table 43, the STEMiness of the sessions varied throughout the unit. Sessions 2, 3, 4 and 7 were moderately STEMy as opposed to the other sessions. The mean scores of session 2 (1.93) and session 3 (1.90) were close to the high range, and the mean score of session 1 (0.91) was close to the moderate.

4.2.10 Analysis of MSC: Lab/ makerspace observations

Global Descriptive Analysis

Table 44. MSC lab/ makerspace observation global mean scores across the grade levels

Math and Science Content	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
MSC1	0.43	0.00	0.00	0.14	MSC1
MSC2	0.52	0.00	0.00	0.17	MSC2
MSC3	0.76	0.00	0.00	0.25	MSC3
MSC4	0.95	0.00	0.00	0.32	MSC4
MSC5	0.24	0.00	0.00	0.08	MSC5
MSC6	0.05	0.00	0.00	0.02	MSC6
MSC7	0.62	0.00	0.00	0.21	MSC7
MSC8	1.29	0.00	0.00	0.43	MSC8
MSC9	1.67	0.00	0.00	0.56	MSC9
MSC10	0.71	0.00	0.00	0.24	MSC10

Table 44 shows the MSC lab/ makerspace observation global mean scores across the grade levels. The math and science content was poorly covered in the lab and makerspace as evidenced by MSC10, *summary: Quality of Mathematics and Science Content*, with a low mean score of 0.24. All of the indicators obtained low mean scores with MSC6, *teacher and students discussed key mathematical or science ideas and concepts in depth*, being the lowest with a mean score of 0.02.

HWOO(3)L was the only unit that covered math and science content in the lab and makerspace as opposed to HTWW(3)L and HTWW(4)L. In HWOO(3)L, MSC8, *appropriate connections were made to other areas of mathematics/science or to other disciplines*, and MSC9, *appropriate connections were made to real-world contexts*, obtained moderate mean scores of 1.29 and 1.67, respectively.

Grade-3 and Grade-4 Descriptive Analysis

Table 45. MSC lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Math and Science Content	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
MSC1	0.00	0.00	0.33	1.00	0.67	1.00	0.00	0.43	MSC1
MSC2	0.00	0.00	0.00	0.33	1.33	2.00	0.00	0.52	MSC2
MSC3	1.00	0.33	0.00	0.67	1.33	2.00	0.00	0.76	MSC3
MSC4	0.67	0.67	0.00	0.33	2.00	3.00	0.00	0.95	MSC4
MSC5	0	0	0	0	0.667	1	0	0.24	MSC5
MSC6	0	0	0	0.333	0	0	0	0.05	MSC6
MSC7	1.67	0	0.667	0.667	0.667	0.667	0	0.62	MSC7
MSC8	2	2	0	0	2	3	0	1.29	MSC8
MSC9	2.00	2.00	1.33	1.33	2.00	3.00	0.00	1.67	MSC9
MSC10	0.69	0.46	0.21	0.54	1.23	1.82	0.00	0.71	MSC10

Table 46. MSC lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Math and Science Content	Session 1	Session 2	Mean	
MSC1	0.00	0.00	0.00	MSC1
MSC2	0.00	0.00	0.00	MSC2
MSC3	0.00	0.00	0.00	MSC3
MSC4	0.00	0.00	0.00	MSC4
MSC5	0	0	0.00	MSC5
MSC6	0	0	0.00	MSC6
MSC7	0.00	0	0.00	MSC7
MSC8	0	0	0.00	MSC8
MSC9	0.00	0.00	0.00	MSC9
MSC10	0.00	0.00	0.00	MSC10

Table 47. MSC lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Math and Science Content	Session 1	Session 2	Mean	
MSC1	0.00	0.00	0.00	MSC1
MSC2	0.00	0.00	0.00	MSC2
MSC3	0.00	0.00	0.00	MSC3
MSC4	0.00	0.00	0.00	MSC4
MSC5	0	0	0.00	MSC5
MSC6	0	0	0.00	MSC6
MSC7	0.00	0	0.00	MSC7
MSC8	0	0	0.00	MSC8
MSC9	0.00	0.00	0.00	MSC9
MSC10	0.00	0.00	0.00	MSC10

Tables 45, 46 and 47 show the MSC lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in table 44, MSC9*, appropriate connections were made to real-world contexts,* was highly respected across the sessions as almost all of its indicators obtained moderate to high mean scores that ranged between 1.33 and 3.00. Similarly, most of the sessions had moderate to high mean scores of MSC8, *appropriate connections were made to other areas of mathematics/science or to other disciplines*. The MSC8 and MSC9 mean scores of 2.00 in Sessions1, 2, 5 and 6 were close to the high range.

Furthermore, sessions 5 and 6 in HWOO(3)L were characterized with moderate STEM application as evidenced by MSC10 with mean scores of 1.23 and 1.86. Most of the indicators in these sessions had moderate to high mean scores. In session 5, MSC2, MSC2, MSC2, *teacher's presentation or clarification of mathematics or science content* *knowledge was clear*, MSC3, *teacher used accurate and appropriate mathematics or science vocabulary*, MSC4, *teacher/students emphasized meaningful relationships among different facts, skills, and concepts*, MSC8, *appropriate connections were made to other areas of mathematics/science or to other disciplines,* and MSC9, *appropriate connections were made to real-world contexts,* had moderate mean scores of 1.33, 1.33, 2.00, 2.00 and 2.00, respectively. While in session 6, MSC2 and MSC3 had moderate mean scores of 2.00, which were closer to the high range. MSC4, MSC8 and MSC9 had high mean scores of 3.00.

Interpretive Analysis

Only HWOO(3)L covered science content in the lab and makerspace. When students were building their cities, they were making connections to environmental science as they were thinking of sustainable solutions for their city models. For example, one group decided to build solar panels and they thought of using a light bulb to simulate the sun.

Furthermore, the students were trying to think how the parts of the little bits can be used in real-life context. For example, one group thought of useful parts in the healthcare system; they thought that they can use a LED light to help surgeons in operations and use a fan to cool the temperature in the rooms.

4.2.11 Analysis of CEM: Lab/ makerpsace observations

Global Descriptive Analysis

Table 48. CEM lab/ makerspace observation global mean scores across the grade levels

Student Cognitive Engagement in Meaningful Instruction	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
CEM1	1.95	1.33	2.50	1.93	CEM1
CEM2	1.10	0.00	0.00	0.37	CEM2
CEM3	1.38	0.00	0.00	0.46	CEM3
CEM4	1.81	1.17	2.50	1.83	CEM4
CEM5	1.05	0.50	2.50	1.35	CEM5
CEM6	0.67	0.00	0.00	0.22	CEM6
CEM7	1.38	0.48	1.11	0.99	CEM7

Table 48 shows the CEM lab and makerspace observation global mean scores across the grade levels. Although CEM7, *summary: Quality of Student Cognitive Engagement in Meaningful Instruction*, indicates a poor application of CEM, its mean score of 0.99 was closer to the moderate. Three indicators had moderate mean scores with CEM1, *students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.*, being the highest with a mean score of 1.93; whereas three indicators had low mean scores with CEM6, *students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena* being the lowest with a mean score of 0.22.

CEM1 and CEM4, s*tudents used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena*, were highly respected across the units, whereas CEM6 was poorly respected across the units. The latter three indicators were also absent in HTWW(3)L.

HWOO(3)L had the highest application of CEM when compared to the other units as evidenced by CEM7's mean score of 1.38. Most of the indicators in HWOO(3)L had moderate mean scores, with CEM1 being the highest with a mean score of 1.95, which was close to the high range. However, HTWW(4)L had three indicators (CEM1, CEM4 and CEM5, *students were asked to apply knowledge to a novel situation*) with high mean scores of 2.50; whereas three indicators (CEM2, s*tudents were asked to explain or justify their thinking*, CEM3, *students were given opportunities to summarize, synthesize, and generalize,* and CEM6) were absent as their mean scores were 0.

Grade-3 and Grade-4 Descriptive Analysis

Table 49. CEM lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
CEM1	2.00	2.67	2.00	1.00	2.00	2.67	1.33	1.95	CEM1
CEM2	0	2	0.333	0.333	2	3	0	1.10	CEM2
CEM3	2	2.00	0.00	0.67	2.00	3.00	0.00	1.38	CEM3
CEM4	2	2.33	1.33	1.00	2.00	2.67	1.33	1.81	CEM4
CEM5	1.333	0.67	0.00	0.33	2.00	3.00	0.00	1.05	CEM5
CEM6	0	0.00	0.00	1.33	1.33	2.00	0.00	0.67	CEM6
CEM7	1.26	1.81	0.67	0.74	1.93	2.78	0.44	1.38	CEM7

Table 50. CEM lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Mean	
CEM1	1.33	1.33	1.33	CEM1
CEM2	0	0	0.00	CEM2
CEM3	0	0.00	0.00	CEM3
CEM4	1	1.33	1.17	CEM4
CEM5	1	0.00	0.50	CEM5
CEM6	0	0.00	0.00	CEM6
CEM7	0.52	0.44	0.48	CEM7

Table 51. CEM lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Student Cognitive Engagement in Meaningful Instruction	Session 1	Session 2	Mean	
CEM1	2.00	3.00	2.50	CEM1
CEM2	0	0	0.00	CEM2
CEM3	0	0.00	0.00	CEM3
CEM4	2	3.00	2.50	CEM4
CEM5	2	3.00	2.50	CEM5
CEM6	0	0.00	0.00	CEM6
CEM7	0.89	1.33	1.11	CEM7

Tables 49, 50 and 51 show the CEM lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in table 49, most of the lab and makerspace sessions in HWOO(3)L obtained moderate to high mean scores of CEM7, *summary: Quality of Student Cognitive Engagement in Meaningful Instruction*. Sessions 5 and 6 were characterized with moderate and high application of CEM. In session 5, all of its indicators, except CEM6 (moderate mean score of 1.33), had moderate mean scores of 2.00, which were close to the high range. However, in session 6, all of its indicators, except for CEM6 (mean score of 2.00), had high mean scores. CEM2, *students were asked to explain or justify their thinking*, CEM3, *students were given opportunities to summarize, synthesize, and generalize,* and CEM5, *students were asked to apply knowledge to a novel situation*, obtained the highest mean score of 3.00.

As shown in table 51, CEM1, *students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.*, CEM4, *students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena*, and CEM5, *students were asked to apply knowledge to a novel situation*, were highly respected across the sessions. These indicators obtained moderate mean scores of 2.00, which was close to the high range, in session 1, and then they had high mean scores of 3.00 in session 2.

However, as shown in table 50, HTWW(3)L was characterized with poor CEM application as evidenced by the low mean scores of CEM7, *summary: Quality of Student Cognitive Engagement in Meaningful Instruction*, across the sessions, and having most of its indicators with low mean scores. Only CEM1 was highly respected across the sessions.

Interpretive Analysis

The high mean scores of CEM1, CEM4 and CEM5 in HWOO(3)L and HTWW(4)L can be explained due to the nature of the activities that were applied. In sessions 5 and 6 in HWOO(3)L, the technology coordinator was assisting in the lab and makerspace, and the students were building their own cities and creating a sustainable solution for the their cities. They were using their blueprints as a way to guide them through their building. Similarly, in HTWW(4)L, all of the sessions were assisted by the technology coordinator, and the students were creating their inventions. Thus, they experienced high cognitive demand of activities and applied knowledge in a novel situation as they planned the steps of building their inventions. In addition, in both unit, the students used a variety of means to represent their cities or inventions as they planned the needed materials and decided the way they want to represent their final product.

Moreover, the high mean scores of CEM2, CEM3 and CEM6 in HWOO(3)L were due to the more in-depth learning than HTWW(4)L. As the students were building, the teacher and the lab instructor were circulating in the makerspace and asking students questions about their city models, and their rationale in choosing certain materials while building.

However, in HTWW(3)L, the mean scores of most of the CEM indicators were low because the lab sessions were structured and guided. For example, in one session, they had to build a structure that resists earthquake using Kapla blocks, and in another session, they had to simulate a volcanic eruption through building a volcano using a soda can and cardboard. In both sessions, the students were exploring how to build the structure, and the teacher did not give them directive hints or solutions.

4.2.12 Analysis of IBL: Lab/ makerspace observations

Global Descriptive Analysis

Table 52. IBL lab/ makerspace observation global mean scores across the grade levels

Inquiry Learning, PjBL & PBL	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
IBL1	2.05	1.33	2.50	1.96	IBL1
IBL2	1.95	2.17	2.50	2.21	IBL2
IBL3	0.38	1.00	0.00	0.46	IBL3
IBL4	1.48	0.50	2.50	1.49	IBL4
IBL5	0.71	0.50	2.50	1.24	IBL5
IBL6	0.71	0.00	0.00	0.24	IBL6
IBL7	1.05	1.67	2.50	1.74	IBL7
IBL8	0.00	0.00	0.00	0.00	IBL8
IBL9	1.10	0.33	2.50	1.31	IBL9
IBL10	1.14	0.93	1.79	1.29	IBL10

Table 52 shows the IBL lab and makerspace observation global mean scores across the grade levels. IBL was moderately applied in the lab and makerspace as evidenced by the mean score of IBL10, *summary: Quality of Inquiry learning; Project-based learning; and Problem-based instruction*, of 1.29. Most of the indicators had moderate mean scores. IBL2, *students engaged in hands-on or real-life problem solving activities or a lab experiment*, obtained the highest mean score of 2.21, which is high, and it was highly respected across the units. In addition, IBL1, *students were engaged in open-ended tasks or questions*, and IBL7, *students worked on a project requiring creativity*, were highly respected as well.

Yet, IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process,* had the lowest mean score of 0, and it was absent from all of the units. Besides, IBL3, *students developed their own questions and/or hypotheses to explore or test,* and IBL6, *students had to present or explain results of project,* were poorly respected across the units.

Furthermore, HTWW(4)L was characterized with the highest CEM application as evidenced by CEM7's mean score of 1.70, and having most of its indicators with high mean scores. As shown in table 51, IBL1, *students were engaged in open-ended tasks or questions,* IBL2, *students engaged in hands-on or real-life problem solving activities or a lab experiment*, IBL4, *students engaged in scientific inquiry process (tested hypotheses and made inferences),* IBL5, *students determined which problem-solving strategies to use*, IBL7, *students worked on a project requiring creativity,* and IBL9, *there was an explicit evidence of students using engineering (or reverse engineering) design process*, had high mean scores of 2.50.

Grade-3 and Grade-4 Descriptive Analysis

Table 53. IBL lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
IBL1	2.00	3.00	2.00	1.00	2.00	3.00	1.33	2.05	IBL1
IBL2	2.00	2	2	0.667	2	3	2	1.95	IBL2
IBL3	0.00	0	0	0	0.333	0.333	2	0.38	IBL3
IBL4	2.00	1.67	1.33	0.33	2.00	3.00	0.00	1.48	IBL4
IBL5	0.00	0	0	0	2	3	0	0.71	IBL5
IBL6	0.00	0.00	0.00	0.00	2.00	3.00	0.00	0.71	IBL6
IBL7	0.67	0.33	0.00	0.00	2.00	3.00	1.33	1.05	IBL7
IBL8	0	0	0	0	0	0	0	0.00	IBL8
IBL9	1.33	1.333	0	0	2	3	0	1.10	IBL9
IBL10	1.00	1.07	0.76	0.29	1.62	2.40	0.86	1.14	IBL10

Table 54. IBL lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Mean	
IBL1	1.33	1.33	1.33	IBL1
IBL2	2.33	2	2.17	IBL2
IBL3	0.00	2	1.00	IBL3
IBL4	1.00	0.00	0.50	IBL4
IBL5	1.00	0	0.50	IBL5
IBL6	0.00	0.00	0.00	IBL6
IBL7	2.00	1.33	1.67	IBL7
IBL8	0	0	0.00	IBL8
IBL9	0.67	0	0.33	IBL9
IBL10	1.00	0.86	0.93	IBL10

Table 55. IBL lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Inquiry Learning, PjBL & PBL	Session 1	Session 2	Mean	
IBL1	2.00	3.00	2.50	IBL1
IBL2	2	3	2.50	IBL2
IBL3	0.00	0	0.00	IBL3
IBL4	2.00	3.00	2.50	IBL4
IBL5	2.00	3	2.50	IBL5
IBL6	0.00	0.00	0.00	IBL6
IBL7	2.00	3.00	2.50	IBL7
IBL8	0	0	0.00	IBL8
IBL9	2	3	2.50	IBL9
IBL10	1.43	2.14	1.79	IBL10

Tables 53, 54 and 55 display the IBL lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in table 53, IBL was mostly evident in sessions 5 and 6. In session 5, all of the indicators, except for IBL3, *students developed their own questions and/or hypotheses to explore or test*, and IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process*, had moderate mean scores of 2.00, which were close to the high range. In session 6, all of the indicators, except for IBL3 and IBL8, had high mean scores of 3.00. Hence, these two sessions were characterized by a high application of STEM as these sessions were closer to STEM approaches than the other sessions.

Similarly, as shown in table 55, the two lab and makerspace sessions in HTWW(4)L were characterized by a high application of inquiry learning, hence the sessions were closer to STEM approaches. All of the indicators, except for IBL3, *students developed their own questions and/or hypotheses to explore or test*, IBL6, s*tudents had to present or explain results of project*, and IBL8, *there was an explicit evidence of teacher modeling engineering (or reverse engineering) design process*, had moderate (2.00) to high (3.00) mean scores.

As shown in table 54, IBL was poorly applied in HTWW(3)L as evidenced by low mean scores of IBL10 across the lab and makerspace sessions. However, IBL1, *students were engaged in open-ended tasks or questions*, IBL2, *students engaged in hands-on or real-life problem solving activities or a lab experiment*, and IBL7, *students worked on a project requiring creativity*, were highly respected across the sessions.

Interpretive Analysis

Inquiry learning was mostly evident in HWOO(3)L and HTWW(4)L. In both units, the tasks and activities done were open-ended, and they were hands-on and related to real life. In addition, the students were engaged in scientific inquiry. For example, in one of the sessions in HWOO(3), the students were using standardized weights to measure several objects on the balance. They had to predict on their own which standardized is reasonable to use for each object (e.g. wooden stick, tennis ball, tape, etc.). In another session, the students were experimenting with little bits and making connections with the city's networks. So the technology coordinator, who was assisting in the lab/ makerspace, emphasized that being a good scientist requires writing down notes of the observations while working, thus, encouraging students to write down notes.

Furthermore, project-based learning and engineering design were also evident mostly in HWOO(3)L and HTWW(4)L, particularly in the sessions that were assisted by the technology coordinator. For example, in both of these units, the students were creating a final product, which they had to test and improve. The planning and research phases were done in class, while the application phase was done in the lab and makerspace. While working on their final products, some students faced challenges in their functions, thus they had to improve their designs. For example, in HWOO(3)L, one group of students were building and electric car using little bits, and while connecting the wheels together, they found out that the wheel rotations were not synchronized and the car was not moving in a straight direction. Similarly, in HTWW(4)L, the students were facing problems with their inventions and they had to figure out how to solve those problems (e.g. coding on the iPad application was not working, the windshield was not working properly, the design of the cloth didn't fit properly…).

However, in HTWW(3)L, the two lab experiments done were basic, structured and not challenging for students when compared to the tasks that were given to students in HWOO(3)L and HTWW(4)L. The students were not provided with an engineering design challenge or a real-life problem that they need to solve. For example, when the students were building the volcano, they focused on the shape and design of the volcano, because the lab teacher emphasized that the group with the best design will be chosen for the simulation of the volcanic eruption. Hence, the arts was the dominant subject in the session. Besides, the students were given the materials, rather than choosing the materials they needed.

4.2.13 Analysis of FA: Lab/ makerspace observations

Global Descriptive Analysis

Table 56. FA lab/ makerspace observation global mean scores across the grade levels

Teacher Instruction/ Formative Assessment	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
FD	0.38	0.17	0.00	0.18	FD
FA2	0.24	0.17	0.00	0.13	FA2
FA3	1.33	0.67	0.00	0.67	FA3
FA4	1.10	0.00	1.67	0.92	FA4
FA5	0.00	0.00	1.33	0.44	FA5
FA6	0.90	0.33	0.00	0.41	FA6
FA7	0.19	0.00	2.00	0.73	FA7
FA8	0.61	0.23	0.50	0.45	FA8

Table 56 shows the FA lab and makerspace observation global mean scores across the grade levels. All of the indicators obtained low mean scores, with FA2, *teacher provided clear criteria for success/examples of good work to students*, being the lowest with a mean score of 0.13. Although FA4, *teacher provided specific feedback to students*, had a low mean score of 0.92, it is closer to the moderate.

In HTWW(3)L, all of the indicators had low mean scores, whereas in HWOO(3)L and HTWW(4)L, few indicators had moderate mean scores. In HWOO(3)L, FA3, *teacher used a variety of strategies to monitor student learning and understanding throughout the lesson*, and FA4, *teacher provided specific feedback to students*, had moderate mean scores of 1.33 and 1.10, respectively. In HTWW(4)L, FA4, FA5, *students were engaged in self- and/or peer-assessment*, and FA7, *students* *were given opportunities to reflect on their own learning*, had moderate mean scores of 1.67, 1.33 and 2.00, respectively.

Grade-3 and Grade-4 Descriptive Analysis

Table 57. FA lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
FD	0.67	0.00	0.67	0.67	0.67	0.00	0.00	0.38	FD
FA2	0.00	0	0	0.667	1	0	0	0.24	FA2
FA3	2.00	2.00	0.33	1.00	1.33	2.00	0.67	1.33	FA3
FA4	1.333	0.67	0.00	0.67	2.00	3.00	0.00	1.10	FA4
FA5	0	0	0	0	0	0	0	0.00	FA5
FA6	2.00	2.00	0.00	0.67	0.67	1.00	0.00	0.90	FA6
FA7	0	1	0	0.333	0	0	0	0.19	FA7
FA8	0.87	0.77	0.20	0.63	0.87	0.80	0.13	0.61	FA8

Table 58. FA lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Mean	
FD	0.33	0.00	0.17	FD
FA2	0.33	0	0.17	FA2
FA3	0.67	0.67	0.67	FA3
FA4	0	0.00	0.00	FA4
FA5	0	0	0.00	FA5
FA6	0.67	0.00	0.33	FA6
FA7	0	0	0.00	FA7
FA8	0.33	0.13	0.23	FA8

Table 59. FA lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Teacher Instruction/ Formative Assessment	Session 1	Session 2	Mean	
FD	0.00	0.00	0.00	FD
FA2	0.00	0	0.00	FA2
FA3	0.00	0.00	0.00	FA3
FA4	1.333	2.00	1.67	FA4
FA5	0.667	2	1.33	FA5
FA6	0	0.00	0.00	FA6
FA7	1	3	2.00	FA7
FA8	0.30	0.70	0.50	FA8

Tables 57, 58 and 59 show the FA lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in these tables 57 and 59, limited sessions had moderate mean scores for few indicators (FA3, *teacher used a variety of strategies to monitor student learning and understanding throughout the lesson*, FA4, *teacher provided specific feedback to students*, FA5, *students were engaged in self- and/or peer-assessment*, and FA7, *students were given opportunities to reflect on their own learning*). Yet, all of the indicators had low mean scores in HTWW(3)L as shown in table 58. Hence, formative assessment is poorly implemented in the lab and makerspace sessions.

