Assessing Teachers Education and Professional Development Needs to Implement STEM after Participating in an Intensive Summer Professional Development Program

Ahmad Qablan
Hashemite University, Jordan & University of Alberta, Canada

Abstract

Studies suggest several key aspects of STEM integration for teachers but translating the findings and recommendations of these studies into fruitful changes in teachers' classroom practices remains a challenge. In this study, an assessment of teachers who participated in an intensive professional development STEM program was conducted to better understand their perspectives on the content of the program, their anticipated challenges to effectively implement STEM education in their schools, and the supports needed to help them overcome their challenges. Both quantitative (surveys) and qualitative (participant interviews) were used to collect data to examine the impact of the program on teachers' content knowledge, their anticipated challenges, and the supports needed to integrate STEM in their classroom. Results showed that the majority of the participants reported that the program enhanced their knowledge and abilities on how to teach science through the STEM approach. Participants also reported several anticipated challenges that will limit their integration of STEM in the classroom such as; lack of physical resources, dealing with students' expectations, attitudes, and abilities, lack of time for collaboration with other teachers, and other important administrative challenges. Participants also provided specific suggestions to support their integration of STEM education in their classrooms.

Introduction

The diverse social, economic, cultural, and environmental changes that are facing humanity today require profound societal transformations (Hampson, 2012). However, Education is considered a powerful transformational tool to enable future generations to actively contribute to finding solutions for future challenges. Consequently, several countries around the world are seeking to prepare individuals who are well-equipped in their fields and can add innovation to their expertise to contribute to solving their communities' problems and challenges (Groff, 2013). In fact, 21st-century economies demand the need for such individuals with experts' competencies in their fields with a good understanding of critical subjects such as Science, Technology, Engineering, and Mathematics (STEM) (Berland, 2013).

Although the need for individuals with sufficient knowledge in these areas increased, current education systems fell short at this point to raise such people (Yıldırım & Selvi, 2015). Science, Technology, Engineering, and Mathematics (STEM) approach is seen as a hope and a tool to enable new generations to actively engage in solving future problems and challenges (National Academy of Engineering & National Research Council, 2009).

Researchers also envision that K-12 classrooms are increasingly asked to integrate STEM learning goals by contextualizing student work in science, math, and engineering around engineering design challenges (Baker & Galanti, 2017). Science education has demonstrated the efficacy of design challenges that contextualize student exploration and learning of science and math concepts (Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman, 2004; Kanter, 2010). However, developing students' understanding and appreciation of how the four fields of STEM are connected and complement each other, is not an easy task (Honey, Pearson & Schweingruber, 2014; Moore, Stohlmann, Wang, Tank, Glancy, & Roehrig, 2014). As Moore et al. (2014) noted that even if the connections between STEM subjects are emphasized in a curriculum, there is no guarantee that students will identify them or make the connections on their own. Consequently, the anticipated integrated STEM learning may not be achieved. Similarly, Shaughnessy (2013) emphasized the importance of making Mathematics, in STEM, explicit to students. Therefore, more research is needed to find out ways to help students make STEM connections more transparent and meaningful across disciplines, including how this might be achieved at different grade levels. However, students cannot make the needed connections without receiving help and support from a skillful teacher who is well prepared and trained. Therefore, further research is required on ways to assist science teachers to foster these connections and particularly when curriculum content, frameworks, and resources are lacking.