Interpretive Analysis

In HWOO(3)L, the teacher used more strategies to monitor student learning throughout the sessions. For example, the teacher circulated and asked open-ended questions and guiding questions (e.g. How do we use buzzers in real-life? Have you ever heard a loud noise? How could the loud noise help people?), gave a worksheet (students had to draw the circuit that they built, write what city network could this be part of and how could it help people) and did an exit ticket (2 stars and 1 wish: 2 things they learned and 1 thing they wish next time will do).

However, in HTWW(4)L, students were given opportunities to reflect on their own learning as they tested their prototypes. They had to reflect on their results and improve their prototypes accordingly.

4.2.14 Analysis of CIF: Lab/ makerspace observations

Global Descriptive Analysis

Table 60. CIF lab/ makerspace observation global mean scores across the grade levels

Common Instructional Framework	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
CIF1	2.00	2.17	2.50	2.22	CIF1
CIF2	1.14	0.00	0.00	0.38	CIF2
CIF3	1.43	0.00	0.00	0.48	CIF3
CIF4	1.29	0.83	1.00	1.04	CIF4
CIF5	1.81	2.17	2.50	2.16	CIF5
CIF6	1.53	1.03	1.20	1.26	CIF6

Table 60 shows the CIF lab and makerspace observation global mean scores across the grade levels. CIF6, *summary: Overall rating of Quality of Common Instructional Framework implementation*, had a mean score of 1.26, which indicates that the CIF implementation across the units was moderate. CIF1, *students worked collaboratively in teams or groups*, had the highest mean score of 2.22, whereas CIF2, *students used writing to communicate what they had learned*, had the lowest mean score of 0.38.

Furthermore, CIF1, *students worked collaboratively in teams or groups*, and CIF5, *students engaged in discussion with each other,* were highly respected across the units. Hence, group work and discussions were highly implemented in the lab and makerspace.

However, CIF2, *students used writing to communicate what they had learned*, and CIF3, *teachers asked open-ended questions that required higher level thinking*, were absent in HTWW(3)L and HTWW(4)L as they had mean scores of 0.

Furthermore, HWOO(3)L was the unit with most CIF application in the lab and makerspace, and all of its indicators obtained moderate mean scores. Although CIF1 had a moderate mean score of 2.00, it was closer to the high range.

Grade-3 and Grade-4 Descriptive Analysis

Table 61. CIF lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Common Instructional Framework	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
CIF1	2.00	2.00	2.00	1.00	2.00	3.00	2.00	2.00	CIF1
CIF2	2.00	3.00	0.00	1.33	0.67	1.00	0.00	1.14	CIF2
CIF3	2.00	3.00	1.00	0.67	1.33	2.00	0.00	1.43	CIF3
CIF4	2.00	2.00	0.67	0.67	1.33	2.00	0.33	1.29	CIF4
CIF5	1.33	1.67	2.00	0.67	2.00	3.00	2.00	1.81	CIF5
CIF6	1.87	2.33	1.13	0.87	1.47	2.20	0.87	1.53	CIF6

Table 62. CIF lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Common Instructional Framework	Session 1	Session 2	Mean	
CIF1	2.33	2.00	2.17	CIF1
CIF2	0.00	0.00	0.00	CIF2
CIF3	0.00	0.00	0.00	CIF3
CIF4	1.33	0.33	0.83	CIF4
CIF5	2.33	2.00	2.17	CIF5
CIF6	1.20	0.87	1.03	CIF6

Table 63. CIF lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Common Instructional Framework	Session 1	Session 2	Mean	
CIF1	2	3.00	2.50	CIF1
CIF2	0.00	0.00	0.00	CIF2
CIF3	0.00	0.00	0.00	CIF3
CIF4	1.00	1.00	1.00	CIF4
CIF5	2.00	3.00	2.50	CIF5
CIF6	1.00	1.40	1.20	CIF6

Tables 61, 62 and 63 show the CIF lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in table 61, CIF implementation was highly respected in sessions 1, 2, 5 and 6 as all or most of its indicators had moderate to high mean scores. In addition, the lab sessions in

HWOO(3)L had more CIF applications than the lab sessions in HTWW(3)L and HTWW(4)L. Group work and discussions were highly respected across all the sessions in all of the units.

Interpretive Analysis

In all of the lab sessions, the students were always working in groups and discussing together. Furthermore, in HWOO(3)L, the students used writing to communicate what they learned as they were given worksheets to fill and they had to write their observations, notes, steps, materials, etc. on their journals. In addition, the teacher provided assistance when students struggled through further questioning.

4.2.15 Analysis of SE: Lab/ makerspace observations

Global Descriptive Analysis

Table 64. SE lab/ makerspace observation global mean scores across the grade levels

Student Engagement	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
SE1	2.33	2.33	2.50	2.39	SE1
SE2	2.24	1.50	2.50	2.08	SE2
SE3	1.90	0.50	0.00	0.80	SE3
SE4	1.95	0.83	2.50	1.76	SE4
SE5	0.81	0.33	0.00	0.38	SE5
SE6	1.85	1.10	1.50	1.48	SE6

Table 64 shows the SE lab and makerspace observation global mean scores across the grade levels. SE6, *summary: Student Engagement*, had a mean score of 1.48

indicating that the lab and makerspace sessions implemented student engagement moderately. SE1, *students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions),* and SE2, *the time in class was spent productively on meaningful task*, had high mean scores of 2.39 and 2.08, respectively. Besides, they were highly respected across the grade levels.

However, SE4, *students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem),* had a moderate mean score of 1.76. HWOO(3)L obtained a moderate mean score of 1.95, which was closer to the high range, and HTWW(4)L obtained a high mean score of 2.50 as opposed to HTWW(3)L (0.83).

Grade-3 and Grade-4 Descriptive Analysis

Table 65. SE lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Student Engagement	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
SE1	2.67	2.33	1.67	1.67	2.67	3.00	2.33	2.33	SE1
SE2	2.67	2.67	1.67	1.67	2.67	3.00	1.33	2.24	SE2
SE3	3	2	1.333	1	3	3	0	1.90	SE3
SE4	3	2.667	1	1.333	2	3	0.667	1.95	SE4
SE5	0.00	0.67	1.00	0.67	1.33	2.00	0.00	0.81	SE5
SE6	2.27	2.07	1.33	1.27	2.33	2.80	0.87	1.85	SE6

Table 66. SE lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Student Engagement	Session 1	Session 2	Mean	
SE1	2.33	2.33	2.33	SE1
SE2	1.67	1.33	1.50	SE2
SE3	1	0	0.50	SE3
SE4	1	0.667	0.83	SE4
SE5	0.67	0.00	0.33	SE5
SE6	1.33	0.87	1.10	SE6

Table 67. SE lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Student Engagement	Session 1	Session 2	Mean	
SE1	2.00	3.00	2.50	SE1
SE2	2.00	3.00	2.50	SE2
SE3	0	0	0.00	SE3
SE4	2	3	2.50	SE4
SE5	0.00	0.00	0.00	SE5
SE6	1.20	1.80	1.50	SE6

Tables 65, 66 and 67 show the SE lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in the three tables, SE1 and SE2 were highly respected across the sessions in all the units. However, SE4, *students appeared cognitively engaged (ask questions of the teacher and* *each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem),* was highly respected across the sessions in HTWW(4)L (see table 67) and moderately respected across the sessions in HWOO(3)L (see table 65).

Interpretive Analysis

In all of the units, the students were behaviorally engaged as they were busy doing something (e.g. lab experiment, simulation and hands-on activity). However, they appeared to be more cognitively engaged in HWOO(3)L and HTWW(4)L as the activities were more challenging and meaningful to the students and required problem solving.

4.2.16 Analysis of UOT: Lab/ makerspace observations

Global Descriptive Analysis

Table 68. UOT lab/ makerspace observation global mean scores across the grade levels

Use of Technology	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean	
UOT1	1.95	1.00	2.50	1.82	UOT1
UOT2	1.29	0.33	2.50	1.37	UOT2
UOT3	1.57	0.67	2.50	1.58	UOT3
UOT4	0.24	0.00	0.00	0.08	UOT4
UOT5	0.00	0.00	0.00	0.00	UOT5
UOT6	0.00	0.00	0.00	0.00	UOT6
UOT7	0.00	0.00	0.00	0.00	UOT7
UOT8	0.73	0.29	1.07	0.70	UOT8

Table 68 shows the UOT lab and makerspace observation global mean scores across the grade levels. Most of the indicators obtained low mean scores, with UOT5, *students used technology to practice skills or reinforce knowledge*, UOT6, *technology was used but did not appear to provide any added benefit*, and UOT7, *teacher used technology to achieve instructional goals. (Emphasis on the "teacher" here)*, being the lowest with mean scores of 0. Conversely, UOT1, *technology was used to a high extent (as a proportion of time of the lesson and intensity of use)*, UOT2, *students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding*, and UOT3, *students used technology to generate or manipulate one or more representations of a given concept or idea*, had moderate mean scores, with UOT1 being the highest, with a mean score of 1.82.

Grade-3 and Grade-4 Descriptive Analysis

Table 69. UOT lab/ makerspace observation mean scores for HWOO(3)L across the sessions

Use of Technology	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Mean	
UOT1	2.00	2.33	2.00	1.00	2.00	3.00	1.33	1.95	UOT1
UOT2	1.67	1.667	0	0.667	2	3	0	1.29	UOT2
UOT3	1.67	1.00	2.00	0.00	2.00	3.00	1.33	1.57	UOT3
UOT4	0	0.667	0	1	0	0	0	0.24	UOT4
UOT5	0	0	0	0	0	0	0	0.00	UOT5
UOT6	0	0	0	0	0	0	0	0.00	UOT6
UOT7	0	0	0	0	0	0	0	0.00	UOT7
UOT8	0.83	0.81	0.57	0.38	0.86	1.29	0.38	0.73	UOT8

Table 70. UOT lab/ makerspace observation mean scores for HTWW(3)L across the sessions

Use of Technology	Session 1	Session 2	Mean	
UOT1	0.67	1.33	1.00	UOT1
UOT2	0.67	0	0.33	UOT2
UOT3	0.00	1.33	0.67	UOT3
UOT4	0	0	0.00	UOT4
UOT5	0	0	0.00	UOT5
UOT6	0	0	0.00	UOT6
UOT7	0	0	0.00	UOT7
UOT8	0.19	0.38	0.29	UOT8

Table 71. UOT lab/ makerspace observation mean scores for HTWW(4)L across the sessions

Use of Technology	Session 1	Session 2	Mean	
UOT1	2.00	3.00	2.50	UOT1
UOT2	2.00	3	2.50	UOT2
UOT3	2.00	3.00	2.50	UOT3
UOT4	0	0	0.00	UOT4
UOT5	0	0	0.00	UOT5
UOT6	0	0	0.00	UOT6
UOT7	0	0	0.00	UOT7
UOT8	0.86	1.29	1.07	UOT8

Tables 69, 70 and 71 show the UOT lab and makerspace observation mean scores for HWOO(3)L, HTWW(3)L and HTWW(4)L across the sessions. As shown in table 70, technology was poorly used in the lab sessions of HTWW(3)L as all of the indicators obtained low mean scores. Conversely, as shown in table 71, HTWW(4)L was characterized with moderate use of technology as evidenced by the moderate mean score of UOT8, *summary: Use of technology*.

Furthermore, as shown in tables 70 and 71, the use of technology in HWOO(3)L and HTWW(4)L was focused on UOT1, *technology was used to a high extent (as a proportion of time of the lesson and intensity of use)*, UOT2, *students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding*, and UOT3, *students used technology to generate or manipulate one or more representations of a given concept or idea*, indicating that the lab and makerspace sessions implemented technology in a meaningful way.

Interpretive Analysis

Students always used technological tools, concrete materials or manipulatives in the lab and makerspace. The most commonly used technological tool was the little bits, which was used heavily in the HWOO(3)L and HTWW(4)L lab sessions. For example, in HWOO(3)L, the little bits were used in the first sessions to build different types of circuits that led to an event, and they were used to generate representations of different parts of the city’s networks. In addition, the little bits were used in the last sessions when the students were building their city models. They used the little bits to build one sustainable solution in their city. For example, one group of students built an electric car using little bits and another group built a garbage bin, whose lid opens and closes automatically. In HTWW(4)L, many students used little bits when building their inventions. For example, one student created a doormat that buzzes when a cat steps on it, and stops when the cat escapes.

Furthermore, various concrete materials and manipulatives were used, such as Kapla blocks, Geomag, Legos, Magna tiles, strings, ribbons, weights, wooden sticks, etc. However, the way these materials were used in the units differed. For example, in HTWW(3)L, the students utilized the Kapla blocks to build a structure that resists earthquakes. They were limited to use only Kapla blocks. However, in HWOO(3)L and HTWW(4)L, the students decided on the materials needed to build their cities and create their inventions. Hence, there was a meaningful purpose behind using the concrete materials and manipulatives.

4.2.17 Analysis of the average scores of the units in the lab

Global Descriptive Analysis of the overall STEMiness of the units in the lab

Table 72. Mean scores of the units in the lab

	HWOO(3)L	HTWW(3)L	HTWW(4)L	Mean
Average Score for the session	1.24	0.63	1.10	0.99

Table 72 shows the average scores of the units conducted in the lab and makerspace, that indicate the overall STEMiness of these units. Two units obtained moderate mean scores, with HWOO(3)L being the highest with a mean score of 1.24.

HTWW(3)L had a low mean score of 0.63, indicating that the overall lab sessions were not STEMy.

Interpretive Analysis

HWOO(3)L and HTWW(4)L were moderately STEMy as the students were involved in various STEM engagements and the sessions implemented approaches that were close to STEM education. However, in HTWW(3)L, the sessions included simple and structured lab experiments or simulations without having students to work on authentic engineering challenges, projects or problems.

4.2.18 Summary of the findings from observations

Table 73 summarizes the overall STEMiness of each dimension, which is the mean score of the summary ratings for each dimension, across the units. The scale given for each dimension was L (low), M (moderate) and H (high).

The math and science content is poorly covered across all the units, particularly in the lab. In addition, when the unit is not science-based, the extent to which science content is covered is low. In addition, explicit integration of mathematics was absent across all the units. Mostly, science is integrated with technology or engineering, such as in HWOO(3).

Moreover, the student cognitive engagement in meaningful instruction was moderate in HWOO(3), HTWW(3), HTWW(4), HWOO(3)L and HTWW(4)L as students were given opportunities to summarize, synthesize, explain their thinking and use various means of representation. However, students were able to apply their knowledge to a novel situation when the unit integrated engineering design, especially because in HWOO(3) and HTWW(4), the students had to create a product by the end of the unit.

Furthermore, inquiry learning was mostly evident in the lab and makerspace sessions of HWOO(3)L and HTWW(4)L due to the challenging hands-on activities and tasks that were implemented, rather than the simple and structured simulations done in HTWW(3)L lab sessions. In addition, HTWW(4) had moderate application of IBL as the students were involved in the engineering design process throughout the whole unit, whereas, in HWOO(3), engineering design was mostly an application of the student's understanding.

Regarding the formative assessment, all of the units, except for HWOO(3), was poorly applied, due to the limited techniques used by teachers. In HWOO(3), the teacher used more strategies to formatively assess students, such as varying the strategies to monitor student learning and providing more specific feedback.

The common instructional framework and the students engagement dimensions were the dimensions that were applied the best. In all of the units, the students were frequently engaged in group work, discussions and open-ended questions. Besides, the teachers always request from students to communicate their understanding through writing.

Furthermore, in all the units, the students were behaviorally engaged, but the cognitive engagement varied. When the tasks required problem solving and were challenging, the students appeared more cognitively engaged.

Finally, the use of technology was poor in all the units, except for HTWW(4)L, where the students were engaged in creating their inventions and used various technological tools in the makerspace. However, in the other units, the way the technology was used varied. For example, in many sessions across all the units, the technology was used to explore ideas or concepts or to generate one or more representations of a given concept.

Table 73. Overall STEMiness of each dimension across the units

	HWOO(3)	HTWW(3)	WWA(4)	HTWW(4)	HWOO(3)L	HTWW(3)L	HTWW(4)L
MSC	L	L	L	L	L	L	L
CEM	M	M	L	M	M	L	M
IBL	L	L	L	M	M	L	M
FA	M	L	L	L	L	L	L
CIF	H	M	M	M	M	M	M
SE	H	M	M	M	M	M	M
UOT	L	L	L	L	L	L	M

4.3 Surveys

Online questionnaires were sent to French homeroom teachers teaching CP, CE1, CE2, CM1 and CM2 levels and English homeroom teachers teaching Grade 1, Grade 2 and Grade 5 levels in the elementary school. The Grade 3 and Grade 4 English homeroom teachers were excluded from the surveys as they were interviewed. Almost all of the teachers responded; a total of 22 respondents (N= 9 English homeroom teachers and N=13 French homeroom teachers) completed the questionnaires.

The questionnaires asked about the strategies used in classroom that reflect integrated STEM education, the support provided to enhance teachers' TPACK and the barriers that hinder the implementation of STEM education at the school. Hence, the questionnaires were divided into four categories based on the study's research questions. In the first category, the questions asked information regarding the teacher's background, which are gender, age, academic degree, major, years of teaching experience and grade level that they are currently teaching. In the second category, the teachers were asked questions about what they believe are the best practices that should be used. In the third category, the teachers were asked questions that were intended to uncover the support that they get to enhance their TPACK and the support that they would want to get. In the fourth category, the teachers were asked about the challenges and barriers they encounter in implementing integrated STEM education at the school. The questionnaires were typed in English and French (Appendix G) as some teachers teach English sections, while others teach French sections, and they were sent via Google Forms.

This section presents the quantitative and qualitative data obtained from the online surveys. The data collected will answer the second, third and fourth research questions: *What are the strategies that homeroom teachers use within the elementary classes that reflect integrated STEM education? What kind of support do homeroom teachers get to develop their technological pedagogical content knowledge (TPACK) for properly implementing STEM education?* and *What are the challenges and barriers that hinder proper implementation of integrated STEM education within elementary classes?*

4.3.1 Data Analysis Method

The teachers' responses were combined together in one Excel workbook. The first sheet in Excel combined all the responses across the questions. Then, the questions were divided into different sheets; each sheet includes all the questions that would answer one research question. For example, the questions that are intended to answer the second research question were included in one sheet and the sheet was named as "R2", which stands for research question 2; the questions that are intended to answer the third research question were included in another sheet, and the sheet was named as "R3", which stands for research question 3, etc. Besides, a sheet compiled all the biographic data, which include gender, age, highest degree attained, major, years of teaching experience and grade level that you are currently teaching.

The questions that asked the participants to rate from *Always to Never* or from *Very Important to Unimportant* were coded for the purpose of the research. In addition, the ratings were coded. These questions and their codes, and the ratings and their codes are shown in the tables below.

Table 74. Some of the survey questions and their codes

Question	**Code**
Which of these approaches do you adopt in your classroom?	R2A
Project-based learning	R2A-PjBL
Problem-based learning	R2A-PBL
Building models	R2A-M
Technology integration	R2A-T
Hands-on activities	R2A-H
Open-ended questioning	R2A-Q
Discussions	R2A-D
Connections to real-world contexts	R2A-RW
Group work	R2A-G
Student presentations	R2A-P
Lecturing	R2A-L

How do you use technology in your classes?	R2Tech
I use technology as a resource to find ideas and activities	R2Tech-R
I use technology at home to prepare my lessons	R2Tech-H
I use technology as a tool for teaching in class	R2Tech-T
I use technology for coding, programming and other activities	R2Tech-C
Which of the following do you adopt with students?	R2S
I encourage students to develop their own questions and/ or hypothesis	R2S-QH
I ask students to research a topic	R2S-R
I request students to make observations	R2S-O
I request students to record data	R2S-D
I ask students to interpret the results of their exploration	R2S-I
I ask students to define a problem	R2S-P
I allow students to think of the criteria of a solution	R2S-C
I ask students to brainstorm their ideas	R2S-B
I ask students to draw sketches or diagrams to visualize the solution	R2S-S
I ask students to generate multiple potential solutions	R2S-G
I request students to redesign their model	R2S-RD
I encourage students not to give up when solving a problem	R2S-SP
I provide students with occasions to critique others' reasoning	R2S-OC
I allow students to reason abstractly	R2S-A
I ask students to look for patterns	R2S-Pat
I encourage students to attend to precision	R2S-Pre
I ask students to construct viable arguments	R2S-Con
I encourage students to model with math (e.g. write an equation to describe a situation)	R2S-Mod
What kind of resources are provided by the school that influence your content knowledge, teaching practices and/ or technology integration?	R3R
School library	R3R-Lib
Textbooks	R3R-Text
Magazines/ newspapers	R3R-New
Online web resources (e.g. YouTube videos, GoogleDocs, Phet simulations, Padlet, Story jumper, etc.)	R3R-Onli
Tutorials	R3R-Tuto
Coordinator's assistance	R3R-Coor
What are the barriers that interfere with the implementation of STEM education at the school?	R3B
Limited content knowledge in science/ technology/ engineering or mathematics	R3B-CK
Limited familiarity with the student-centered approaches (e.g. problem-based learning, inquiry learning, project-based learning, etc.)	R3B-SCA
Lack of motivation to learn and adopt new approaches	R3B-Mot
Limited technology resources available at the school	R3B-Tech
Poor facility structure (e.g. small classroom sizes, poor lab conditions, etc.)	R3B-Str
Time constraints	R3B-Time

Need to finish the curriculum	R3B-Curr
Limited materials and physical resources (e.g. material kits)	R3B-Res
Insufficient professional development opportunities	R3B-PD
Limited collaboration	R3B-Coll
Insufficient faculty and staff meetings to discuss issues and solutions related to STEM education	R3B-Meet

Table 75. The ratings that were used in the survey and their codes

Rating	**Code**
Always	A
Sometimes	S
Rarely	R
Never	N
Very Important	VI
Important	I
Of Little Importance	LI
Unimportant	UnI

Then, the responses to all of the survey questions were inserted. As mentioned previously, the questions that were coded, asked the participants to rate from *Always* to *Never*, and from *Very Important* to *Unimportant*. Frequencies were computed for the coded questions and biographic data. Then, weights were assigned to each rating. For example, Never and Unimportant were assigned a weight of 0; Rarely and Of Little Importance were assigned a weight of 1; Sometimes and Important were assigned a weight of 2; and Always and Very Important were assigned a weight of 3. Then, an index was computed by multiplying the weight assigned with the frequencies of each rating and dividing by the number of respondents, which is 22.

The qualitative data, which included four open-ended questions were inserted in a Word document. One question asked the teachers to list the topics in math and the topics in science that they teach in an integrated manner. One question asked the participants to describe what the students do in the *Science Lab*, while another question asked them to describe what the students do in the *Makerspace*. These three questions will provide more in-depth understanding of approaches to integration, the strategies that teachers utilize with their students and the way students are being engaged in the lab and makerspace. The last question in the survey asked the teachers for suggestions or recommendations for elevating the barriers that hinder proper implementation of STEM education at the school. Their answers will complement the close-ended questions which asked about the barriers as teachers propose solutions. Coding categories were assigned from the text to detect recurring themes. Then, the recurrent themes were grouped together into one category.

4.3.2 Quantitative findings from surveys

The quantitative findings from the surveys will be discussed in the following sections: Biographic data, adopted strategies and approaches, support provided to teachers and barriers for STEM education.

4.3.2.1 Biographic Data

This section presents the biographic data of the 22 elementary teachers that completed the questionnaire. These data include: 1) Gender and age, 3) highest degree attained and major, 4) years of teaching experience and 5) current grade level.

Gender and age

Results revealed that 19 out of 22 teachers were female and 3 out of 22 teachers were male. With respect to age, half of the teachers (11 out of 22) are between 30 and 39 years old; 8 out 22 teachers are between 40 and 49 years old; 2 out of 22 teachers are between 50 and 59 years old; 1 teacher is 60 years and above; and none of the teachers are between 21 and 29 years old.

Highest Degree Attained and Major

Results showed that 9 out 22 teachers hold a Bachelor’s degree, 6 out of 22 teachers hold a Teaching Diploma and 7 out of 22 teachers hold a Master’s degree. As for the major, most of the teachers (15 out of 22) studied Education. The rest of the teachers’ responses varied. One teacher studied Mathematics, one teacher studied Biology, one teacher studied Educational Technology, one teacher studied Mathematics and Science, one teacher studied Traduction (Translation) and one teacher studied Lettres Françaises.

Years of teaching experience

Results revealed that 2 out of 22 teachers have 1-5 years of teaching experience, 3 out of 22 teachers have 6-10 years of teaching experience, 7 out of 22 teachers have 11-15 years of experience, 1 out of 22 teachers has 16-20 years of teaching experience, 5 out of 22 teachers have 21-26 years of teaching experience and 4 out of 22 teachers have 26 years and above of teaching experience.

Current grade level

In the elementary school, the English grade levels range from Grade 1 till Grade 5, while the French grade levels range from CP to CM2. Results showed that 3 out of 22 teachers teach Grade 1, 3 out of 22 teachers teach Grade 2, 3 out of 22 teachers teach Grade 5, 3 teachers teach CP, 3 teachers teach CE1, 3 teachers teach CE2, 3 teachers teach CM1 and 1 teacher teaches CM2. Hence, the responses from the English grade levels were complete as opposed to the responses from the French grade levels as each grade level has three English homeroom teachers.

4.3.2.2 Adopted strategies and approaches

Table 76. Adopted approaches by elementary teachers and their respective codes, frequency and index

	Name of the approach	Code	Frequency of Always	Frequency of Sometimes	Frequency of Rarely	Frequency of Never	Index of adopted approaches
Which of these approaches do you adopt in your classroom? (R2A[a])	Project-based learning	R2A-PjBL	7	13	1	0	2.18
	Problem-based learning	R2A-PBL	10	11	1	0	2.41
	Building models	R2A-M	5	15	2	0	2.14
	Technology integration	R2A-T	11	11	0	0	2.50
	Hands-on activities	R2A-H	17	5	0	0	2.77
	Open-ended questioning	R2A-Q	12	10	0	0	2.55
	Discussions	R2A-D	20	2	0	0	2.91
	Connections to real-world contexts	R2A-RW	19	3	0	0	2.86
	Group work	R2A-G	16	6	0	0	2.73
	Student presentations	R2A-P	10	12	0	0	2.45
	Lecturing	R2A-L	1	17	4	0	1.86

[a] Code of the question “Which of these approaches do you adopt in your classroom”

Table 76 shows the adopted approaches by elementary teachers in their classrooms and their frequency of use, according to teachers, on scale of 0 to 3 with 0 corresponding to Never and 3 corresponding to Always. An index of the adopted approach was computed for each approach to indicate the most and least frequently used approaches. All of the indicated approaches are adopted by teachers, however the extent to which each approach is adopted differ. As shown in table 76, discussions and connections to real-world contexts are most frequently used among teachers as evidenced by the index of the adopted approaches of 2.91 and 2.86, respectively. In addition, hands-on activities (index = 2.77), group work (index = 2.73) and open-ended questioning (index = 2.55) are more used than other approaches mentioned.

However, lecturing is the least used as evidenced by its index of 1.86. The low score of lecturing is expected in a school that follows the International Baccalaureate – Primary Years Program, which requires more student-centered learning. Apart from lecturing, building models and project-based learning are also among the least used approaches with indices of 2.14 and 2.18, respectively.

Table 77. The way technology is used by elementary teachers and their respective codes, frequencies and indices of usage of technology

	Usage of Technology	Code	Frequency of Always	Frequency of Sometimes	Frequency of Rarely	Frequency of Never	Index of usage of technology
How do you use technology in your classes? (R2Tech[a])	I use technology as a resource to find ideas and activities	R2Tech-R	17	5	0	0	2.77
	I use technology at home to prepare my lessons	R2Tech-H	13	8	1	0	2.55
	I use technology as a tool for teaching in class	R2Tech-T	13	8	1	0	2.55
	I use technology for coding, programming and other activities	R2Tech-C	3	16	3	0	2.00

[a] Code of the question: "How do you use technology in your classes?"

Table 77 shows the way technology is used by elementary teachers in their classrooms and their frequency of use, according to teachers, on scale of 0 to 3 with 0 corresponding to Never and 3 corresponding to Always. An index of the usage of technology was computed to indicate the extent to which each method is used. All teachers used technology, but the way technology is used differed. As shown in Table 77, R2Tech-R (I use technology as a resource to find ideas and activities), was the most common way of making use of technology as evidenced by an index of 2.77. Hence, the elementary teachers rely on technology as a resource to search for ideas and activities for their lessons. However, R2Tech-C (I use technology for coding, programming and other activities), was least commonly used among elementary teachers as evidenced by an index of 2.00, indicating that coding and programming are not emphasized at school.

Furthermore, RTech-H (I use technology at home to prepare my lessons) and R2Tech-T (I use technology as a tool for teaching in class) obtained equivalent indices of 2.55, indicating frequent usage of technology for preparing the lessons and for teaching in class.

Table 78. Strategies used by elementary teachers with their students and their respective frequencies and indices of the adopted strategies

	Name of category	Name of strategy	Code	Frequency of Always	Frequency of Sometimes	Frequency of Rarely	Frequency of Never	Index of adopted strategies
Which of the following do you adopt with students? (R2S[a])	*Scientific Inquiry*	I encourage students to develop their own questions and/ or hypothesis	R2S-QH	16	6	0	0	2.73
		I ask students to research a topic	R2S-R	10	11	1	0	2.41
		I request students to make observations	R2S-O	19	3	0	0	2.86
		I request students to record data	R2S-D	11	10	1	0	2.45
		I ask students to interpret the results of their exploration	R2S-I	13	8	1	0	2.55
	Engineering Design	I ask students to define a problem	R2S-P	11	8	2	0	2.32
		I allow students to think of the criteria of a solution	R2S-C	10	9	3	0	2.32

		I ask students to brainstorm their ideas	R2S-B	16	6	0	0	2.73
		I ask students to draw sketches or diagrams to visualize the solution	R2S-S	10	10	1	0	2.32
		I ask students to generate multiple potential solutions	R2S-G	8	13	1	0	2.32
		I request students to redesign their model	R2S-RD	14	5	2	0	2.45
	Mathematical Thinking	I encourage students not to give up when solving a problem	R2S-SP	19	3	0	0	2.86
		I provide students with occasions to critique others' reasoning	R2S-OC	15	6	1	0	2.64
		I allow students to reason abstractly	R2S-A	10	11	1	0	2.41
		I ask students to look for patterns	R2S-Pat	8	12	2	0	2.27
		I encourage students to attend to precision	R2S-Pre	14	7	1	0	2.59
		I ask students to construct viable arguments	R2S-Con	14	7	1	0	2.59
		I encourage students to model with math (e.g. write an equation to describe a situation)	R2S-Mod	15	6	0	0	2.59

[a] Code of the question: "Which of the following do you adopt with students?"

Table 78 shows the adopted strategies by elementary teachers with their students and their frequency of use, according to teachers, on scale of 0 to 3 with 0 corresponding to Never and 3 corresponding to Always. An index of the adopted strategy was computed to indicate the most and least frequently used strategies. These strategies are categorized into the STEM education components with respect to the conceptual framework of integrated STEM Education elements as stated in the literature review (Kelley & Knowles, 2016). All elementary teachers used the mentioned strategies, however, the extent to which each strategy is used differed.

With respect to scientific inquiry, R2S-O (I request students to make observations) was most frequently used by elementary teachers as evidenced by its index of adopted strategy of 2.86. Besides, R2S-QH (I encourage students to develop their own questions and/ or hypothesis) obtained an index of 2.73, indicating that this strategy is also frequently used. However, R2S-R (I ask students to research a topic) and R2S-D (I request students to record data) were least frequently used as their indices of adopted strategies are 2.41 and 2.45, respectively.

Regarding engineering design, R2S-B (I ask students to brainstorm their ideas) was the most frequently used by elementary teachers as its index is 2.73. However, R2S-P (I ask students to define a problem), R2S-C (I allow students to think of the criteria of a solution), R2S-S (I ask students to draw sketches or diagrams to visualize the solution) and R2S-G (I ask students to generate multiple potential solutions) were the least frequently used as evidenced by their indices of adopted strategies of 2.32. The low scores of the indices indicate that engineering design is not heavily adopted or emphasized by teachers.

With respect to mathematical thinking, R2S-SP (I encourage students not to give up when solving a problem) obtained the highest index of 2.86, indicating that teachers frequently use this strategy. In addition, other strategies that were frequently used by elementary teachers include R2S-OC (I provide students with occasions to critique others' reasoning), R2S-Pre (I encourage students to attend to precision), R2S-Con (I ask students to construct viable arguments) and R2S-Mod (I encourage students to model with math) as their indices were 2.64, 2.59, 2.59, 2.59 and 2.59, respectively. However, R2S-Pat (I encourage students to look for patterns) was least frequently used as evidenced by its index of 2.27.

Among all the elements of the conceptual framework of integrated STEM education, scientific inquiry was adopted the most by elementary teachers, whereas engineering design was adopted the least by elementary teachers. The high scores of the scientific inquiry indices may be interpreted due to the essence of the PYP program that follows an inquiry-based approach.

4.3.2.3 Support provided to teachers

Table 79. Resources that enhance teachers' TPACK with their respective codes, frequencies and indices of resources provided

	Name of resource	Code	Frequency of Very Important	Frequency of Important	Frequency of Of little Importance	Frequency of Unimportant	Index of Resources provided
What kind of resources are provided by the school that influence your content knowledge, teaching practices and/ or technology integration? (R3R[a])	School library	R3R-Lib	8	7	6	1	2.00
	Textbooks	R3R-Text	10	9	3	0	2.32
	Magazines/ newspapers	R3R-New	5	11	5	1	1.91
	Online web resources (e.g. YouTube videos, GoogleDocs, Phet simulations, Padlet, Story jumper, etc.)	R3R-Onli	18	4	0	0	2.82
	Tutorials	R3R-Tuto	3	17	1	0	2.00
	Coordinator's assistance	R3R-Coor	11	11	0	0	2.50

[a] Code of the question: "What kind of resources are provided by the school that influence your content knowledge, teaching practices and/ or technology integration?"

Table 79 shows the resources that would enhance elementary teachers' TPACK with their respective codes, frequencies and indices of resources provided. The elementary teachers rated the extent to which each resource was important for enhancing their TPACK; the ratings ranged from Very Important to Unimportant. As shown in table 79, R3R-Onli (online web resources) obtained the highest index of 2.82, indicating that online web resources are most important in improving their TPACK. The second most important resource was R3R-Coor (coordinator's assistance) with an index of 2.50, indicating that the coordinators are a valuable resource and play a major role in promoting teachers' TPACK. The third most important resource was R3R-Text (textbooks) with an index of 2.32, indicating that textbooks are also important for teachers' TPACK. However, the least important resource was R3R-New (magazines/ newspapers) with an index of 1.91. The low index score of the latter may be interpreted due to the availability of information online, hence teachers may easily access the information from any electronic device.

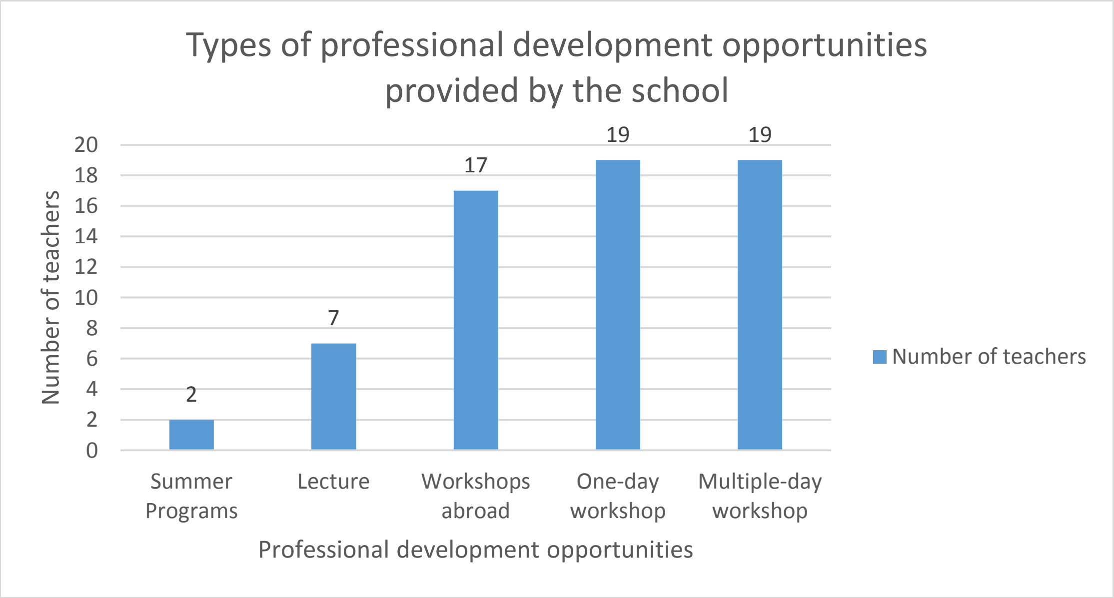


Figure 2. Types of professional development opportunities provided by the school

Teachers were asked to select the types of professional development opportunities that are provided by the school. They were given the option to choose multiple answers. Figure 2 shows the types of professional opportunities that are provided by the school as reported by teachers. As shown in Figure 2, few teachers mentioned “Lectures” (7 teachers out of 22) and just 2 teachers mentioned “Summer Programs”. So, we can consider that the school mainly provides “Workshops Abroad”, “One-day Workshop” and “Multiple-day Workshop”, as most teachers selected these options.

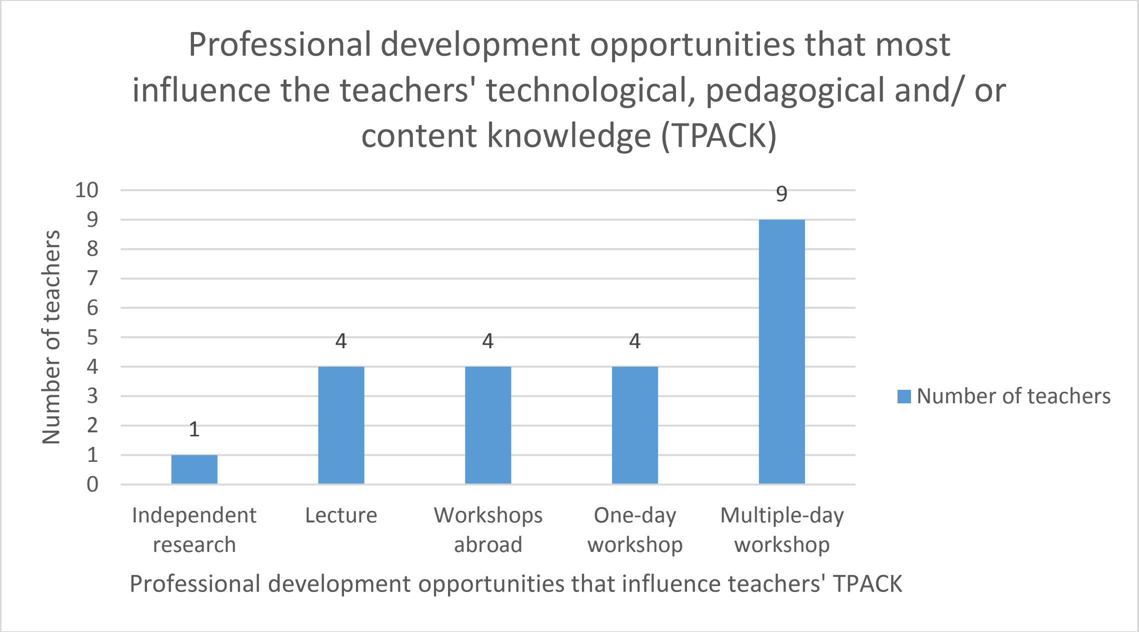


Figure 3. Professional development opportunities that most influence the teachers' technological, pedagogical and/ or content knowledge

The next question asked the teachers to choose from the selected professional development opportunities, the one that influenced their content, pedagogical and/ or technological knowledge the most. The responses are displayed in Figure 3. “Multiple-day Workshop” got the highest number of responses as 9 teachers out of 22 chose it. “Lecture”, “Workshops Abroad”, and “One-day Workshop” were equally important as 4 teachers out of 22 chose these options. Only 1 teacher out of 22 mentioned “Independent Research”, which was not one of the choices. The participant added it, meaning none of the professional development options are considered beneficial for the teacher’s content, pedagogical and/ or technological knowledge.

Table 80. Frequency of teachers' participation in professional development per year

Frequency of participating in professional development per year	**Number of teachers**
6-8 times per year	1
4-6 times per year	2
More than 8 times per year	2
1-3 times per year	17

Teachers were asked about the number of times they participate in professional development opportunities per year. The results are shown in table 80. Most of the respondents, 17 out of 22 teachers, attend 1-3 times per year. Only 3 teachers out of 22 participate in professional development opportunities 4-8 times per year, and only 2 teachers out of 22 attend more than 8 times per year.

4.3.2.4 Barriers to STEM Education

Table 81. Barriers of STEM education at the school with their respective codes, frequencies of importance according to elementary teachers and indices of barriers

	Type of barrier	Code	Frequency of Very Important	Frequency of Important	Frequency of Of little Importance	Frequency of Unimportant	Index of Barriers
What are the barriers that interfere with the implementation of STEM education at the school? (R3B[a])	Limited content knowledge in science/ technology/ engineering or mathematics	R3B-CK	6	8	6	0	1.82
	Limited familiarity with the student-centered approaches (e.g. problem-based learning, inquiry learning, project-based learning, etc.)	R3B-SCA	3	13	4	0	1.77
	Lack of motivation to learn and adopt new approaches	R3B-Mot	9	7	3	1	2.00
	Limited technology resources available at the school	R3B-Tech	6	6	4	2	1.55
	Poor facility structure (e.g. small classroom sizes, poor lab conditions, etc.)	R3B-Str	8	5	4	2	1.73

	Time constraints	R3B-Time	6	6	5	2	1.59
	Need to finish the curriculum	R3B-Curr	1	8	7	2	1.18
	Limited materials and physical resources (e.g. material kits)	R3B-Res	4	7	5	2	1.41
	Insufficient professional development opportunities	R3B-PD	7	4	4	4	1.50
	Limited collaboration	R3B-Coll	5	6	6	2	1.50
	Insufficient faculty and staff meetings to discuss issues and solutions related to STEM education	R3B-Meet	8	5	4	2	1.73

[a] Code of the question: “What are the barriers that interfere with the implementation of STEM education at the school?”

Table 81 displays the barriers of STEM education and their level of importance according to elementary teachers. An index of barriers was computed to indicate the extent to which each barrier is important at the school. R3B-Mot (lack of motivation to learn and adopt new approaches) obtained the highest index of barrier of 2.00, indicating that the lack of motivation acts as a major barrier in the school. Other barriers that seemed important according to the elementary teachers include: R3B-CK (limited content knowledge in science/ technology/ engineering or mathematics) with an index of 2.82, R3B-SCA (limited familiarity with the student-centered approaches) with an index of 1.77, R3B-Str (poor facility structure (e.g. small classroom sizes, poor lab conditions, etc.) with an index of 1.73 and R3B-Meet (insufficient faculty and staff meetings to discuss issues and solutions related to STEM education).

Some of the less important barriers were R3B-Res (limited materials and physical resources) with an index of 1.41, R3B-PD (insufficient professional development opportunities) with an index of 1.50 and R3B-Coll (limited collaboration) with an index of 1.50. The least important barrier was revealed to be R3B-Curr (need to finish the curriculum) with an index of 1.18, indicating that the curriculum does not act as a major barrier for implementing STEM education. Since the curriculum that is followed at school is the IB-PYP, the inquiry-based approach of the curriculum is closely aligned with STEM education, which could be a possible interpretation for the low index score.

4.3.3 Qualitative findings from surveys

The qualitative findings were obtained from four questions in the survey and these findings will be discussed in this section.

4.3.3.1 Teaching of integrated topics

When teachers were asked to list the topics in math and the topics in science that they teach in an integrated manner, where students learn both math and science concepts/ skills, three out of 22 teachers answered. One possible interpretation for the few responses could be due to not understanding the question.

Two teachers indicated “shape and space”. One of these teachers added other ways of integration, such as “showing their thinking and justifying their work especially when solving word problems; breaking clues to solve math riddles just like scientist who analyzes his materials before he makes a final conclusion; and [using] scientific method like estimation on math.” Another teacher indicated that “climate and graphs” are topics that integrate science with math. “Data handling” was indicated by one of these teachers, without providing further explanation of the way data handling is integrated with other topics.

4.3.3.2 Teaching and learning in the Science Lab

When the participants were asked to describe what the students do in the Science Lab, 13 out of 22 teachers responded. Four teachers indicated that students “follow the scientific method” or “ils suivent la demarche scientifique” (*They follow the scientific method*). Two teachers indicated that students “observe a science project.” Seven teachers stated that students “make/ test their hypothesis” or “formuler des hypotheses” (*They formulate hypotheses*). Seven teachers said that students “do experiments” or “Ils font des experiences” (*They perform experiments*). Two teachers indicated that students “record data” and “draw conclusions.” One teacher indicated “analyser des données” (*analyze data*). Two teachers stated that students “build models” or “ils construisent des prototypes de modèles ou de situations” (*They build prototypes of situations*).

Based on the answers given, the students mostly engage in making or testing their hypothesis, performing experiments and following the scientific methods. Observations, recording data, drawing conclusions and building models are less used than the others.