One way to support science teachers to integrate STEM in their classrooms is through engaging them in continuous high-quality professional development opportunities (Guzey, Moore & Harwell, 2016; Brophy, Klein, Portsmore & Roger, 2008; Roehrig, Wang, Moore & Park, 2012). Continuing Professional Development (CPD) opportunities can help teachers acquire up-to-date knowledge about new teaching practices or content (Estapa & Tank, 2017), enhance their professional pedagogical content knowledge (PCK), challenge their beliefs, improve their classroom instructional practices, and foster their students' learning and achievement (Borko, Jacobs, Eiteljorg & Pittman, 2008; Guskey 1986, 2002). Research on PD emphasizes several characteristics that should be available in any CPD to be inspiring and useful for teachers such as; continuity, interactive, sustained, coherent, collaborative, reflective, and focus on content knowledge to lead to real changes in teachers' practices (Garet, Cronen, Eaton, Kurki, Ludwig, Jones, Uekawa, Falk, Bloom, Doolittle, Zhu & Szteinberg, 2008). Relevant research on STEM has also found that CPD opportunities should help teachers develop deeper understandings of content-specific knowledge within the four disciplines (Brophy et al. 2008; Cunningham and Hester 2007; Ejiwale, 2013), explore various approaches for connecting content across the disciplines (Moore & Smith, 2014; Moore et al. 2014), and develop participants' beliefs and understandings related to integrated STEM education (Roehrig et al. 2012; Stohlmann, Moore & Roehrig, 2012).

As a response to these calls, several CPD programs have been designed to enable science teachers to integrate STEM thinking processes in their classroom practices. These programs intend to enhance teachers' understanding and capacities of STEM education to help them advance their students' potential and capacities towards creativity and creative design thinking. One of these programs is the Queen Rania Teacher Academy (QRTA) intensive STEM-PD program that is offered every summer to science teachers in Jordan. The purpose of this program is to enhance science teachers' capacities to design STEM learning activities and integrate them into their classroom instructional practices.

This study came to understand the challenges and obstacles that science teachers face to implement STEM approach at Jordanian schools. The study came to gain an in-depth understanding from science teachers who participated in an intensive STEM-PD program offered during summer 2019. The study intends to answer the following research questions:

1. What is science teachers' evaluation of content and delivery of the summer STEM-PD program?
2. What are the anticipated challenges to effectively implement STEM education at their schools?
3. What supports would be most helpful for them to overcome these challenges?

Queen Rania Teacher Academy (QRTA):

Queen Rania Teacher Academy (QRTA) is an independent non-profit organization committed to the vision of Her Majesty Queen Rania AL-Abdullah of empowering educators with the skills, recognition, and support necessary to excel in their classrooms. QRTA was launched in 2009 under the patronage of Her Majesty Queen Rania Al Abdullah and in partnership with Columbia University's Teachers College (TC), Columbia University Middle East Research Center (CUMERC), and the Jordanian Ministry of Education.

QRTA offers a wide variety of PD programs and opportunities for teachers in Jordan and the region. The School PD Networks Program, State of the art seminars, short courses, and intensive summer STEM-PD program are examples of the PD opportunities that QRTA offers to educators.

QRTA STEM-PD Program:

In 2018, the QRTA launched a pilot PD program on STEM. The program is a 1-week summer intensive STEM learning experience for science teachers. The program provides (24) STEM activities for science teachers to spark their interest in STEM and enhance their classroom instructional practices. The goal of the program is to engage science teachers in a variety of STEM activities through authentic (real-life problems) and hands-on instruction to increase their interest in integrating STEM in their classroom science teaching. The eight science and engineering practices (NGSS Lead States, 2013) are present throughout the sessions. The activities are designed to help science teachers actively live the experience of designing, building, and testing their structures to develop their STEM pedagogical practices. This allowed them to engage in engineering design while experiencing several science and engineering practices such as planning and carrying out investigations, obtaining, evaluating, and communicating information, and understanding the mathematical content knowledge that is applied. An example of the training activities was redesigning crutches. In that activity, participants worked in teams to design assistive devices that modify crutches to help people carry things such as books and school supplies. They were provided with a list of constraints, including a device weight limit and minimum load capacity. They started by brainstorming ideas and then made detailed plans for their best solutions. They created prototypes and then tested them for functionality by loading them and using them, making improvements with each iteration. At a concluding design expo, teams presented their concepts and demonstrated their final prototype devices. Appendix (1) provides a list of the training activities that were offered during the program.

The training was designed and facilitated by an expert professor of science education who has extended experience in designing and training teachers on STEM education.