4.3.3.3 Teaching and learning in the makerspace

When the teachers were asked to describe what the students do in the makerspace, varied answers were obtained. Eight out of 22 participants responded to this question. Four teachers utilize the makerspace similar to the lab engagements that were mentioned above. For example, one teacher indicated: “Use the items available to run an experiment. They make observations, hypotheses and examine what’s available, compare between materials, make predictions and conclusions.” Another teacher stated: “Students try to create experiments out of materials given to them. They also try to come up with a hypothesis and test it.” Similarly, one teacher limited the makerspace to few steps of the scientific method as follows: “Ils observent, décrivent et tirent des conclusions” (*They observe, describe and draw conclusions*).

On the other hand, three teachers indicated that students create and design in the makerspace. For example, one teacher stated: “makerspace activities, planning and design process followed by creating, recording findings.” Another teacher specified: “invent their own machines using different reusable resources.”

However, one teacher indicated that the makerspace is not being used yet, as exemplified in this response: “not yet, we are using the classroom instead.” The diverse responses indicate that much ambiguity remains in the meaning of the makerspace, the way it is to be used and the type of engagements that should take place.

4.3.3.4 Suggestions for proper implementation of STEM education

Various suggestions for elevating the barriers that hinder proper implementation of STEM education were provided. Seven out of 22 teachers responded to this question.

Two teachers indicated that professional development related to STEM education is necessary, as shown in this response: “PD to inform and teach educators proper ways to integrate STEM in the classroom.” In addition, two teachers stated that there should be “more collaborative planning” and faculty meetings. For example, one teacher said: “réunions insuffisantes du corps professoral et du personnel pour discuter des problèmes et des solutions liés à l'éducation STEM” (*Insufficient faculty and staff meetings to discuss issues and solutions related to STEM education*). Two teachers indicated that “motivation” is needed.

Other suggestions included “good clear curriculum with clear content to teach”, “having a plan/ vision to follow”, “le materiel nécessaire” (*the necessary materials*), “installer les coins sciences et le matériel par exemple en classe tout long de l'année” (*install science corners and equipment for example in class all year round*).

4.3.4 Summary of the findings from surveys

In conclusion, elementary homeroom teachers adopt student-centered approaches, including discussions, making connections to real-world contexts, group work, scientific inquiry and mathematical thinking. The extent to which each student-centered approach is used differed; approaches that correspond to engineering design and technological literacy were the least commonly used. In addition, the makerspace is being used as a science lab more than constructing models as teachers indicated the application of scientific method. Furthermore, the most commonly reported types of support were online resources, coordinator’s assistance and textbooks. Besides, most teachers indicated that multiple-day workshops influence their TPACK. Finally, the barriers that were most commonly reported include lack of motivation to adopt new approaches, limited content knowledge in science, technology, engineering or math and limited familiarity with student-centered approaches.

Chapter 5

Discussion

This chapter discusses the cross-verified results of the study in accordance to the research questions and their connection to the literature. The following headings guide this chapter:

1. Triangulation of results from the instruments
2. Discussion by research question
3. Comparison with the literature
4. Limitations of the study
5. Implications and recommendations for further practice
6. Perspectives for future research

5.1 Triangulation of results from the instruments

Triangulation was established when multiple methods of data collection and multiple sources of data are used. In this study, observations, interviewing and surveying were carried out to collect data, and data were collected from different types of people (teachers, coordinators and director of ERC) to gain various perspectives and insights. In addition, the observations were done in two grade-3 sections and two grade-4 sections and the teachers of these respective sections were interviewed. At the individual level, the teachers’ approaches were consistent between the observations and interviews.

Overall, the results generated from the interviews, observations and surveys show that STEM education is implemented implicitly among teachers at various levels. The teachers' and administrators' understanding of the meaning of STEM education varied as some are aware of its meaning, while others are not familiar with the term. However, the teaching strategies reflect certain aspects of STEM education, such as integrating disciplines, making connections to real-world problems/ examples, using student-centered approaches, involving students in discussions, applying scientific inquiry and using technology to a certain extent. On the other hand, project-based learning, engineering design, technological literacy and problem-based learning were rarely implemented. Particularly, teachers have limited understanding of engineering design, and are not aware of how to incorporate it within their units or apply it without the assistance of the technology integration coordinator.

5.2 Discussion by research question

This section attempts to answer the research questions through cross-verifying and synthesizing the results obtained from each instrument.

5.2.1 Research question 1: What are teachers' and administrators' perceptions and beliefs about integrated STEM education and relevant strategies?

Data from the interviews were used to answer the first research question. The director's, coordinators' and teachers' perceptions and beliefs about integrated STEM education varied. The director and the coordinators were familiar with the term STEM, unlike the teachers, most of whom did not know what the term stands for. In addition, the director and coordinators mentioned that STEM education includes integration of subjects and making connections between STEM fields. However, the director of ERC added “arts” as part of the definition, indicating that he is familiar with the term “STEAM.”

Unlike the director, the definitions provided by the coordinators were limited to the acronym STEM and they gave few details about integration. Hence, their answers reflect basic knowledge of STEM education, especially because one coordinator referred to STEM education as a curriculum. Besides, the definitions provided by teachers reflect their limited understanding of STEM education as ambiguity was evident in their diverse responses.

As for the beliefs held by the director, coordinators and teachers about STEM education, the director believes that STEM education prepares the students for future STEM-related jobs, whereas the coordinators and teachers considered STEM as a trend that is gaining popularity worldwide. The director’s belief indicates that he considers STEM education important from a global and futuristic perspective, whereas the teachers and coordinators are not aware of the rationale or importance of STEM education for the future.

Furthermore, the director’s, coordinators’ and teachers’ beliefs about the relevant strategies for STEM education varied as well. The director and coordinators held similar beliefs, by indicating that project-based learning is important for implementing STEM. More specifically, the director emphasized that project-based learning is applied best in the makerspace or the technology lab. However, the teachers’ beliefs were diverse as almost each teacher gave a different answer ranging from student-centered approaches such as inquiry-based learning to lack of knowledge in strategies for STEM education.

The diversity in the answers obtained could be explained by the lack of familiarity or training in STEM education.

5.2.2 Research question 2: What are the strategies that homeroom teachers use within the elementary classes that reflect integrated STEM education?

Data from the observations, interviews and surveys were used to answer the second research question. The strategies that were revealed from the procedures used will be discussed below.

5.2.2.1 Student-centered approaches

Results from these three procedures revealed that student-centered approaches are used by all teachers, which is expected in a school that follows the program of the IB PYP. Most of the teachers indicated in the interviews that they act as facilitators and that learning is led by students. The student-centered approaches that were mentioned in interviews, and were revealed in the observations and surveys included group work, pair work, class discussions, hands-on activities, making connections to real-life and building on background knowledge. During the observed sessions, teachers frequently engaged students in group work, hands-on activities, discussions and open-ended questions/ tasks in all of the units. Similarly, the surveys revealed that these strategies were the most commonly used when compared to the other strategies.

5.2.2.2 Inquiry-based learning

Results from the interviews and surveys revealed that inquiry-based learning is used by all teachers. Data from the interviews showed that the scientific process or the scientific method is part of inquiry learning. The methods of inquiry that teachers reported of using include observing, asking and writing questions, formulating hypothesis, predicting, researching, carrying out investigations, doing experiments, analyzing data, drawing conclusions, reflecting on the conclusions and presenting their findings.

The data from the surveys showed to which extent the inquiry strategies are adopted by teachers. The results showed that requesting students to make observations was most frequently used followed by encouraging students to develop their own questions/ hypothesis, followed by asking students to research and record data.

However, results from the observations revealed poor scores for “students developing their own questions to explore or test”, which is perplexing given the results from interviews and surveys. The reason for this discrepancy is that teachers do encourage students to ask questions and develop their own questions when doing class discussions, yet, sometimes teachers provide students with a list of questions that students need to find answers about when conducting experiments or doing research (e.g. provide ready-made questions to research about natural hazard in HTWW(3)). Hence, the students are not developing their own questions to explore or test.

In addition, scientific inquiry is more implemented in the science lab/ makerspace than in the classrooms as evidenced by the observations. In the makerspace, students are always working in groups and were more involved in making predictions, experimenting, making connections and recording data/ notes than in the classrooms.

5.2.2.3 Problem-based learning

Results revealed that the efficacy of implementing problem-based learning by teachers varies. The surveys showed that most teachers use problem-based learning frequently in their classes. However, in the interviews, the teachers showed different ways of applying PBL in the classroom ranging from applying teacher-taught strategies for math word problems to solving everyday problems in the class. In addition, a teacher indicated that PBL is rarely being used, if not absent in the classroom. Besides, the observations revealed poor application of PBL in the classrooms as evidenced by the scores of IBL5, *students determined which problem solving strategies to use,* across all the units. The significant differences in the application of PBL indicate that teachers have mixed understandings of how to apply problem solving, which affects the way it is implemented.

However, the application of PBL was more evident in the makerspace in one unit, which required students to use problem solving to find solutions for a real-life problem that they are attempting to solve through their inventions. Hence, the type of the activity/ task that students are engaged in determines the extent of using problem solving.

5.2.2.4 Project-based learning and constructing models

Results from the surveys revealed that PjBL and constructing models were among the least frequently used strategies by teachers, with PjBL obtaining a slightly higher score than constructing models. The interviews and the observations confirm the results from the surveys. In the interviews, the teachers provided several examples of different projects that students usually work on throughout the year (e.g. building a city, create a well-being market, etc.), and provided limited and few examples of instances of constructing models. In some projects, students are provided with the materials, while in other projects, students have to plan the needed materials. Sometimes, students are given ownership in the way they want to conduct their presentations.

Results from the observations revealed that only two units (HWOO(3) and HTWW(4)) engaged students in PjBL and engineering design as students were required to create a final product (PjBL) (building a city in HWOO(3); creating an invention in HTWW(4)). More specifically, these two strategies were more evident in the makerspace than in the classroom. Engineering design was implemented more explicitly in HTWW(4) as students were engaged in the engineering design process from the beginning of the unit (step 1: identify a problem; step 2: develop solutions; step 3: choose a solution; step 4: build a prototype; step 5: test the prototype; step 6: communicate your results). The classroom and makerspace sessions were dedicated for the steps in the engineering design process. The students identified several problems through asking questions to identify the user's needs. Then, they had to ideate and generate solutions to meet the user's needs and share the solutions and receive feedback. Afterwards, they had to choose one problem that they want to address and discuss it with the teacher for the feasibility before proceeding to step 3 (choosing a solution). After receiving the teacher's feedback, the students planned the materials needed and the procedure for building the prototype, and drew sketches of their designs. Finally, the students built their prototypes and presented their prototypes to third graders. On the other hand, in HWOO(3), engineering design was mostly an application of the student's understanding by the end of the unit, where they had to build a city that consists of one sustainable solution. Hence, prior to the makerspace sessions, the students drew blueprints of their designs and then used their designs in the makerspace to construct their city model.

The few learning experiences for constructing models can be explained with the limited experience of teachers with engineering design. Results from the interviews showed that teachers have little or no experience with engineering design and few indicated that they are unaware of the meaning of engineering design. In addition, the lab sessions of the HWOO(3) and HTWW(4), which implemented the engineering design process, were facilitated by the technology integration coordinator, who is an expert in STEM education.

5.2.2.5 Technology integration

Results from the observations, interviews and surveys revealed that technology was integrated within the units, however, technology was being used mostly as a tool for teaching and learning and as a resource to find activities and ideas. Teachers use the SMART board for teaching their lessons and display videos frequently about the unit. Moreover, students use technological tools for learning (*Mr. Body, virtual t-shirt for organs, etc.)*, exploring new topics/ concepts (*Nearpod to explore natural hazards)* and showing their understanding (*iMovies, Book Creator, etc.*). In addition, technology was being used a tool for communication and research. All teachers use the e-portfolio, Seesaw, to post students' work, and laptops and iPads for conducting research or creating presentations.

On the other hand, technology was used to make objects or artifacts only in the makerspace sessions of HWOO(3) and HTWW(4). During these sessions, students were using materials, such as Kapla blocks, lego, little bits, magna tiles, etc., from the makerspace to build their cities or invent their own products.

Data from the surveys showed that the least common way of using technology was coding and programming, which aligns with the response of one of the interviewees, who stated that coding and programming are not authentically integrated within the units.

5.2.2.6 Integration of Mathematics

Data from the interviews showed that mathematics gets integrated within the units when it can be authentically integrated. The math strands that are usually integrated within the units are measurement, geometry and data handling, whereas the number strands are usually taught as stand-alone. The results from the observations revealed that mathematics was completely absent in all of the units. There was no explicit teaching of mathematics during the observed sessions, although the unit HWOO(3), which was about the cities, could have been enriched with the integration of geometry, especially because students drew blueprints for the cities and built their own cities.

Although mathematics was not authentically integrated, results from the interviews, observations and surveys revealed that students use mathematical strategies or thinking regardless of the unit. For example, students would collect data, graph when needed, analyze the data, interpret the results, justify their thinking, critique others' reasoning and not give up when solving any kind of problems.

5.2.3 Research question 3: What kind of support do homeroom teachers get to develop their technological pedagogical content knowledge (TPACK) for properly implementing STEM education?

Data from the interviews and surveys were used to answer the third research question. Results from the interviews showed that there are various types of support for enhancing teachers' TPACK, including collaboration, coaching, professional development opportunities and different types of resources. Teachers reported various ways of collaboration, which included sharing sessions, assistance of subject experts and teachers as curriculum writers. The sharing sessions provide an opportunity for teachers to share their ideas, discuss the activities/ tasks that occur in class and plan the learning engagements for the unit. Hence, the teachers benefit from each other's experiences and expertise. The assistance of subject experts or school-wide coordinators is another way of collaboration among teachers and subject experts. The teachers can schedule meetings with these school-wide coordinators, who would give their input regarding the units and provide support for teachers, particularly in content knowledge (e.g. science, social studies, etc.). In addition, the school opened the opportunity for teachers to be curriculum writers as the school developed various curriculum committees. Hence, teachers who are interested in taking an active role in developing the curriculum can sign up for the curriculum committee they are interested in being part of (i.e. science, social studies, language, mathematics, etc.) and work on developing the chosen curriculum throughout the year.

Furthermore, coaching is another way to support teachers' TPACK at the school. The ways that coaching is implemented are through one-on-one planning, co-teaching and conducting classroom observations followed by feedback on the teaching. Teachers can plan their lessons with the coordinators on a one-on-one basis; the coordinators go over the lesson plans, modify them, provide ideas for the teaching practices and tools for the learning engagements, and support with the assessment. In addition, sometimes, the technology coordinator co-teaches with the homeroom teacher and provides demo-lessons as a way to assist the homeroom teacher in his/ her class. Occasionally, the principal and coordinators conduct classroom observations and provide teachers with feedback on their instructional practices.

Moreover, professional development opportunities enhance teachers' TPACK as teachers mentioned several examples of them. One example is the study groups, which are conducted once every month. During these sessions, a teacher who is expert in a certain domain/ field/ topic (e.g. technology) facilitates the session. Another example that was shared by all teachers was the workshops. Workshops, whether one-day or multiple-day, are provided at the school, and these workshops are either given by a guest speaker or teachers or administrators from the school. An example of a one-day workshop that was repeated several times in the interviews is the professional development sessions that are usually conducted during faculty meetings.

As for the multiple-day workshops, the examples that were given and repeated often were the "in-service days" that are conducted three times a year, and the after-school workshops given by administrators or coordinators. Usually, these workshops actively involve teachers through hands-on activities. For example, an after-school multiple day workshop was conducted for enhancing teachers' technological pedagogical knowledge, which aimed at exposing teachers to several ways of approaching research strategies with the students using technological applications. Although the professional development opportunities are tailored to the IB training and PYP needs, many aspects of STEM education, such as inquiry-based learning, are reflected in the IB-PYP. Hence, teachers are being indirectly exposed to training in STEM education. However, the director of the ERC mentioned in the interviews that STEM-related workshops will be more evident the following year.

Results from the surveys showed additional types of professional development opportunities that are provided at the school and the extent of their importance in enhancing teachers' TPACK. Besides the one-day and multiple-day workshops, lectures, summer programs and workshops abroad were indicated. Based on the responses, the workshops, regardless of their types, obtained the highest number of responses, indicating that the school mainly provides these professional development opportunities. However, the multiple-day workshops seemed to influence the teachers' TPACK the most followed by workshops abroad, one-day workshops and lectures, which all were equally important.

Results from the interviews revealed several types of resources that influence teachers' TPACK, which included physical resources, online resources and human resources. The physical resources consisted of computers, laptops, iPads, manipulatives, makerspace, textbooks, coding resources (e.g. sphero robots, makey makey), little bits, SMART board, 3D printers and microscopes. The online resources mentioned were reading through A to Z, science through A to Z, iPad applications, IXL, e-portfolio

(Seesaw), encyclopedia Britannica, RAZ kids, educational channels, links provided by the school and the shared math folder, which has websites, worksheets and text resources. The human resources mentioned were the coordinators and co-teachers.

Results from the surveys indicated the extent of importance for the different types of resources. The most important type of resource was the online web resources followed by the coordinator's support followed by the textbooks. Since the school provides teachers with access to various online resources (e.g. reading A to Z, IXL, encyclopedia Britannica, etc.), these resources are readily available and easily accessible for teachers. Furthermore, the coordinator's support is essential as the coordinator assists the teachers in various aspects of teaching, such as planning, providing reliable resources, co-teaching, etc. Finally, the textbooks provide the teachers with the content knowledge needed for a specific unit, especially because homeroom teachers are responsible to teach math, social studies, science and language.

5.2.4 Research question 4: What are the challenges and barriers that hinder proper implementation of integrated STEM education within elementary classes?

Data from the interviews and surveys were used to answer the fourth research question. Results revealed that there are two types of barriers: External and internal. Each type of barrier will be discussed in detail from the different perspectives of the director of ERC, coordinators and homeroom teachers.

5.2.4.1 External barriers

The coordinators and teachers agreed on three barriers, which were lack of vision, curricular issues and lack of support.

Teachers and coordinators indicated that the school does not follow STEM education and it does not have a clear policy about STEM. However, the director had a different view as he affirmed that the school is working towards incorporating STEM education into the school's vision. He emphasized that STEM education should be a shared vision by the leadership team to support its implementation and avoid becoming an individual effort on the behalf of the teacher.

Apart from the lack of vision, the curricular issues that emerged were having limited opportunities for authentically integrating STEM in the units, and lack of in-depth science integration within the units. First, the curriculum does not have adequate opportunities for authentically integrating STEM-related activities within the units, and the PYP POI should be revised to make room for STEM education. For example, coding cannot be authentically integrated with the current curriculum. Besides, the school is focused on language teaching (Arabic, French and English), which takes off teaching periods from STEM-related activities/ tasks. Furthermore, the science scope and sequence is not rich and the science program is not rigorous. Therefore, the scientific concepts are not covered in-depth. Although some units in the PYP POI are science-based, the experiments conducted do not delve into in-depth understanding of the scientific content. The data from the observations confirm the latter result. Although the observed sessions covered science-based units, the science content was poorly covered across all the units.

Besides the curricular issues, lack of support was shared between coordinators and teachers. Teachers indicated that they need adequate coordinator's support, and the coordinator's support is limited. One coordinator reflected on the support provided to teachers as she stated that the school lacks a science coordinator.

Furthermore, the teachers reported in the interviews additional barriers, including time constraints, number of students in the classroom, limited technological advances and/ or resources, lack of professional development opportunities. Similar results emerged from the surveys. Teachers reported that they are overloaded and they do not have enough time to finish the curriculum. Planning is time consuming and teachers need to be given sufficient collaboration time to plan, implement, reflect and revise. However, the director of the ERC did not consider time to be a barrier in the elementary school, rather it is an issue with the upper grades due to the payment of teachers in the Lebanese law. Particularly, middle and secondary teachers are paid by the hour and any extra hour should be paid as per the Lebanese law. The director reported that the working hours are barely enough for teaching, hence it is difficult to find time for teachers to collaborate as opposed to the elementary school, because teachers are hired as full timers for their full day.

Another issue that the teachers shared was the high number of students in the classroom, which is 27. Teachers indicated that handling 27 students is a lot for one teacher, thus they need more support in the classroom to properly implement STEM.

Furthermore, the teachers indicated that the school has limited technological resources, specifically iPads, and does not keep track of the technological upgrades and lacks professional development opportunities related to STEM education. Teachers are not trained in STEM education and never attended a workshop on STEM.

On the other hand, the director of ERC highlighted some other barriers, which were not mentioned by any of the other interviewees, such as lack of space and financial barrier. According to the director of ERC, space allocation is an issue in the school. Although the elementary school has a science lab/ makerspace, the director indicated that a school needs at least 3 makerspaces for students to carry out STEM-related activities or projects. One room should be specific for coding/ robotics, one for projects that deal with metal and wood cutting and one for the “clean projects” that do not make a mess.

Another barrier that was considered a major issue in the school is the financial burden. Although the teachers and coordinators did not find money as a barrier, the director asserted that financial barrier is always present, and the school is trying its best to overcome this barrier. However, the machinery needed for STEM-related projects or activities, such as 3D printers and robots, are expensive.

5.2.4.2 Internal barriers

Some of the interviewees, including the director of ERC, coordinators and homeroom teachers agreed that insufficient technological and content knowledge acts as a barrier for implementing STEM education. They indicated that teachers might not have a strong background in a certain discipline. The director and one coordinator indicated that all elementary education students get specialized in a certain discipline, however, teachers in this school are homeroom teachers, who will be teaching science, social studies, language and mathematics. Besides content knowledge, some teachers reported lack of familiarity with several technological applications, and they need support in knowing when and how to use them, especially because they cannot keep track of the technological advances on their own.

On the other hand, the coordinators and teachers shared common internal barriers, which were personal challenges and teacher understanding of STEM education. Examples of personal challenges that were reported include resistance to new strategies or change, lack of motivation, unwilling to teach more difficult or challenging content and insufficient time to learn something new that requires additional effort. Besides the personal challenges, the understanding of the meaning of STEM education is lacking in the school. Many teachers were not aware of STEM education and the rationale behind it.

5.2.4.3 Suggestions for addressing the barriers

Various suggestions for addressing the barriers that hinder proper implementation of STEM education were mentioned in the interviews and surveys. First, there should be a clear vision for STEM education and proper and common understanding of it: What is STEM? Why is it important? and why is it needed? Besides, the school should make the teacher feel comfortable with implementing STEM education and seeing that STEM complements the learning. Hence, teachers should be encouraged to try something new, discuss its successes and suggest ways for improvement. In addition, the school must supplement teachers with proper support in terms of physical resources, materials, time, more collaborative planning, learning engagements for STEM education, ongoing professional development and workshops related to STEM education. Finally, the curriculum has to have more opportunities for

STEM education, and there should be more support for science standards to make the program more rigorous

5.3 Comparison with the literature

The purpose of the study was to investigate the implementation of integrated STEM education by homeroom teachers in elementary classes in a private school in Beirut. Data from this study was generated from three distinct instruments (observation, interview and questionnaire). Some findings coincided with results from previous research studies discussed in the literature review, while other results differed from other research findings. The findings of this study will be compared against the conceptual framework for integrated STEM education that was proposed by Kelley and Knowles, and then the findings will be compared against the results of other research studies.

5.3.1 Connection to the conceptual framework for integrated STEM education

According to Kelley and Knowles (2016), integrated STEM education requires teaching and connecting STEM content to at least two STEM disciplines within an authentic context, while current practices are tackling STEM disciplines as isolated subjects. Thus, they proposed a conceptual framework that consists of six components: Situated STEM learning, engineering design, mathematical thinking, scientific inquiry, technological literacy and community of practice.

The learning experiences from this study showed that situated STEM learning can be found at various levels. Participant teachers try to make the students' learning experiences authentic as evidenced by the two units in grade-3 and grade-4, where students had to build their own city that consists of one sustainable solution and create their own inventions. These two units allowed students to be immersed in the situations and build connections to their environment, which are at the core of authentic learning (Kelley & Knowles, 2016). However, in the other two units, the teachers failed to engage students in authentic learning experiences that are representative of real-life STEM practices. The students were involved mostly in hands-on activities and research without being immersed in situations which connect them to their environment. For example, the lab sessions in HTWW(3) were structured, not challenging and not authentic. In one of the sessions, the student had to build an earthquake resistant structure using Kapla blocks. This experiment could have been more authentic if students were given the option of selecting materials and the task was more open-ended.

In this study, engineering design was implemented to a certain extent in some units (HWOO(3) and HTWW(4)), while being more evident in the latter. When engineering design was implemented since the beginning of the HTWW(4) unit, the students were able to pass through the engineering design phases (*Problem identification, ideation, research, potential solutions, optimization, solution evaluation, alterations and learned outcomes*) (Wells, 2016), and apply their engineering practices. However, explicit connections to science and mathematics were lacking when engineering design was implemented. Students were applying their mathematical thinking and scientific inquiry implicitly without making clear connections.

As discussed by Kelley and Knowles (2016), scientific inquiry allows students to think and act like scientists, and provides the opportunity to apply knowledge by conducting scientific investigations. This was portrayed in the results of the study as students engaged in scientific inquiry through various ways, whether in the classroom or in the makerspace. They observed certain phenomena, defined problems, asked questions, researched, carried out investigations and communicated their findings. Moreover, Wells (2016) emphasized that questioning is an essential driver in scientific inquiry, and the results of this study showed that teachers always ask students open-ended questions that require higher level of thinking.

Furthermore, Kelley and Knowles (2016) differentiated between using technology (engineering perspective) and developing technological literacy (humanities perspective). Technology serves human needs and influences the economy, environment, society and culture. Thus, technology is more than merely tools or artifacts, and STEM educators need to be aware of the humanities aspect of technology. As observed in this study, technology was mainly used as objects and tools (engineering perspective). The humanities perspective of technology was lacking, and only one teacher highlighted the importance of identifying the suitable tool for a specific situation or task the function of that technological tool.

Moreover, Kelley and Knowles (2016) argued that students need to engage in mathematical thinking through being given opportunities where they can make sense out of what they are doing. Students need to apply the learned mathematical concepts and see their connections to real world problems. However, in this study, the application of mathematical thinking was not observed although teachers and coordinators indicated that mathematics, particularly data handling, is integrated within the unit when it can be authentically integrated. One mathematical practice was observed to a certain extent in the lab sessions of one unit (HWOO(3)). This mathematical practice is to “persevere in solving problems.”

Moreover, Kelley and Knowles (2016) connected all components of the framework with the community of practice (COP), which was proposed by Wenger et al. (2002). According to Wenger et al. (2002), communities of practice enable people to share a common problem, interact regularly, share their wide range of expertise, contribute to the community and design solutions to these problems. A community of practice constitutes three elements: “domain of knowledge…community of people…and shared practice” (Wenger et al., 2002, p. 27). The idea of community of practice was reflected in this study, although the participants did not mention the term *community of practice*. However, their interactions through regular meetings and professional development communities, and supporting each other through sharing their expertise, collaborating and co-teaching make them part of a COP.

5.3.2 Comparison with other research studies

5.3.2.1 Perceptions and beliefs about integrated STEM education

In this study, the meaning of integrated STEM education is not well understood. Fewer than half of the interviewed participants were able to describe STEM education and define it beyond providing the meaning of its acronym. These results were consistent with previous research (Brown et al., 2011; Lamberg &Trzynadlowski, 2015). Brown et al. (2011) concluded that a small proportion of their participants provided a clear definition of STEM education and understood the concept of STEM. Similarly, Lamberg and Trzynadlowski (2015) revealed that teachers, including STEM academy teachers, do not have a shared understanding of the meaning of STEM education.

The beliefs held by interviewees regarding STEM education revealed that the school does not share a clear and common vision of STEM education. The director of ERC believes that STEM is essential for future preparation, the coordinators believe that STEM is a trend (although one of the coordinators noted that it's a trend with a meaningful purpose) and teachers showed mixed beliefs. In addition, the beliefs held concerning the relevant strategies that are needed to implement STEM varied among all interviewees. Hence, the needed strategies to implement STEM at the school are not shared and clear for teachers. The strategies mentioned by interviewees included project-based learning, inquiry-based learning, student-driven learning, using technology, questioning, observing, modelling and applying. These results conform to the results from the study conducted by Brown et al. (2011). In their study, a clear vision regarding STEM education was lacking among all the participants as they held diverse beliefs. Some believed that STEM education is applied through problem-solving skills, others believed that it is applied through hands-on activities and integration.

5.3.2.2 Strategies for implementing STEM education

Student-centered approaches

In this study, all participating teachers agreed on using student-centered approaches, such as group work, discussions and hands-on activities. These approaches were evident during the observed sessions as they were always present. In many instances, students were acting as scientists or engineers as they explored, researched, experimented and created. The students were behaviorally engaged in all units. However, when the tasks required problem solving and were challenging, the students appeared more cognitively engaged. These results coincided with findings from previous research (Ejiwale, 2013; Gao & Schwartz, 2015; Lamberg & Trzynadlowski, 2015; Parker et al., 2015; Stohlmann et al., 2012). These studies emphasized the importance of implementing student-centered approaches for applying STEM education and for achieving engaging classrooms.

Engineering design challenges

English (2017) indicated that engineering design is neglected in the elementary level and rarely being applied. The results from this study accord with English's findings as engineering design was rarely applied in most of the observed sessions. As mentioned previously, only two units engaged students in engineering design. When applied, the students displayed more cognitive engagement in the activities compared to other observed sessions. These results are consistent with Lesseig et al. (2016). The researchers emphasized that design challenges increase student motivation and classroom engagement as students are involved in solving a problem related to real-life.

On the other hand, Capobianco and Rupp (2014) found that while implementing engineering design-based instruction, the teachers concentrated on the introductory phases of the design process, such as identifying the problem and planning, and dedicated a limited amount of time for other important engineering practices such as design testing, communicating results and re-designing. The results from this study showed otherwise. In the unit where students were creating their own inventions, they were explicitly following the engineering design process since the beginning of the unit. Hence, students were learning about the unit through engineering design, which allowed them to test their prototypes, evaluate their results, make alterations accordingly and retest it.

However, findings from this study revealed that math and science content were absent when students were engaged in engineering design and the teachers did not discuss content in-depth. Moreover, students were not explicitly making the connections between math and science content within their work. Hence, engineering design was either integrated as *add on* or *implicitly* as suggested by Guzey et al. (2017). In HTWW(4), engineering design was *implicitly* integrated as engineering was integrated within the science unit, yet no explicit connections were made to scientific concepts. On the other hand, in certain instances, particularly in the lab sessions of HTWW(3), engineering design was seen as an *add on* to science instruction. Students were using engineering through tinkering rather than a problem solving approach, and the students ended up doing an arts activity. One possible explanation for this finding is that teachers do not have sufficient knowledge and experience in engineering design, thus they were not able to explicitly make connections between engineering design and science concepts. The findings agreed with results from previous research (Dare et al., 2018; Guzey et al., 2017; Roehrig et al., 2012). These researchers found that connections to mathematics and science were not made explicit as students were working on the engineering design challenges. There was limited integration of the scientific and mathematical concepts, and the teachers and students focused on the engineering aspect.

Project-based learning

PjBL was implemented in only one unit where students had to build their own city that consists of one sustainable solution by the end of the unit. The students were using science inquiry and applying their engineering practices while they worked on their projects. In order to build a sustainable solution in their cities, students had to use their environmental science knowledge acquired in class to be able to build models of these solutions (e.g. solar panel, electric garbage bin, etc.). The findings are in line with previous research. Roehrig et al. (2012) stated that some teachers choose to integrate two disciplines (science and engineering) through PjBL. The teachers assigned an engineering design project as an end product to a science unit. For instance, the students were asked to design a submarine that would sink and float as a project for the unit on chemical reactions. The students were expected to use their scientific knowledge about chemical reactions to achieve the changes in the density.

Technology integration

Lamberg and Trzynadlowski (2015) indicated that any form of technology, such as laptops, iPads and smart boards, can be used to implement STEM education. Results from this study did not align with Lamberg and Trzynadlowski's finding. In certain observed lab sessions, the students used the materials in the makerspace, but the activities and engagements were structured and not authentic. The students were limited with the choice of materials and they were not provided with a meaningful learning experience).

Furthermore, Gao and Schwartz (2015) stated that using technology in a STEM classroom helps students visualize phenomena that are difficult to picture. They reported that technology integration facilitates classroom engagement, aids in explaining difficult theories and concepts and enhances students' digital communication skills. In their study, the teachers incorporated simulations, videos and visual demonstrations in their STEM lessons, and the students participated in classroom and online discussions, shared their opinions and asked questions (Gao & Schwartz, 2015). Results from this study confirmed with Gao and Schwartz's research as the study showed that students engaged in discussions when the teacher used technology to explore a certain concept related to the unit, such as videos and interactive iPad applications. For example, the teacher introduced the unit on natural hazards (HTWW(4)) through Nearpod, where students were shown 360 degrees images of real natural hazards and students had to write what they see, what they think and what they wonder about these pictures.

Despite the positive outcomes of technology integration, the way technology is integrated in the classroom influences students' learning experiences. Brown et al. (2011) argued that the mere use of technology (e.g. laptops) does not result in technological literacy. The technological aspect in STEM education goes beyond the use of technology, and includes learning about technology and its concepts (Brown et al., 2011). Results aligned with these findings because technological literacy was absent among students; students were only using technology without learning about it.

Moreover, Parker et al. (2015) emphasized that teachers who use technology that is aligned with STEM practices tended to adhere to student-centered approaches more than teachers who use instructional technologies. Moreover, the teachers who used technology to present the lesson, such as online demonstrations or videos for instruction, tended to have passive learners, who showed minimal interest in the lesson. However, findings from this study revealed otherwise; the way technology was used did not affect the application of student-centered approaches as teachers always engaged students in discussions, hands-on, group work, etc. The reason for this could be because teachers are following the IB PYP program, which advocates for student-centered approaches. In addition, during the observed sessions where videos were used to present the lesson, the teacher encouraged students to ask questions and be engaged in discussions. Hence, students were not passive learners, and did not show minimal interest in the lesson).

5.3.2.3 Types of support for enhancing teachers' TPACK

Collaboration

Stohlmann et al. (2012) reported that teachers implementing integrated STEM education promoted their knowledge in different STEM subjects through collaboration. Planning the units and lessons together enhanced their confidence in the subject matter since each teacher is knowledgeable in one specific discipline (science, technology or mathematics). Results from this study coincided with the findings from Stohlmann et al. (2012) as teachers indicated planning together and sharing their expertise and teaching experiences together during sharing sessions. The sharing sessions provide an opportunity for teachers to share their ideas, discuss the activities/ tasks that occur in class and plan the learning engagements for the unit. Hence, the teachers benefit from each other's experiences and expertise.

Furthermore, this research's findings revealed that teachers can meet with subject experts, who would give their input regarding the units and provide support for teachers, particularly in content knowledge as some teachers might have gaps in certain subject areas (e.g. science, social studies, etc.). This finding resembles the findings from the study conducted by Roehrig et al. (2011). The researchers argued that collaboration helped many teachers, who had gaps in different STEM disciplines and suggested that they could benefit from a networking system. For instance, some teachers faced difficulties in technology integration due to their limited technological literacy, thus they avoided integrating it in their classrooms.

Professional development

Another way to provide support for teachers' TPACK is through involving teachers in professional development opportunities that train them in the strategies for integrated STEM education. Lamberg and Trzynadlowski (2015) found that teachers benefited from attending professional development workshops that provided training in strategies such as problem-, engineering design- and inquiry-based learning. Teachers enhanced their teaching strategies and adopted them in their classrooms. Partcipating teachers, in this study, positively agreed that professional development opportunities are essential for enhancing their TPACK. For example, since inquiry learning is at the core of the PYP program, the teachers were given a session on the inquiry learning through discussing the inquiry cycle, which clarified the implementation of inquiry among teachers.

Coaching

The study revealed that coaching is one of the ways to support teachers at the school. The participant teachers affirmed that the coordinators, particularly the technology integration coordinator who is a STEM expert, may help them with planning and implementing their lessons. The coordinators go over the lesson plans, modify them, provide ideas for the teaching practices and tools for the learning engagements, and support with the assessment. When requested from the teacher, the technology coordinator co-teaches with the homeroom teacher and provides demo-lessons as a way to assist the homeroom teacher in his/ her class.) These findings were also reflected in other studies (Lamberg & Trzynadlowski, 2015; Parker et al., 2015). The researchers emphasized the central role of STEM coaches in assisting teachers in implementing integrated STEM education. The STEM coaches assisted teachers in lesson planning and acquiring materials. Most of the teachers reported that the coaches were a source of encouragement, and they played a major role in improving the teachers' pedagogical and content knowledge and technology integration.

Physical resources

The school should support the teachers with physical resources in order to properly implement STEM education. In their study (2015), Lamberg and Trzynadlowski asserted that the physical resources influenced the way STEM was implementedMany teachers stated that their school provides them with different resources including laptops, iPads, wireless notebooks, Smart Boards, science kits and STEM labs.(Results from the study affirmed the importance of physical resources including iPads, laptops, manipulatives, SMART boards, makerspace, textbooks and coding resources for STEM education. Additional types of resources were identified which were not mentioned by the previous research, such as online resources and human resources. The online resources mentioned were reading through A to Z, science through A to Z, iPad applications, IXL, e-portfolio (Seesaw), encyclopedia Britannica, RAZ kids, educational channels, links provided by the school and the shared math folder, which has websites, worksheets and text resources. The human resources mentioned were the coordinators and co-teachers.

5.3.2.4 Internal barriers to STEM education

Research concerning STEM education suggests that there are several internal barriers. One barrier could be limited content knowledge to teach STEM disciplines. Although the results from this study revealed that limited content knowledge acts as a barrier to implement STEM, this barrier was noted from the perspective of the coordinators and the director of ERC, rather than teachers. Previous research noted that teachers reported limited content knowledge in certain STEM disciplines and found difficulty in integrating concepts from different disciplines (Asghar et al., 2012; Guzey et al., 2016). However, in this study, the coordinators and the director of ERC reported that teachers might not have a strong background in a certain discipline. For example, the director and coordinators stated that all elementary education students get specialized in a certain discipline. However, teachers in this school are homeroom teachers, who will be teaching science, social studies, language and mathematics. Thus, their content knowledge may be limited in a certain subject area.

Furthermore, previous research indicated that limited familiarity with the pedagogical approaches and strategies for STEM education constitutes a barrier for teachers as they need to shift from teacher-centered teaching to a student-centered one (Schmidt & Fulton, 2016). Results from this study revealed otherwise. Teachers did not indicate that pedagogical approaches constitute as a barrier, and it was evidenced from the observations that they adopted student-centered approaches in their classrooms. However, limited familiarity with the technological knowledge was reported to act as a barrier for implementing STEM education. Some teachers reported lack of familiarity with several technological applications, and they need support in knowing when and how to use them, especially because they cannot keep track of the technological advances on their own. Hence, some teachers have limited technological literacy, which is a crucial component for STEM education.

On the other hand, teachers in this study reported resistance to new strategies or change, lack of motivation, unwilling to teach more difficult or challenging content and insufficient time to learn something new as barriers for implementing STEM. These findings were also reflected in Schmidt and Fulton's (2016) findings about feeling resistant or uncomfortable in adopting new strategies.

5.3.2.5 External barriers to STEM education

Even if the teachers are willing to adopt new strategies, the external barriers, such as inadequate resources, hinder the implementation of new approaches to teaching. Teachers in this study agreed that there are limited technological resources, specifically iPads, which is also reported in Roehrig et al.'s (2011) study. The teachers believed that technology is essential for STEM teaching. However, they weren't able to use technology effectively due to limited technological resources.

Moreover, teachers in this study noted that the student to teacher ratio is high as the average classroom accommodates 27 students per teacher. This is consistent with one of the barriers stated in Ejiwale's (2013) study. Ejiwale (2013) indicated that if school lack the appropriate facility structure (e.g. overcrowded classrooms), it will be difficult to implement STEM education. Moreover, another barrier that was brought up in this study was limited space. The director of ERC highlighted the need for adequate space to carry out STEM-related activities. Having one makerspace is not sufficient, thus the school should work on addressing the issue of space distribution. This finding is reflected in the study conducted by Stohlmann et al. (2012). The researchers emphasized that classroom size and space were essential for students to have adequate space in order to work on their projects, roam easily around the classroom and store the materials and projects in an organized manner.

Furthermore, time constraints were mentioned as one of the barriers for implementing STEM education. The participating teachers emphasized that the time dedicated for planning is insufficient. In order to properly implement STEM education, teachers need to be given adequate collaboration time to plan, implement and reflect. This finding is also reflected in other studies (Parker et al., 2015; Shernoff et al., 2017). Parker et al. (2015) argued that teachers are pressured to learn new strategies, implement them and assess their effectiveness without providing them with adequate time to complete these actions. In their study, all of the teachers reported that inadequate time serves as a major barrier to learn and adopt new teaching practices related to integrated STEM education.

In addition, in this study, curricular issues emerged as part of the barriers. One coordinator highlighted having limited opportunities for authentically integrating STEM in the units, and lack of in-depth science integration within the units. For example, coding cannot be authentically integrated with the current curriculum. This finding was consistent with other studies (El-Deghaidy et al., 2017; Lesseig et al., 2016; Moore & Smith, 2014). Lesseig et al. (2016) found that teachers had difficulty creating engineering design challenges that are interdisciplinary due to the curricular challenges. However, these challenges did not align with the school's curricular goals as they involved understanding of different scientific concepts which were not required to be addressed at the same grade level (Lesseig et al., 2016). Moreover, Moore and Smith

(2014) argued that curricula need to be changed to include STEM contexts for teaching science and mathematics content in meaningful ways.

Moreover, previous research noted that lack of administrative and school support hinders adopting the STEM approach and implementing integrated STEM education (Asghar et al., 2012; Moore & Smith, 2014). According to Asghar et al. (2012), administrative and school support includes (a) developing a common vision and writing clear goals, (b) offering professional development opportunities, (c) assigning regular faculty and staff meetings to discuss issues and solutions related to STEM education, (d) allocating sufficient time for teachers to collaborate and work in teams, (e) providing teachers with feedback regarding their implementation of STEM education, (f) acknowledging teachers' efforts through providing rewards and incentives. Moreover, Moore and Smith (2014) argued that the school needs to support the change for STEM education and administrators need to engage teachers in professional development experiences that will prepare them to implement STEM within their classrooms. Few of these factors (a, b and d) were identified to be lacking in the participating school. Teachers and coordinators agreed that the school doesn't have a clear policy or vision regarding STEM education, doesn't offer professional development opportunities related to STEM education and have limited time for planning and finishing the curriculum. However, the director of ERC affirmed that STEM education will be part of the school's vision as of next year, and professional development workshops related to STEM education will be administered as well.

In addition, the teachers reported limited coordinator's support, whereas one coordinator indicated that lacking a science coordinator contributes to lack of support for teachers. This findings coincided with previous research. Lamberg and Trzynadlowski (2015) revealed that teachers seek assistance from the coordinators for lesson planning and demonstrations, indicating the crucial role of the coordinators in supporting teachers' TPACK.

Finally, the financial burden was only mentioned by the director of ERC. He argued that STEM education is costly in terms of purchasing machinery and resources specific for STEM, such as 3D printers. However, teachers and coordinators in the elementary school did not consider money as a barrier. One possible explanation for this finding is that the expensive resources are heavily needed for the upper grades (middle and secondary levels), hence elementary teachers are not aware of this financial barrier. This explanation is consistent with the study conducted by Shernoff et al. (2017). The researchers reported that lack of resources, in general, was a barrier, and they argued that many resources and machinery for STEM activities were more likely to be needed at the upper grade levels.

To conclude all the above, STEM education is implicitly applied in the participating school, and mixed understandings of STEM is present. STEM education is applied mainly through using student-centered approaches (e.g. class discussions and group work), integrating disciplines, making connections to real-world problems/ examples, involving students in discussions, applying scientific inquiry and using technology to a certain extent. Project-based learning, engineering design and technological literacy are rarely implemented due to perceived teachers' limited understanding. In the elementary school, teachers are supported through collaboration, coaching, certain professional development opportunities (e.g. in-service days) and different types of resources (e.g. textbooks and online resources). Finally, various types of barriers were identified by the participants. The barriers that were commonly reported was insufficient technological/ content knowledge. However, the director, in the interview, stated two barriers, limited space and financial barrier, which were not mentioned by coordinators and teachers. Coordinators and teachers shared common barriers, including lack of vision for STEM, curricular issues, lack of support, personal challenges such as resistance, and teacher understanding of STEM. Time constraints were reported by teachers.

5.4 Limitations of the study

There were some limitations of the study. First, the sample size of one school and the number of teachers and coordinators interviewed and surveyed constitute a small sample size. Hence, the results cannot be generalized to schools in Lebanon or even in Beirut. However, the researcher studied a certain phenomenon in-depth and provided a rich, holistic and descriptive analysis of the case. Besides, the researcher was able to interview the 10 participants and obtained adequate responses from the surveys (22 teachers out of 24). Thus, the results obtained are representative of the participating elementary school. In addition, the elementary school is following the IB PYP program, thus, the results cannot be generalized for the middle or secondary school, which follow different types of programs.

Furthermore, the number of observed sessions were limited as the researcher was not able to observe additional sessions within the same unit due to time conflicts with the work schedule. However, the researcher observed an additional unit in grade-3 and grade-4 to compensate for the small number of the observed sessions. In addition, the questionnaires did not include questions related to the perceptions and beliefs of homeroom teachers as they were only tackled in the interviews.