It is worth mentioning that the program did not have a follow-up component to support teachers in their implementation of the newly learned practices. The reason behind that is to reduce the cost of the program. However, to make sure that participants will receive continuous support from their schools to implement the program's practices, QRTA asked each participating school to invite at least one science subject coordinator to attend the program.

Methodology:

Based on the nature of the research questions and the issues being investigated, both quantitative and qualitative data collection methods were used. A quantitative data collection method (a predesigned evaluation survey) was used to answer the first research question, however, both the second and third research questions were answered using the qualitative data collection method (informal participant's interviews).

Participants

Twenty middle school science teachers from 7 international private schools in Amman, Jordan participated in the program. Each school is a house of at least 700 students ranging from grades 6-10. Each teacher has at least 7 years of experience in teaching science and each of them has a bachelor's degree in one of the four science disciplines, 6 of them were specialized in Physics, 6 were specialized in Biology, 4 were specialized in Chemistry, and 4 were specialized in Geology.

Data Collection

This study is an interpretive analysis of learning for 20 science teachers who participated in the QRTA summer STEM-PD program. The author was the designer and the lead trainer of the program and acted as a "participant-observer" in this study. Data were collected using two different sources; A predesigned evaluation survey administered to participants at the end of the institute to answer the first research question and (15) participant's interviews conducted after one month from the end of the program to answer the second and third research questions.

Evaluation Survey

The survey was designed by a team of professionals that consists of (a program designer, three science educators and trainers at QRTA, and two M & E experts at QRTA), to assess the impact of the intensive program on participating teachers. The survey consisted of two parts; the first part consisted of 7 items that ask participants to evaluate the content of the program. The second part consisted of 6 items that ask participants to evaluate their abilities that were enhanced during the program.

Participant Interviews

Additionally, 15 informal interviews were conducted with participants who agreed to be interviewed to gain a deeper understanding of teacher's perceptions of STEM. The interview questions included; what they enjoyed most about the STEM learning experience, what were the most anticipated challenges that they will encounter while try-

Appendix 1

List of Program Activities

1. Welcome & Introduction
2. How Many Screws can you put in a cup of water?
3. What will happen if. . . .
4. Design a Digital Information Sign
5. What is Engineering?
6. Designing a Balloon Rocket
7. The Engineering Design Cycle
8. Designing A spirometer Device
9. End of Day 1 Reflection
10. Science & Engineering Practices (SEPs)
11. Build an Electromagnet
12. Build an Electric Motor
13. Designing A Sound Speaker
14. Assessing the implementation of SEPs
15. Modeling How Lungs Work
16. Designing a Hovercraft
17. End of Day 2 Reflection
18. Designing a water wheel
19. Designing an Electric Car
20. Modifying the Design of Crutches
21. Designing Students' Challenges and Activities
22. Planning to Teach A Unit in Science
23. Share your Unit Plan
24. End of Day 3 Reflection

ing to integrate STEM in their teaching, how the informal learning experience will help them teach their science classes, what have they enjoyed about STEM program, and in what ways does STEM program prepare them to teach science classes. All interviews were audio-recorded. The interviewer also took notes to conduct member checks during and at the end of the interview. Data gathered from both quantitative and qualitative sources were then critically analyzed to understand participating teachers' views and experiences in the program.

Data Analysis

Data collection and analysis occurred simultaneously throughout the study. For the quantitative part of the study, Excel software was utilized to get the required statistical indices. However, qualitative data gathered from the 15 participants' interviews were transcribed, and a pseudonym was assigned to each participant (Bogden & Biklen, 1998). All collected data were analyzed in two major stages: open and focused coding (Emerson, Fretz, & Shaw, 1995). In doing so, an inductive approach to analyze the data was utilized to systematically manage, reduce, and organize data (Dey, 1993; LeCompte, 2000). The process started by creating initial coding to develop an early code list (Saldaña, 2016). The purpose of these codes was to briefly describe and summarize "in a word or a short phrase" the idea presented in the data (Saldaña, 2016). The extracted initial codes help the researcher draw a picture of the teachers' most salient perceptions related to their participation in the summer STEM learning experience.