5.5. Implications and recommendations for further practice

The results of this research paper can be used for various purposes. A unified understanding of the meaning, rationale and implementation of STEM education will be helpful for developing a common understanding among all teachers and coordinators. Besides, teachers need opportunities to learn new strategies, skills and knowledge to implement STEM approaches. Thus, professional development and continuous training in STEM education are needed to ensure proper understanding and implementation of STEM education. In addition, making the connection between STEM education and the PYP, and making room for authentic STEM-related activities/ tasks/ engagements within the curriculum will make it easier for teachers to implement STEM education.

Moreover, merely integrating STEM disciplines is not enough. Teachers need to have access to high quality resources that would provide students with meaningful learning experiences while ensuring that rigorous STEM content is being taught. In addition, teachers are advised to practice scientific inquiry, mathematical thinking, engineering design and technological literacy with their students in order to teach science and math content.

In general, the results of this research paper will be useful for schools that intend to go into STEM and helpful for principals and administrators to devise plans in order to support teachers and remedy the barriers that are faced in schools' and teachers' attempts for implementing STEM education.

In addition, the results of the study provided a descriptive interpretation of the way STEM is adopted in a school that follows the IB PYP, especially because there is limited literature on the way a PYP school would adopt STEM education in their teaching approaches. For example, Stohlmann, et al., (2012) studied the implementation of STEM education in a school that follows an integrated curriculum Project Lead The Way; Lamberg and Trzynadlowski, 2015 conducted their study in STEM-focused schools which follow a STEM program. Having this study conducted in a school that follows the IB PYP will offer a different perspective on the adoption of STEM education. Having the PYP an international program which aims to develop internationally minded students, many aspects in the PYP, such as inquiry, questioning, reflecting, and connecting various disciplines, are consistent with integrated STEM education. Hence, STEM education could be explicitly reflected in PYP curricula.

5.6 Perspectives for future research

This research study can be conducted in different schools in Lebanon to become a multiple case study. It can be carried out with a larger sample which represents the population to generalize the results to the Lebanese population. Observations can be conducted for more than two grade levels and can cover more sessions of the unit. Alongside, video-taping the observed sessions and taking pictures of students' work in the classroom and makerspace would be more helpful in analyzing the data. Furthermore, the questionnaires should include questions related to the teachers' perceptions and beliefs about integrated STEM education to obtain more in-depth understanding.

Moreover, the findings of the study revealed certain ideas that would benefit from further research. As teachers and coordinators noted the lack of clear policy or vision concerning STEM education, the director of ERC affirmed that the school is working towards incorporating STEM education into the school’s vision. Hence, teachers and coordinators will acquire a shared understanding of STEM education, and the school will be taking a more active role in administering professional development opportunities related to STEM education. Therefore, it would be beneficial to conduct the same study after STEM education being included in the school’s vision, and study how the perception and implementation of STEM education changed. In addition, a research study can be conducted to investigate whether the professional development opportunities related to STEM education influenced or modified teachers’ practices in the classroom.

In addition, an action research can be conducted about explicitly and authentically integrating STEM education within the PYP program. Modifications to the PYP Program of Inquiry can be made to include more STEM rigorous content, activities and learning engagements, and experiment the modified curriculum at the school.

Furthermore, this study focused on the teaching strategies and methods in the PYP sessions, however, further research can be conducted in the mathematics sessions. Besides, other grade levels can be studied, such as the middle school and secondary school.

References

Ackermann, E. (2001). Piaget’s constructivism, Papert’s constructionism: What’s the difference. *Future of learning group publication, 5*(3), 438.

Apple, M. W. (2017). *Can STEM be stemmed? an essay review of andrew hacker, the math myth and other STEM delusions (new york, NY: The new press, 2016. 239 pp. $25.95. ISBN 978-1-62097-068-3).* Los Angeles, CA: SAGE Publications. doi:10.1177/0895904816681528

Asghar, A. a., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM Education in Secondary Science Contexts. *Interdisciplinary Journal of Problem-Based Learning, 6*(2), 85-125. doi:10.7771/1541-5015.1349

Belief. (2018). In *English Oxford Dictionaries online*. Retrieved from https://en.oxforddictionaries.com/definition/belief

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current perceptions. *Technology and Engineering Teacher, 70*(6), 5.

Brown, J. (2012). The current status of STEM education research. *Journal of STEM Education: Innovations and Research, 13*(5), 7.

Bybee, R. W., & National Science Teachers Association. (2013). *The case for STEM education: Challenges and opportunities*. Arlington, Va: National Science Teachers Association.

Capobianco, B. M., & Rupp, M. (2014). STEM teachers' planned and enacted attempts at implementing engineering design-Based instruction. *School Science and Mathematics,114*(6), 258-270. doi:10.1111/ssm.12078

Common Core State Standards Initiative (CCSSI). (2010). Common Core State Standards for Mathematics. Retrieved from http://www.corestandards.org/assets/CCSSI_Math%20Standards.pdf

Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education and Science, 39*(171).

Czajka, C. D., & McConnell, D. (2016). Situated instructional coaching: a case study of faculty professional development. *International Journal of STEM Education*, 3(1), 1-14.

Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education*, *5*(1), 1-19. doi:10.1186/s40594-018-0101-z

Edmunds, J. A., Arshavsky, N., Lewis, K., Hutchins, B.C. & Coyle, V. (2017). STEM Early College Expansion Partnership (SECEP): External Evaluation Report: Site Visits. Greensboro, NC: The SERVE Center, University of North Carolina at Greensboro.

Ejiwale, J. A. (2013). Barriers to successful implementation of STEM education. *Journal of Education and Learning*, *7*(2), 63-74.

El-Deghaidy, H., Mansour, N., Alzaghibi, M., & Alhammad, K. (2017). Context of STEM Integration in Schools: Views from In-service Science Teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(6), 2459-2484.

English, L. l. (2017). Advancing Elementary and Middle School STEM Education. *International Journal Of Science & Mathematics Education*, *15*5-24. doi:10.1007/s10763-017-9802-x

Fraenkel, J. R., Wallen, N. E., & Hyun, H. (2012). *How to design and evaluate research in education* (8th ed.). New York: McGraw-Hill.

Gao, X., Schwartz, B. (2015). Classroom implementation of active instructional strategies for undergraduate STEM education. *International Journal of Information and Education Technology, 5*(9), 688-692. doi:10.7763/IJIET.2015.V5.593

Guzey, S. s., Moore, T. J., & Harwell, M. (2016). Building up STEM: An Analysis of Teacher-Developed Engineering design-Based STEM Integration Curricular Materials. *Journal of Pre-College Engineering Education Research, 6*(1), 11-29. doi:10.7771/2157-9288.1129

Guzey, S. S., Ring-Whalen, E. A., Harwell, M., & Peralta, Y. (2017). Life STEM: A case study of life science learning through engineering design. *International Journal of Science and Mathematics Education,* doi:10.1007/s10763-017-9860-0

Honey, M., Pearson, G., & Schweingruber, A. (2014). *STEM integration in K-12 education: status, prospects, and an agenda for research.* Washington: National Academies Press.

Hora, M. T., Oleson, A., & Ferrare, J. J. (2013). Teaching dimensions observation protocol (TDOP) user’s manual. *Madison: Wisconsin Center for Education Research*.

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science and Mathematics, 101*(5), 259-268. doi:10.1111/j.1949-8594.2001.tb18028.x

International Baccalaureate Organization (2012). *Developing a transdisciplinary programme of inquiry*. Cardiff, Wales: Author.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), 1-11. doi:10.1186/s40594-016-0046-z

Lamberg, T., & Trzynadlowski, N. (2015). How STEM academy teachers conceptualize and implement STEM education. *Journal of Research in STEM Education, 1*(1), 45-58.

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers’ implementation of STEM design challenges. *School Science and Mathematics,116*(4), 177-188. doi:10.1111/ssm.12172

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation* (3rd ed). San Francisco, Calif: Jossey-Bass.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054. doi:10.1111/j.1467-9620.2006.00684.x

Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education : Innovations and Research, 15*(1), 5.

Moore, T. J., Matins, C. A., Guzey, S. S., Glancy, A. W., & Siverling, E. A. (2014). STEM integration in the middle grades: A case study of teacher implementation. Paper presented at the 1-8. doi:10.1109/FIE.2014.7044312

Morrison, J., Roth McDuffie, A., & French, B. (2015). Identifying key components of teaching and learning in a STEM school: Identifying key components. *School Science and Mathematics, 115*(5), 244-255. doi:10.1111/ssm.12126

Nadelson, L. S., Seifert, A., Moll, A. J., & Coats, B. (2012). i-STEM summer institute: An integrated approach to teacher professional development in STEM. *Journal of STEM Education: Innovations and Research, 13*(2), 69.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research, 106*(2), 157.

National Council of Teachers of Mathematics (NCTM). (2000). Principles and Standards for School Mathematics. Reston, VA: The Council. http://www. standards.nctm.org.

Parker, C., Abel, Y., & Denisova, E. (2015). Urban elementary STEM initiative. *School Science and Mathematics, 115*(6), 292-301. doi:10.1111/ssm.12133

Parker, C. E., Stylinski, C. D., Bonney, C. R., Schillaci, R., & McAuliffe, C. (2015). Examining the quality of technology implementation in STEM classrooms: Demonstration of an evaluative framework. *Journal of Research on Technology in Education, 47*(2), 105-121. doi:10.1080/15391523.2015.999640

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). Newbury Park, Calif: Sage Publications.

Pellegrino, J. W., & Hilton, M. L. (Eds.). (2013). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Academies Press.

Perception. (2018). In *English Oxford Dictionaries online.* Retrieved from https://en.oxforddictionaries.com/definition/perception

Roehrig, G. H., Moore, T. J., Wang, H., & Park, M. S. (2012). Is adding the E enough? investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31-44. doi:10.1111/j.1949-8594.2011.00112.x

Roehrig, G. H., Park, M. S., Wang, H., Moore, T. J. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER), 1*(2) doi:10.5703/1288284314636

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, 68*(4), 20.

Sawada, D., Piburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., & Bloom, I. (2002). Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School Science and Mathematics, 102*(6), 245-253.

Schmidt, M., & Fulton, L. (2016). Transforming a traditional inquiry-based science unit into a STEM unit for elementary pre-service teachers: A view from the trenches. *Journal of Science Education and Technology, 25*(2), 302-315. doi:10.1007/s10956-015-9594-0

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education, 4*(1), 1-16. doi:10.1186/s40594-017-0068-1

Slavit, D., Nelson, T. H., & Lesseig, K. (2016). The teachers' role in developing, opening, and nurturing an inclusive STEM-focused school. *International Journal of STEM Education, 3*(1), 1-17. doi:10.1186/s40594-016-0040-5

Smith, K. A., Douglas, T. C., & Cox, M. F. (2009). Supportive teaching and learning strategies in STEM education. *New Directions for Teaching and Learning, 2009*(117), 19-32. doi:10.1002/tl.341

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER), 2*(1) doi:10.5703/1288284314653

Strimel, G. G., & Grubbs, M. m. (2016). Positioning Technology and Engineering Education as a Key Force in STEM Education. *Journal of Technology Education, 27*(2), 21-36.

Tseng, K., Chang, C., Lou, S., & Chen, W. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education, 23*(1), 87-102. doi:10.1007/s10798-011-9160-x

Walonick, D.S. (2005). Elements of a research proposal and report. Retrieved from http://www.scribd.com/doc/24495903/Elements-of-a-Research-Proposal-andReport

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). Looking inside the classroom: A Study of k–12 mathematics and science education in the united states. *Chapel Hill, NC: Horizon Research Inc.*

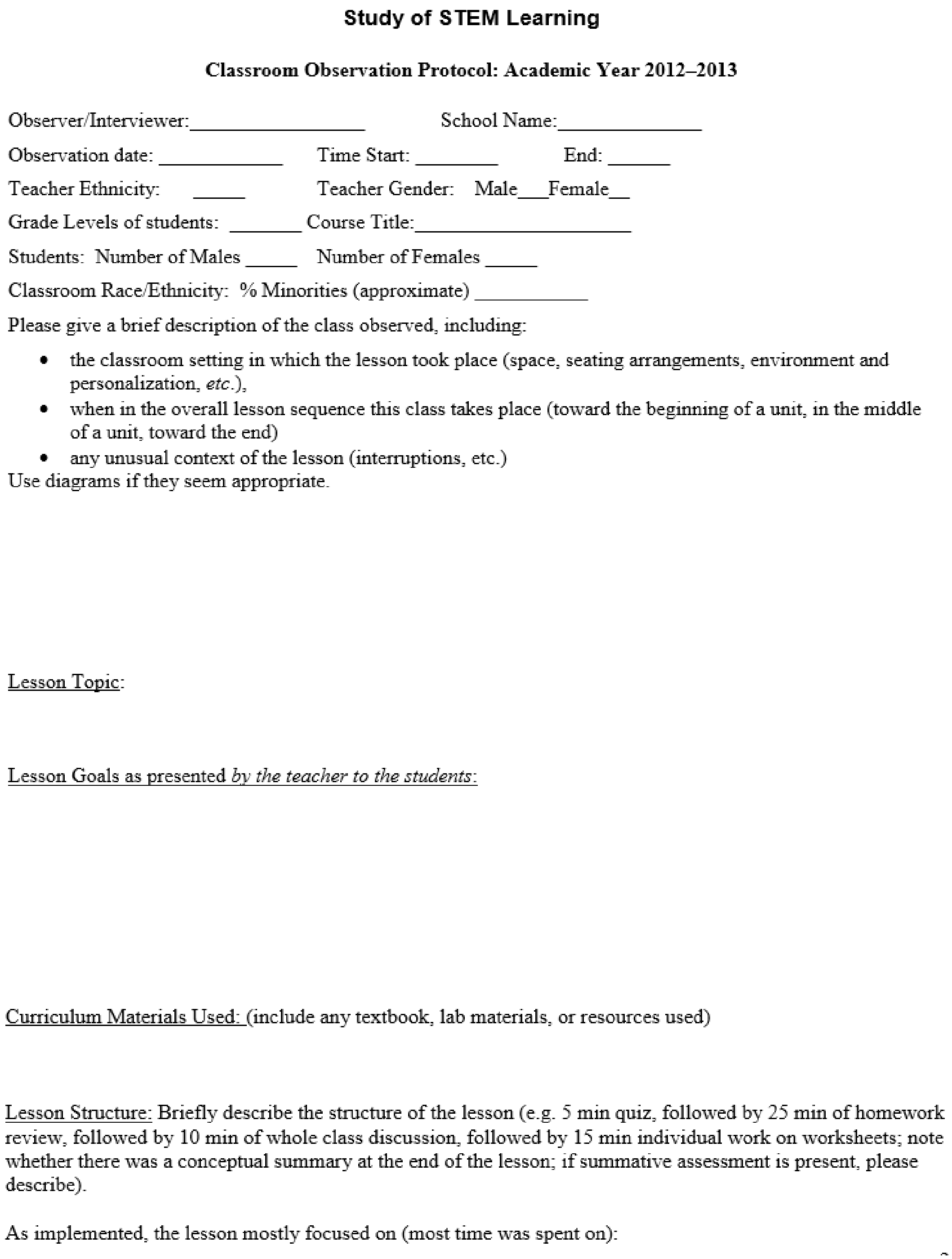
Wells, J. G. (2016). PIRPOSAL model of integrative STEM education: Conceptual and pedagogical framework for classroom implementation. *Technology and Engineering Teacher, 75*(6), 12.

Wenger, E., McDermott, R. A., & Snyder, W. (2002).*Cultivating communities of practice: A guide to managing knowledge*. Boston, Mass: Harvard Business School Press.

Yin, R. K. (2008). *Case study research: Design and methods* (4th ed.). Thousand Oaks, CA: Sage.

Appendix A

STEM Classroom Observation Protocol (Edmunds et al., 2017)



Study of STEM Learning

Classroom Observation Protocol: Academic Year 2012–2013

Observer/Interviewer:_________________ School Name:______________

Observation date: ____________ Time Start: ________ End: ______

Teacher Ethnicity: _____ Teacher Gender: Male___Female__

Grade Levels of students: _______ Course Title:_____________________

Students: Number of Males _____ Number of Females _____

Classroom Race/Ethnicity: % Minorities (approximate) ___________

Please give a brief description of the class observed, including:

- the classroom setting in which the lesson took place (space, seating arrangements, environment and personalization, *etc*.),
- when in the overall lesson sequence this class takes place (toward the beginning of a unit, in the middle of a unit, toward the end)
- any unusual context of the lesson (interruptions, etc.)

Use diagrams if they seem appropriate.

Lesson Topic:

Lesson Goals as presented *by the teacher to the students*:

Curriculum Materials Used: (include any textbook, lab materials, or resources used)

Lesson Structure: Briefly describe the structure of the lesson (e.g. 5 min quiz, followed by 25 min of homework review, followed by 10 min of whole class discussion, followed by 15 min individual work on worksheets; note whether there was a conceptual summary at the end of the lesson; if summative assessment is present, please describe).

As implemented, the lesson mostly focused on (most time was spent on):

☐ Most time spent on practicing algorithms/basic skills and procedures/vocabulary
☐ About equal time spent on practicing algorithms/basic skills and procedures/vocabulary and on concept development and meaningful learning
☐ Most time spent on inquiry/meaningful learning and genuine problem solving

1. Mathematics and Science Content

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.
DK = Observer does not know or is not able to make this determination.

1a. Math and science content information was accurate.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1b. Teacher's presentation or clarification of mathematics or science content knowledge was clear.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1c. Teacher used accurate and appropriate mathematics or science vocabulary.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1d. Teacher/students emphasized meaningful relationships among different facts, skills, and concepts.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1e. Student mistakes or misconceptions were clearly addressed (emphasis on correct content here).	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1f. Teacher and students discussed key mathematical or science ideas and concepts in depth.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1g. Teacher connected information to previous knowledge.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1h. Appropriate connections were made to other areas of mathematics/science or to other disciplines.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
1i. Appropriate connections were made to real-world contexts.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	DK ☐
Summary: Quality of Mathematics and Science Content	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

2. Student Cognitive Engagement in Meaningful Instruction

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

2a. Students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2b. Students were asked to explain or justify their thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2c. Students were given opportunities to summarize, synthesize, and generalize	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2d. Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2e. Students were asked to apply knowledge to a novel situation.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2f. Students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Quality of Student Cognitive Engagement in Meaningful Instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

3. Inquiry learning; Project-based learning; and Problem-based instruction

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.
NA = not applicable to activity being observed (since projects may not occur in every lesson)

3a. Students were engaged in open-ended tasks or questions.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3b. Students engaged in hands-on or real-life problem solving activities or a lab experiment.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3c. Students developed their own questions and/or hypotheses to explore or test.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3d. Students engaged in scientific inquiry process (tested hypotheses and made inferences)	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3e. Students determined which problem-solving strategies to use.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3f. Students had to present or explain results of project.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3g. Students worked on a project requiring creativity.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3h. There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3i. There was an explicit evidence of students using engineering (or reverse engineering) design process.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
Summary: Quality of Inquiry learning; Project-based learning; and Problem-based instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

4. Teacher Instruction/ Formative Assessment

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

4a. Teacher provided clear learning goals to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4b. Teacher provided clear criteria for success/examples of good work to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4c. Teacher used a variety of strategies to monitor student learning and understanding throughout the lesson.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4d. Teacher provided specific feedback to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4e. Students were engaged in self- and/or peer-assessment.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4f. Teacher adjusted or differentiated instruction based on evidence of student learning.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
4g. Students were given opportunities to reflect on their own learning.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐
Summary: Quality of Teacher Instruction/ Formative Assessment	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐

Record specific examples below.

5. Common Instructional Framework

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

5a. Students worked collaboratively in teams or groups.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5b. Students used writing to communicate what they had learned.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5c. Teachers asked open-ended questions that required higher level thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5d. Teachers provided assistance/scaffolding when students struggled.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5e. Students engaged in discussion with each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	
5f. Students participated in guided reading discussions.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
Summary: Overall rating of Quality of Common Instructional Framework implementation	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

6. Student Engagement

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

6a. Students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6b. The time in class was spent productively on meaningful tasks.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6c. Teacher pursued the active engagement of **all** students.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6d. Students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
6e. Students showed perseverance when solving math/science problems.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Student Engagement	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

7. **Use of technology**

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

7a. Technology was used to a high extent (as a proportion of time of the lesson and intensity of use)	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7b. Students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7c. Students used technology to generate or manipulate one or more representations of a given concept or idea.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7d. Students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7e. Students used technology to practice skills or reinforce knowledge.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7f. Technology was used but did not appear to provide any added benefit.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7g. Teacher used technology to achieve instructional goals. (Emphasis on the "teacher" here)	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Use of technology	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

8. **Classroom Culture**

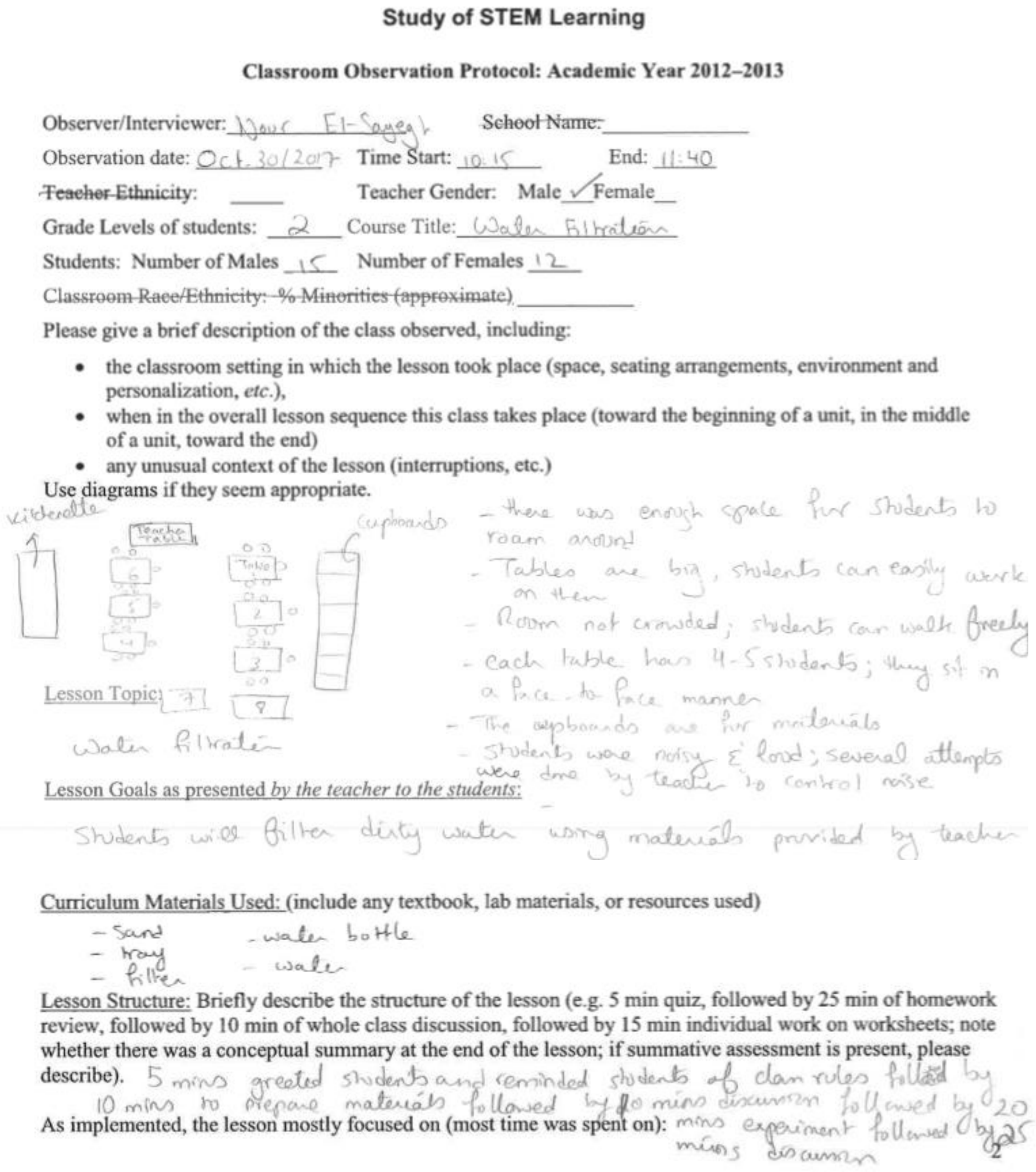
Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

8a. Students exhibited positive classroom behavior.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8b. The classroom exhibits a respectful environment.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8c. There is a climate of respect and encouragement for students' ideas, questions, and contributions; mistakes are viewed as an opportunity to learn	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8d. Students and teacher appear to have positive relationships and to enjoy spending time with each other (laughing, easy relationship).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8e. Students actively seek and provide assistance or guidance.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
8f. Teachers and students provide positive reinforcement and feedback to each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Classroom Culture	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

Appendix B

Pilot Observation in Grade-2 and Grade-4



Study of STEM Learning

Classroom Observation Protocol: Academic Year 2012–2013

Observer/Interviewer: Nour El-Sayegh ~~School Name:~~ ______________

Observation date: Oct. 30/2017 Time Start: 10:15 End: 11:40

~~Teacher Ethnicity~~: _____ Teacher Gender: Male ✓ Female__

Grade Levels of students: 2 Course Title: Water Filtration

Students: Number of Males 15 Number of Females 12

~~Classroom Race/Ethnicity: % Minorities (approximate)~~ ___________

Please give a brief description of the class observed, including:

- the classroom setting in which the lesson took place (space, seating arrangements, environment and personalization, *etc.*),
- when in the overall lesson sequence this class takes place (toward the beginning of a unit, in the middle of a unit, toward the end)
- any unusual context of the lesson (interruptions, etc.)

Use diagrams if they seem appropriate.

- there was enough space for students to roam around
- Tables are big, students can easily work on them
- Room not crowded; students can walk freely
- each table has 4-5 students; they sit in a face-to-face manner
- The cupboards are for materials
- students were noisy & loud; several attempts were done by teacher to control noise

Lesson Topic: Water filtration

Lesson Goals as presented *by the teacher to the students*:

Students will filter dirty water using materials provided by teacher

Curriculum Materials Used: (include any textbook, lab materials, or resources used)

- sand
- tray
- filter
- water bottle
- water

Lesson Structure: Briefly describe the structure of the lesson (e.g. 5 min quiz, followed by 25 min of homework review, followed by 10 min of whole class discussion, followed by 15 min individual work on worksheets; note whether there was a conceptual summary at the end of the lesson; if summative assessment is present, please describe). 5 mins greeted students and reminded students of class rules followed by 10 mins to prepare materials followed by 10 mins discussion followed by 20 mins experiment followed by 25 mins discussion

As implemented, the lesson mostly focused on (most time was spent on):

2

☐ Most time spent on practicing algorithms/basic skills and procedures/vocabulary
☐ About equal time spent on practicing algorithms/basic skills and procedures/vocabulary and on concept development and meaningful learning
☑ Most time spent on inquiry/meaningful learning and genuine problem solving

1. Mathematics and Science Content

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation. DK = Observer does not know or is not able to make this determination.

1a. Math and science content information was accurate.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	DK ☐
1b. Teacher's presentation or clarification of mathematics or science content knowledge was clear.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	DK ☐
1c. Teacher used accurate and appropriate mathematics or science vocabulary.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	DK ☐
1d. Teacher/students emphasized meaningful relationships among different facts, skills, and concepts.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	DK ☐
1e. Student mistakes or misconceptions were clearly addressed (emphasis on correct content here).	(0) ☑	(1) ☐	(2) ☐	(3) ☐	DK ☐
1f. Teacher and students discussed key mathematical or science ideas and concepts in depth.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	DK ☐
1g. Teacher connected information to previous knowledge.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	DK ☐
1h. Appropriate connections were made to other areas of mathematics/science or to other disciplines.	(0) ☑	(1) ☐	(2) ☐	(3) ☐	DK ☐
1i. Appropriate connections were made to real-world contexts.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	DK ☐
Summary: Quality of Mathematics and Science Content	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

- The teacher stated that filter channels are thick for the sand and pebbles to pass through the filter.

- Teacher related walter filtration to the tap water and drinking water and that the companies work on filtering water that is safe to drink
- Math was not evident. No connections to math.

2. Student Cognitive Engagement in Meaningful Instruction

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

2a. Students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
2b. Students were asked to explain or justify their thinking.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
2c. Students were given opportunities to summarize, synthesize, and generalize	(0) ☐	(1) ☐	(2) ☑	(3) ☐
2d. Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
2e. Students were asked to apply knowledge to a novel situation.	(0) ☐	(1) ☑	(2) ☐	(3) ☐
2f. Students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena	(0) ☐	(1) ☐	(2) ☐	(3) ☑
Summary: Quality of Student Cognitive Engagement in Meaningful Instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

- Teacher passed around each table & asked questions where the student need to justify their thinking.
- Students used concrete materials only. (sand, water bottle, tray...)
- During the discussion, the teacher asked the students to interpret the results of their experiment.
-

3. Inquiry learning; Project-based learning; and Problem-based instruction

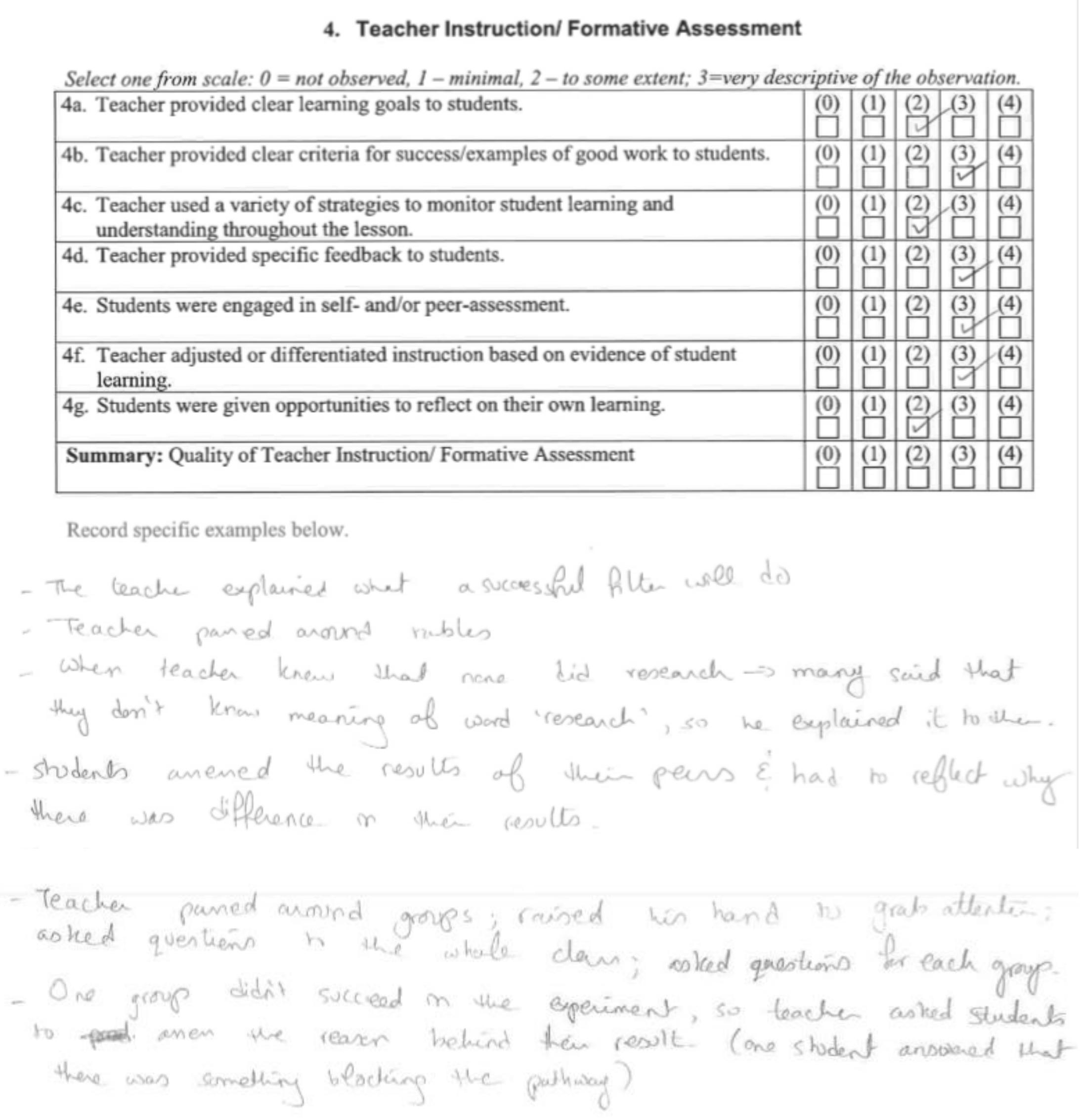
Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.
NA = not applicable to activity being observed (since projects may not occur in every lesson)

3a. Students were engaged in open-ended tasks or questions.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	NA ☐
3b. Students engaged in hands-on or real-life problem solving activities or a lab experiment.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	NA ☐
3c. Students developed their own questions and/or hypotheses to explore or test.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	NA ☐
3d. Students engaged in scientific inquiry process (tested hypotheses and made inferences)	(0) ☐	(1) ☐	(2) ☐	(3) ☑	NA ☐
3e. Students determined which problem-solving strategies to use.	(0) ☐	(1) ☑	(2) ☐	(3) ☐	NA ☐
3f. Students had to present or explain results of project.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	NA ☐
3g. Students worked on a project requiring creativity.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	NA ☐
3h. There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process.	(0) ☑	(1) ☐	(2) ☐	(3) ☐	NA ☐
3i. There was an explicit evidence of students using engineering (or reverse engineering) design process.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	NA ☐
Summary: Quality of Inquiry learning; Project-based learning; and Problem-based instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

- The students had to determine how they will conduct their experiment.
- The students had to design a water filter that filters dirty water to clean water.
- The teacher asked students after conducting the experiment how they will redesign it and improve it.

- Teacher guided students with challenging questions. For example they had to think how they will construct the water filter with one plastic bottle. One student suggested to cut the bottle in half, so the first half is used to collect the filtered water and the second half is used to insert dirty water.



4. Teacher Instruction/ Formative Assessment

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

4a. Teacher provided clear learning goals to students.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	(4) ☐
4b. Teacher provided clear criteria for success/examples of good work to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4c. Teacher used a variety of strategies to monitor student learning and understanding throughout the lesson.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	(4) ☐
4d. Teacher provided specific feedback to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4e. Students were engaged in self- and/or peer-assessment.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4f. Teacher adjusted or differentiated instruction based on evidence of student learning.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4g. Students were given opportunities to reflect on their own learning.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	(4) ☐
Summary: Quality of Teacher Instruction/ Formative Assessment	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐

Record specific examples below.

- The teache explained what a successful filter will do
- Teacher passed around tables
- When teacher knew that none did research → many said that they don't know meaning of word 'research', so he explained it to them.
- students assessed the results of their peers & had to reflect why there was difference in their results.

- Teacher passed around groups; raised his hand to grab attention; asked questions to the whole class; asked questions for each group.
- One group didn't succeed in the experiment, so teacher asked students to assess the reason behind their result. (one student answered that there was something blocking the pathway)

5. Common Instructional Framework

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

5a. Students worked collaboratively in teams or groups.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5b. Students used writing to communicate what they had learned.	(0) ☑	(1) ☐	(2) ☐	(3) ☐	
5c. Teachers asked open-ended questions that required higher level thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5d. Teachers provided assistance/scaffolding when students struggled.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5e. Students engaged in discussion with each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5f. Students participated in guided reading discussions.	(0) ☑	(1) ☐	(2) ☐	(3) ☐	NA ☐
Summary: Overall rating of Quality of Common Instructional Framework implementation	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Record specific examples below.

- students were constantly discussing in their groups.
- Teacher asked where they found difficulty & how they will improve their design + why group 4's model didn't work? why there's a difference between groups 1 & 6.
- all explanation and interpretation were done through talking

6. Student Engagement

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

6a. Students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions).	(0) ☐	(1) ☐	(2) ☑	(3) ☐
6b. The time in class was spent productively on meaningful tasks.	(0) ☐	(1) ☑	(2) ☑	(3) ☐
6c. Teacher pursued the active engagement of **all** students.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
6d. Students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem).	(0) ☐	(1) ☐	(2) ☐	(3) ☑
6e. Students showed perseverance when solving math/science problems.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
Summary: Student Engagement	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

- Much time was lost due to class management
- students didn't give up while constructing the water filter model

7. Use of technology

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

7a. Technology was used to a high extent (as a proportion of time of the lesson and intensity of use)	(0) ☐	(1) ☐	(2) ☑	(3) ☐
7b. Students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
7c. Students used technology to generate or manipulate one or more representations of a given concept or idea.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
7d. Students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective).	(0) ☑	(1) ☐	(2) ☐	(3) ☐
7e. Students used technology to practice skills or reinforce knowledge.	(0) ☑	(1) ☐	(2) ☐	(3) ☐
7f. Technology was used but did not appear to provide any added benefit.	(0) ☑	(1) ☐	(2) ☐	(3) ☐
7g. **Teacher** used technology to achieve instructional goals. (Emphasis on the "teacher" here)	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Use of technology	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

- No digital technology
- Students used concrete materials to conduct experiment

8. Classroom Culture

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

8a. Students exhibited positive classroom behavior.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8b. The classroom exhibits a respectful environment.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8c. There is a climate of respect and encouragement for students' ideas, questions, and contributions; mistakes are viewed as an opportunity to learn	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8d. Students and teacher appear to have positive relationships and to enjoy spending time with each other (laughing, easy relationship).	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8e. Students actively seek and provide assistance or guidance.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
8f. Teachers and students provide positive reinforcement and feedback to each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
Summary: Classroom Culture	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

- All questions and answered were encouraged.
- Students were eager to learn
- Teacher praised students who answered correctly
- Teacher played music to calm them down (the students were loud)

Study of STEM Learning

Classroom Observation Protocol: Academic Year 2012–2013

Observer/Interviewer:________________ ~~School Name:~~____________

Observation date: Mon. Nov. 19 Time Start: ________ End: ______

~~Teacher Ethnicity:~~ _____ Teacher Gender: Male__ Female__

Grade Levels of students: 4 Course Title: Oil spill

Students: Number of Males 11 Number of Females 16

~~Classroom Race/Ethnicity: % Minorities (approximate)~~___________

Please give a brief description of the class observed, including:

- the classroom setting in which the lesson took place (space, seating arrangements, environment and personalization, *etc.*),
- when in the overall lesson sequence this class takes place (toward the beginning of a unit, in the middle of a unit, toward the end)
- any unusual context of the lesson (interruptions, etc.)

Use diagrams if they seem appropriate.

Lesson Topic:

oil spill in ocean

Lesson Goals as presented *by the teacher to the students*:

will simulate oil spill in ocean

Curriculum Materials Used: (include any textbook, lab materials, or resources used)

Lesson Structure: Briefly describe the structure of the lesson (e.g. 5 min quiz, followed by 25 min of homework review, followed by 10 min of whole class discussion, followed by 15 min individual work on worksheets; note whether there was a conceptual summary at the end of the lesson; if summative assessment is present, please describe).

As implemented, the lesson mostly focused on (most time was spent on):

- 10 min introduction (inquiry questions) followed by
- 10 min planning (group work)
- 2 min listing materials needed
- 30 sec. to choose TH
- ~~10~~ 15 mins to set up the experiment (gathered materials &

☐ Most time spent on practicing algorithms/basic skills and procedures/vocabulary
☐ About equal time spent on practicing algorithms/basic skills and procedures/vocabulary and on concept development and meaningful learning
☑ Most time spent on inquiry/meaningful learning and genuine problem solving

1. Mathematics and Science Content

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation. DK = Observer does not know or is not able to make this determination.

	(0)	(1)	(2)	(3)	DK
1a. Math and science content information was accurate.	☐	☐	☐	☐	☐
1b. Teacher's presentation or clarification of mathematics or science content knowledge was clear.	☐	☐	☐	☐	☐
1c. Teacher used accurate and appropriate mathematics or science vocabulary.	☐	☐	☐	☑	☐
1d. Teacher/students emphasized meaningful relationships among different facts, skills, and concepts.	☐	☐	☐	☐	☐
1e. Student mistakes or misconceptions were clearly addressed (emphasis on correct content here).	☐	☐	☐	☑	☐
1f. Teacher and students discussed key mathematical or science ideas and concepts in depth.	☐	☐	☐	☐	☐
1g. Teacher connected information to previous knowledge.	☐	☐	☐	☐	☐
1h. Appropriate connections were made to other areas of mathematics/science or to other disciplines.	☐	☐	☐	☐	☐
1i. Appropriate connections were made to real-world contexts.	☐	☐	☐	☑	☐
Summary: Quality of Mathematics and Science Content	☐	☐	☐	☐	

planning, density, materials, light, weight

T demonstrated one misconception (capacity)

Record specific examples below.

→ related oil spill to an incident that happened in Lebanon in 2006 (can look it up & find consequences)

① What can you tell me about oil spill? "oil spill makes everything slip & can result in car accident"

- What do we call boat that carries oil? tanker

- Let's focus on oil spill in ocean

- How does it look like? S: "water will look black" what else? S "Thick" "slimy", "big" how big? "it could be huge", T: what else? "floating on water" T: imp detail, why floats? S: "bc also liquid" "oil has diff. consistency", "diff. names" T: you're close.. What does that mean? if I take this pebble & drop it in water what will happen? S: 'sink bc heavier than water', T: If I take small tissue, S: 'will float bc light', S: it weighs less than H_2O, T: water is denser than paper, let's go back to oil & water S: 'it weighs less than H_2O' one S: oil has small capacity compared to ocean, T: good hypothesis, but is it true? Let's test this hypothesis real quick (filled water bowl & put paper & rock so size doesn't matter.

2. Student Cognitive Engagement in Meaningful Instruction

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

2a. Students experienced high cognitive demand of activities because teacher did not reduce cognitive demand of activities by providing directive hints, explaining strategies or providing solutions to problems before students have a chance to explore them, etc.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
2b. Students were asked to explain or justify their thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
2c. Students were given opportunities to summarize, synthesize, and generalize	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2d. Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	(0) ☐	(1) ☐	(2) ☑	(3) ☑
2e. Students were asked to apply knowledge to a novel situation.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
2f. Students were asked to compare/contrast different answers, different solutions, or different explanations/interpretations to a problem or phenomena	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Quality of Student Cognitive Engagement in Meaningful Instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

Ⓥ we will do simulation. What does simulate mean? simulate oil spill in ocean
S: 'reminds me of similar _' S: will try to make model of oil spill'

T: what I need to do? S: 'materials'
Think how simulate ocean then oil spill.
S: 'we have to plan' T: 'will plan first,' how? ~~then~~ if you want follow sci
T: 'have to research, discuss, gather info." so today you will plan together as a group so step 1: Plan"

T: 'if I want to prepare huge dinner party, what I need to do?' S: "need to plan what to cook' T: 'once I know the menu what I need to do?" S: 'get ingredients' T: 'ingredients which are materials' so the same thing you will do in class, will plan an oil spill.

one group: S: said juice ~~vinegar~~ as one of ~~so~~ materials T: why juice ~~vinegar~~ S: written on board T: ~~what is~~ ~~do~~ how does juice relate to oil spill in ocean? does it make sense? always analyze & think. S: ~~so~~ then we need salt for ocean.

made clear instructions for role of table manager → TM (each gp has to pick up one table manager & I'm giving you the opportunity to pick manager but you need to be responsible' only table managers have right to walk & bring materials
15 sec. to choose your TM

3. Inquiry learning; Project-based learning; and Problem-based instruction

questions were open-ended.

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.
NA = not applicable to activity being observed (since projects may not occur in every lesson)

3a. Students were engaged in open-ended tasks or questions.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	NA ☐
3b. Students engaged in hands-on or real-life problem solving activities or a lab experiment.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	NA ☐
3c. Students developed their own questions and/or hypotheses to explore or test.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3d. Students engaged in scientific inquiry process (tested hypotheses and made inferences)	(0) ☐	(1) ☐	(2) ☐	(3) ☑	NA ☐
3e. Students determined which problem-solving strategies to use.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☑
3f. Students had to present or explain results of project.	(0) ☐	(1) ☐	(2) ☐	(3) ☐	NA ☐
3g. Students worked on a project requiring creativity. → stdts had to come up w/ materials needed	(0) ☐	(1) ☐	(2) ☑	(3) ☒	NA ☐
3h. There was an explicit evidence of teacher modeling engineering (or reverse engineering) design process.	(0) ☐	(1) ☑	(2) ☐	(3) ☐	NA ☐
3i. There was an explicit evidence of students using engineering (or reverse engineering) design process.	(0) ☐	(1) ☐	(2) ☑	(3) ☑	NA ☐
Summary: Quality of Inquiry learning; Project-based learning; and Problem-based instruction	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

Simulate oil spill

had to plan & list materials

Record specific examples below.

Stdts had to ~~[illegible]~~ ~~too~~ think of what went wrong in their procedure & had to how to fix it. & plan

③ T: what was a gd idea? wat's gd to keep from your exper. & wat's should be removed?

S: food coloring should be removed bcz paint & food coloring mix together.

T: think of smthn that shud not sink in H_2O. we need dark oil w/dout mixing it w/ water, color it w/ smthn that floats as well. discuss it & plan it.

S: 'take the shaves ~~waste~~ of sharpening & mix it w/ oil'

T: 'wat do we call the shaves?'

S: 'powdered graphic'

T: wat's keyword here? S: 'powder' S: 'can use coffee beans or pepper...'

T: due to limited time, I will run it for you & next time 5 will do smthn else.

All stdts gathered around one table & T demonstrated oil spill → used cocoa powder

idea to use powder bcz it's light / oil spill happens under water bcz there's a leak in tanker under H_2O so now leak is happening

by end of session: formative assessm so ? wat went wrong in your planning or your procedure?

4. Teacher Instruction/ Formative Assessment

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

4a. Teacher provided clear learning goals to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4b. Teacher provided clear criteria for success/examples of good work to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4c. Teacher used a variety of strategies to monitor student learning and understanding throughout the lesson.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	(4) ☐
4d. Teacher provided specific feedback to students.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
4e. Students were engaged in self- and/or peer-assessment.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	(4) ☐
4f. Teacher adjusted or differentiated instruction based on evidence of student learning.	(0) ☐	(1) ☐	(2) ☑	(3) ☐	(4) ☐
4g. Students were given opportunities to reflect on their own learning.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	(4) ☐
Summary: Quality of Teacher Instruction/ Formative Assessment	(0) ☐	(1) ☐	(2) ☐	(3) ☐	(4) ☐

questions & observations

they had to answer if their exp was a success

T asked questions when paused by each gp.

Record specific examples below.

After doing 1st trial, 3 judges: all agreed that although you put a lot of effort, all your exp. were not a success. why?
S: 'oil didn't stay on top, it sank', T: wat else, S: we used paint
T: 3 min to write your procedure & you conclude if it was a success or not. & then you make a new plan (what went wrong & how you will fix it)

5. Common Instructional Framework

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

5a. Students worked collaboratively in teams or groups.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5b. Students used writing to communicate what they had learned.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5c. Teachers asked open-ended questions that required higher level thinking.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5d. Teachers provided assistance/scaffolding when students struggled.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5e. Students engaged in discussion with each other.	(0) ☐	(1) ☐	(2) ☐	(3) ☑	
5f. Students participated in guided reading discussions.	(0) ☑	(1) ☐	(2) ☐	(3) ☐	NA ☑
Summary: Overall rating of Quality of Common Instructional Framework implementation	(0) ☐	(1) ☐	(2) ☐	(3) ☐	

wrote down their plan & procedure

Record specific examples below.

6. Student Engagement

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

6a. Students were behaviorally engaged (following directions, on-task behavior, responding to teachers' questions).	(0) ☐	(1) ☐	(2) ☐	(3) ☑
6b. The time in class was spent productively on meaningful tasks.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
6c. Teacher pursued the active engagement of **all** students.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
6d. Students appeared cognitively engaged (ask questions of the teacher and each other related to the content and ideas being discussed, follow up on each other's responses, clear evidence of students working/thinking hard on a problem).	(0) ☐	(1) ☐	(2) ☐	(3) ☑
6e. Students showed perseverance when solving math/science problems.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
Summary: Student Engagement	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

7. Use of technology

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

7a. Technology was used to a high extent (as a proportion of time of the lesson and intensity of use)	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7b. Students used technology to explore or confirm relationships, ideas, hypotheses, or develop conceptual understanding.	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7c. Students used technology to generate or manipulate one or more representations of a given concept or idea.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
7d. Students used technology as a tool to meet a discreet instructional outcome (like an assignment or specific objective).	(0) ☐	(1) ☐	(2) ☐	(3) ☐
7e. Students used technology to practice skills or reinforce knowledge.	(0) ☑	(1) ☐	(2) ☐	(3) ☐
7f. Technology was used but did not appear to provide any added benefit.	(0) ☑	(1) ☐	(2) ☐	(3) ☐
7g. Teacher used technology to achieve instructional goals. (Emphasis on the "teacher" here)	(0) ☑	(1) ☐	(2) ☐	(3) ☐
Summary: Use of technology	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

8. Classroom Culture

Select one from scale: 0 = not observed, 1 – minimal, 2 – to some extent; 3=very descriptive of the observation.

8a. Students exhibited positive classroom behavior.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8b. The classroom exhibits a respectful environment.	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8c. There is a climate of respect and encouragement for students' ideas, questions, and contributions; mistakes are viewed as an opportunity to learn	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8d. Students and teacher appear to have positive relationships and to enjoy spending time with each other (laughing, easy relationship).	(0) ☐	(1) ☐	(2) ☐	(3) ☑
8e. Students actively seek and provide assistance or guidance.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
8f. Teachers and students provide positive reinforcement and feedback to each other.	(0) ☐	(1) ☐	(2) ☑	(3) ☐
Summary: Classroom Culture	(0) ☐	(1) ☐	(2) ☐	(3) ☐

Record specific examples below.

Appendix C

Interview questions for homeroom teachers

I. Interviewee's background/ demographic data

1. Please tell me briefly about your educational background?
2. Please tell me briefly about your career journey?
3. How many years have you been in the educational field?
4. How many years have you been teaching in this school?

II. Teaching strategies

1. Please describe your science class in a few sentences? What do your students do?
2. What happens during class time?
3. How can you explain, in your own words, what integrated STEM education is?
4. What are, in your opinion, suitable teaching strategies/ methods for STEM education?
5. Do you think that your teaching strategies are consistent with STEM education?
6. What are the topics that you teach in an integrated manner? Give examples.
7. How do you involve your students in the learning activities that happen in class?
8. Explain if and how do you use each of the following in your classroom:
    a. Scientific inquiry
    b. Technological literacy

   c. Engineering-design
   d. Mathematical thinking

9. Please describe an instance when students worked on solving problems.
10. Please describe an instance when students worked on a project.
11. Please describe an instance when students constructed a model.
12. Please describe an instance when students worked with technology in the classroom.

III. Support provided to teachers

1. What does each of the following do to improve your content knowledge, teaching practices and technology integration within your classrooms? Give examples:

	Content Knowledge	Teaching practices	Technology integration
School principal			
PYP coordinator			
Math coordinator			
Technology coordinator			

2. How many professional development workshops or programs do you attend per year?
3. Please provide an example of a workshop or program that influenced your content knowledge, teaching practices and technology integration?
4. Are there any other professional development experiences that influenced your content knowledge, teaching practices and technology integration? If yes, give examples.

5. What are the physical or electronic resources provided by the school that support your teaching in the classroom?
6. In what specific areas do you think you need support to achieve successful implementation of STEM education?

IV. Barriers

1. What are the barriers that interfere with the implementation of STEM education at the school?
2. What would you suggest for proper implementation of STEM education at the school?

Appendix D

Interview questions for coordinators

I. Interviewee's background/ demographic data

1. Please tell me briefly about your educational background.
2. Please tell me briefly about your career journey.
3. How many years have you been in the educational field?
4. How many years have you been working in this school?

II. Perceptions/ beliefs about STEM education

1. How can you explain, in your own words, what integrated STEM education is?
2. What are, in your opinion, suitable teaching strategies/ methods for applying STEM education?

III. Support provided for teacher's TPACK

1. How do you plan the curricular materials, such as the PYP Program of Inquiry?
2. To what extent are the teachers involved in developing the curricular materials?
3. What are the topics that are taught in an integrated manner? Give examples.
4. How do you support the elementary homeroom teachers in the following areas: Give examples.
    a. Content knowledge
    b. Pedagogical knowledge
    c. Technology integration

5. In what specific areas do you think the elementary homeroom teachers need support to achieve successful implementation of STEM education?
6. Are there any other professional development experiences that influenced your content knowledge, teaching practices and technology integration? If yes, give examples.
7. What are the physical or electronic resources provided by the school for the elementary teachers that support their teaching in the classrooms?

IV. Barriers

1. What are the barriers that interfere with the implementation of STEM education at the school?
2. What would you suggest for proper implementation of STEM education at the school?

Appendix E

Interview questions for director of educational resource centre

I. Interviewee's background/ demographic data

1. Please tell me briefly about your educational background.
2. Please tell me briefly about your career journey.
3. How many years have you been working in this school?

II. Perceptions/ beliefs about STEM education

1. How can you explain, in your own words, what integrated STEM education is?
2. What are, in your opinion, suitable teaching strategies/ methods for applying STEM education?

III. Support provided for teachers' TPACK

1. What are the professional development opportunities that are provided to the elementary homeroom teachers?
2. Please provide an example of a workshop or program that aimed at enhancing teachers' technology integration and their pedagogical content knowledge?
3. How does the professional opportunities influence and/ or hinder the elementary homeroom teachers':
   a. Content knowledge
   b. Teaching practices
   c. Technology integration

4. In what specific areas do you think the elementary homeroom teachers need support to achieve successful implementation of STEM education?
5. What are your plans for the upcoming professional development opportunities for the elementary homeroom teachers?
6. Are you planning workshops in STEM education? Please describe.

IV. Barriers

1. What are the barriers that interfere with the implementation of STEM education at the school?
2. What would you suggest for proper implementation of STEM education at the school?

Appendix F

Questionnaire for homeroom teachers

Consent to participate in a Questionnaire
Implementation of integrated STEM education within classrooms: A case study

Hello, I am a graduate student at the Lebanese American University. I would appreciate it if you can complete the following questionnaire as part of my thesis. This questionnaire aims to investigate the implementation of integrated Science, Technology, Engineering and Mathematics (STEM) education within classrooms

The information you provide will be used to enhance and improve our understanding about the implementation of STEM education in schools. Completing the questionnaire will take no more than 10 minutes of your time..

By continuing with the questionnaire, you agree with the following statements:

1. *I have been given sufficient information about this research project.*
2. *I understand that all responses I provide for this study will remain confidential.* ***When the results of the study are reported, I will not be identified by name or any other information that could be used to infer my identity.*** *Only researchers will have access to view any data collected during this research however data cannot be linked to me.*
3. *I understand that I may withdraw from this research any time I wish and that I have the right to skip any question I don't want to answer.*
4. *I understand that my refusal to participate will not result in any penalty or loss of benefits to which I otherwise am entitled.*
5. *I have been informed that the research abides by all commonly acknowledged ethical codes and that the research project has been reviewed and approved by the Institutional Review Board at the Lebanese American University*
6. *I understand that if I have any additional questions, I can ask the research team listed below.*
7. *I have read and understood all statements on this form.*
8. *I voluntarily agree to take part in this research project by completing the following survey.*

If you have any questions, you may contact:

Name (PI)	*Phone number*	*Email address*
Nour El-Sayegh	71-411992	nour.elsayegh@lau.edu

If you have any questions about your rights as a participant in this study, or you want to talk to someone outside the research, please contact the:

IRB Office,

Lebanese American University
3rd Floor, Dorm A, Byblos Campus
Tel: 00 961 1 786456 ext. (2546)

Kindly read each question, and respond by clicking on the circle that corresponds to your answer.

Background

1. Gender:
   - ○ Female
   - ○ Male

2. Age:
   - ○ 21-29 years
   - ○ 30-39 years
   - ○ 40-49 years
   - ○ 50-59 years
   - ○ 60 years and above

3. Highest degree attained:
   - ○ Bachelor’s Degree
   - ○ Teaching Diploma
   - ○ Master’s Degree

4. Major:
   - ○ Education
   - ○ Mathematics
   - ○ Biology
   - ○ Chemistry
   - ○ Physics
   - ○ Other (please specify in the space below)

5. Years of teaching experience:
   - ○ 1-5 years
   - ○ 6-10 years
   - ○ 11-15 years
   - ○ 16-20 years
   - ○ 21-25 years
   - ○ 26 years and above

6. Grade levels that you are currently teaching (if you teach more than one grade level, please select them):
   - ○ Grade 1

- Grade 2
- Grade 3
- Grade 4
- Grade 5

Teaching Strategies

7. Please list below the topics in math and the topics in science that you teach in an integrated manner (where students learn both math and science concepts/ skills)

8. Which of these approaches do you adopt in your classroom?

	Always	Sometimes	Rarely	Never
Project-based learning				
Problem-based learning				
Building models				
Technology integration				
Hands-on activities				
Open-ended questioning				
Discussions				
Connections to real-world contexts				
Group work				
Student presentations				
Lecturing				

9. How do you use technology in your classes?

	Always	Sometimes	Rarely	Never
I use technology as a resource to find ideas and activities				
I use technology at home to prepare my lessons				
I use technology as a tool for teaching in class				
I use technology for coding, programming and other activities				

10. Which of the following do you adopt with students?

	Always	Sometimes	Rarely	Never
I encourage students to develop their own questions and/ or hypothesis				
I ask students to research a topic				
I request students to make observations				
I request students to record data				
I ask students to interpret the results of their exploration				
I ask students to define a problem				
I allow students to think of the criteria of a solution				
I ask students to brainstorm their ideas				
I ask students to draw sketches or diagrams to visualize the solution				
I ask students to generate multiple potential solutions				
I request students to redesign their model				
I encourage students not to give up when solving a problem				
I provide students with occasions to critique others' reasoning				
I allow students to reason abstractly				
I ask students to look for patterns				
I encourage students to attend to precision				
I ask students to construct viable arguments				
I encourage students to model with math (e.g. write an equation to describe a situation)				

11. Please describe briefly what the students do during the *Science Lab*, if applicable.

12. Please describe briefly what the students do during the *Makerspace* class, if applicable

Support provided to teachers

13. Which of these professional development options are provided by the school? (you can choose multiple answers)
    - One-day workshop
    - Multiple-day workshop
    - Workshops abroad
    - Summer programs
    - Lectures
    - Other (please specify in the space below)

14. From the chosen professional development options, which choices influence your content knowledge, teaching practices and/ or technology integration the most?
    - One-day workshop
    - Multiple-day workshop
    - Workshops abroad
    - Summer programs
    - Lectures
    - Other (please specify in the space below)

15. How often do you participate in professional development opportunities per year?
    - 1-3 times per year
    - 4-6 times per year
    - 6-8 times per year
    - More than 8 times per year

16. What kind of resources are provided by the school that influence your content knowledge, teaching practices and/ or technology integration?

	Very important	Important	Of little importance	Unimportant	Not provided
School library					

Textbooks					
Magazines/ newspapers					
Online web resources (e.g. YouTube videos, GoogleDocs, Phet simulations, Padlet, Story jumper, etc.)					
Tutorials					
Coordinator’s assistance					

Barriers to STEM education

17. What are the barriers that interfere with the implementation of STEM education at the school?

	Very important	Important	Of little importance	Unimportant	Not applicable
Limited content knowledge in science/ technology/ engineering or mathematics					
Limited familiarity with the student-centered approaches (e.g. problem-based learning, inquiry learning, project-based learning, etc.)					
Lack of motivation to learn and adopt new approaches					
Limited technology resources available at the school					
Poor facility structure (e.g. small classroom sizes, poor lab conditions, etc.)					
Time constraints					
Need to finish the curriculum					
Limited materials and physical resources (e.g. material kits)					
Insufficient professional development opportunities					
Limited collaboration					

Insufficient faculty and staff meetings to discuss issues and solutions related to STEM education					

18. What would you suggest for proper implementation of STEM education at the school?

Thank you for your participation.

Appendix G

Questionnaire for homeroom teachers (French version)

Consentement à participer à un questionnaire
Investigating implementation of integrated STEM education within classrooms: A case study

Bonjour, je suis une étudiante diplômée de l'Université Libanaise Américaine (LAU). J'apprécierais que vous puissiez remplir le questionnaire suivant dans le cadre de ma thèse. Ce questionnaire vise à étudier la mise en œuvre de l'enseignement intégré des sciences, de la technologie, de l'ingénierie et des mathématiques (STEM) en classes primaires.

Les informations que vous fournirez seront utilisées pour améliorer notre compréhension de la mise en œuvre de l'éducation STEM dans les écoles. Remplir le questionnaire ne prendra pas plus de 10 minutes de votre temps.

En continuant avec le questionnaire, vous êtes d'accord avec les affirmations suivantes:

1. J'ai reçu suffisamment d'informations sur ce projet de recherche.
2. Je comprends que toutes les réponses que je fournis pour cette étude resteront confidentielles. Lorsque les résultats de l'étude sont rapportés, je ne serai pas identifié par mon nom ou toute autre information qui pourrait être utilisée pour déduire mon identité. Seuls les chercheurs auront accès aux données collectées au cours de cette recherche, mais les données ne peuvent pas être liées à moi.
3. Je comprends que je peux me retirer de cette recherche chaque fois que je le souhaite et que j'ai le droit de sauter toute question à laquelle je ne veux pas répondre.
4. Je comprends que mon refus de participer n'entraînera aucune pénalité ou perte d'avantages auxquels j'aurais autrement droit.
5. J'ai été informé que la recherche respecte tous les codes éthiques communément reconnus et que le projet de recherche a été examiné et approuvé par le Conseil de révision institutionnelle de l'Université Américaine de Beyrouth.
6. Je comprends que si j'ai d'autres questions, je peux demander à l'équipe de recherche ci-dessous.
7. J'ai lu et compris toutes les déclarations sur ce formulaire.
8. Je consens volontairement à participer à ce projet de recherche en complétant le sondage suivant.

Si vous avez des questions, vous pouvez contacter:

Nom (PI)	Numéro de téléphone	Adresse e-mail

Nour El-Sayegh 71-411992 nour.elsayegh@lau.edu

Si vous avez des questions sur vos droits entant que participant à cette étude, ou si vous souhaitez parler à quelqu'un en dehors de la recherche, veuillez contacter:

Bureau de l'IRB,
Université Américaine de Beyrouth
3e étage, dortoir A, campus Byblos
Tél: 00 961 1 786456 ext. (2546)
Veuillez lire chaque question et répondez en cliquant sur le cercle correspondant à votre réponse.

Contexte

1. Sexe:

○ Femme
○ Homme

2. Âge:

○ 21-29 ans
○ 30-39 ans
○ 40-49 ans
○ 50-59 ans
○ 60 ans et plus

3. Plus haut degré d’étude atteint:

○ Diplôme d'enseignement
○ License
○ Maîtrise

4. Domaine d’étude:

○ Éducation
○ Mathématiques
○ Biologie
○ Chimie
○ Physique
○ Autre (veuillez préciser dans l'espace ci-dessous)

5. Années d'expérience dans l’enseignement:

○ 1-5 ans
○ 6-10 ans
○ 11-15 ans
○ 16-20 ans
○ 21-25 ans

- ○ 26 ans et plus

6. Niveaux que vous enseignez actuellement (si vous enseignez plus d'un niveau, veuillez les sélectionner):

- ○ CP
- ○ CE1
- ○ CE2
- ○ CM1
- ○ CM2

Stratégies d'enseignement

> Veuillez énumérer ci-dessous les sujets en mathématiques et les sujets en sciences que vous enseignez de manière intégrée (où les élèves apprennent à la fois les concepts et les compétences en mathématiques et en sciences)
>
> Laquelle de ces approches adoptez-vous dans votre classe?

	Toujours	Parfois	Rarement	Jamais
Apprentissage par projet				
Apprentissage par problèmes				
Modèles de construction				
Intégration technologique				
Activités pratiques				
Questions ouvertes				
Discussions				
Connexions à des contextes réels				

Travail de groupe				
Exposés présenté par les élèves				
Cours	Toujours	Parfois	Rarement	Jamais

Lequel des énoncés suivants adoptez-vous avec les élèves?

J'encourage les élèves à développer leurs propres questions et / ou hypothèses				
Je demande aux élèves de rechercher un sujet				
Je demande aux élèves de faire des observations				
Je demande aux élèves d'enregistrer des données				
Je demande aux élèves d'interpréter les résultats de leur exploration				
Je demande aux élèves de définir un problème				
Je permets aux étudiants de penser aux critères d'une solution				
Je demande aux élèves de réfléchir à leurs idées				
Je demande aux élèves de dessiner des croquis ou des diagrammes pour visualiser la solution				
Je demande aux élèves de générer plusieurs solutions potentielles				
Je demande aux élèves de revoir leur modèle				
J'encourage les élèves à ne pas abandonner en résolvant un problème				
J'encourage les élèves à ne pas abandonner en résolvant un problème				
Je permets aux élèves de raisonner de façon abstraite				
Je demande aux élèves de trouver la suite d'une série				
J'encourage les élèves à être précis				
Je demande aux élèves de construire des arguments convaincants				
J'encourage les élèves à modéliser avec les mathématiques (par exemple écrire une équation pour décrire une situation)				

Comment utilisez-vous les nouvelles technologies dans vos cours?

	Toujours	Parfois	Rarement	Jamais
J'utilise les nouvelles technologies				

comme une ressource pour trouver des idées et des activités				
J'utilise les nouvelles technologies à la maison pour préparer mes cours				
J'utilise la technologie comme outil d'enseignement en classe				
J'utilise la technologie pour le codage, la programmation et d'autres activités				

Veuillez décrire brièvement ce que les élèves font pendant le laboratoire de sciences, s'il y a lieu.

Veuillez décrire brièvement ce que les élèves font durant Makerspace, s'il y a lieu.

Soutien aux enseignants

7. Lesquelles de ces options de développement professionnel sont fournies par l'école? (vous pouvez choisir plusieurs réponses)
    - Formation d'une journée
    - Formation de plusieurs jours
    - Formation à l'étranger
    - Programmes d'été
    - Conférences
    - Autre (veuillez préciser dans l'espace ci-dessous)

8. Parmi les options de développement professionnel choisies, quels choix influencent le plus votre connaissance du contenu, les pratiques d'enseignement et / ou l'intégration des nouvelles technologies?

    - Formation d'une journée
    - Formation de plusieurs jours
    - Formation à l'étranger
    - Programmes d'été
    - Conférences
    - Autre (veuillez préciser dans l'espace ci-dessous)

9. À quelle fréquence participez-vous à des occasions de perfectionnement professionnel par année?
    - ○ 1-3 fois par an
    - ○ 4-6 fois par an
    - ○ 6-8 fois par an
    - ○ Plus de 8 fois par an

10. Quels types de ressources fournies par l'école influencent votre connaissance des contenus, vos pratiques d'enseignement et / ou l'intégration des nouvelles technologies dans votre enseignement?

	Très important	Important	De peu d'importance	Pas important
Bibliothèque de l'école				
Manuels scolaires				
Magazines / journaux				
Ressources Web en ligne (vidéos YouTube, GoogleDocs, simulations Phet, Padlet, Story jumper, etc.)				
Tutoriels				
L'assistance du coordinateur				

Obstacles à l'éducation STEM

Quelles sont les barrières qui interfèrent avec la mise en œuvre de l'éducation STEM à l'école?

	Très important	Important	De peu d'importance	Pas important	N'est pas applicable
Connaissance limitée du contenu en science / technologie / ingénierie ou en mathématiques					
Connaissance limitée des approches centrées sur l'élève (par exemple, apprentissage par problèmes, apprentissage par enquête, apprentissage par projet, etc.)					
Manque de motivation pour apprendre et adopter de nouvelles approches					
Ressources technologiques limitées disponibles à l'école					

Mauvaise structure de l'installation (par exemple petites salles, manque de laboratoire ou agencement du laboratoire non adapté, etc.)					
Contraintes de temps					
Besoin de finir le programme					
Matériels et ressources physiques limités					
Opportunités de développement professionnel insuffisantes					
Collaboration limitée					
Réunions insuffisantes du corps professoral et du personnel pour discuter des problèmes et des solutions liés à l'éducation STEM					

Que suggéreriez-vous pour la bonne mise en œuvre de l'éducation STEM à l'école?

Merci pour votre participation