The initial codes were then used to establish the general themes and trends presented in the data (Delamont, 1992; Saldaña, 2016). During this stage, the author inserted his reflecting memos on each of the suggested ideas and themes. In the focused coding, data were further analyzed in light of the ideas and themes previously identified in the open coding stage. All coded data were then combined for further analysis and write-up (Bogdan & Biklen, 1998). The extracted themes were then shared with the participants to resolve any misunderstanding or misinterpretation of the data. All disagreements were discussed until a consensus was reached.

Results:

The analysis of participants' responses to the survey showed that the content of the program was very useful and beneficial to them. Their evaluation of the program's design, content, and delivery ranged between high and very high (Table 1). The majority of participants (95%) believed that the program was well organized and more than 90% of them thought that the learning objectives of the program were met at the end of the training. Concerning the training content, most participants (90%) be-

Item	%				
	Very high	High	Moderate	Weak	Very weak
The training program was well organized	95	5			
Learning objectives were presented to participants at the beginning of the program.	89	11			
Learning objectives were achieved at the end of the program	89	11			
The offered training content has contributed to enrich my knowledge and understanding of STEM science instruction.	87	13			
The training content has provided me with diverse skills that I can implement in my STEM classroom	85	15			
The time allocated for the program was sufficient to cover all training material	67	33			
Offered activities were informed by the national science curricula and are easy to implement in the classroom	100				

Table 1. Percentages of participants' Evaluation of the Program's content and delivery

Item	%				
	Very high	High	Moderate	Weak	Very weak
My knowledge of how to teach through the STEM approach	89	11			
My ability to analyze different experimental designs for several science phenomena	89	11			
My ability to create STEM projects for several science concepts	70	20	10		
Using the engineering design cycle to teach science concepts	78	22			
Implementing STEM science challenges in the classroom	89	11			
Planning to teach through the STEM approach	89	11			

Table 2. Percentages of participants' Evaluation of the Program on their knowledge and abilities to teach through the STEM approach.

lieved that it was useful and contributed to enrich their knowledge and understanding of STEM philosophy and education. Additionally, all participants believed that the offered activities were informed by the national science curricula and were easy to implement in the classroom.

Concerning whether the program helped participants enhance their content knowledge and abilities to teach for STEM in their schools, the majority of the participants (89%) commented that the program enhanced their knowledge and abilities on how to teach science through the STEM approach (Table 2). They mentioned that the activities encouraged them to analyze and test their multiple suggested designs and solutions to solve the problems they encountered (89%). They also commented that their participation in the program's activities helped them develop their abilities to create STEM learning projects for their students (90%). More than 90% of the participants believed that the engineering design cycle is very useful to teach science concepts and more than 90% of them thought that the program helped them become more capable to implement STEM science challenges in the classroom and lastly more than 90% of them believed that they have become skillful in planning to teach using STEM approach.

Similarly, data resulted from analyzing interviews are discussed by topic, focusing on the categories that were mentioned most frequently. The following section presents participants' responses categorized into three major themes; teachers' anticipated needs and supports, Challenges to achieving STEM education, and the support needed to implement STEM at schools.

Teachers' anticipated needs and supports

When asked to identify their teaching needs and anticipated challenges within their teaching area, teachers anticipated that they will lack physical resources and technology (15 of 20), how to deal with changes in student expectations and attitudes (12 of 20), how to deal with various students' abilities and gaps in their understandings (7 of 20), lack of time for planning and collaboration between teachers in the same school who teach the same subject (18 of 20), and lack of administrative support from both schools and districts. However, when asked to comment on the support that they need to overcome their challenges, they mentioned that they need more resources and technology support (18 of 20), more time for collaboration and planning with teacher colleagues (18 of 20), more specific professional development opportunities (14 of 20), and more aligned curriculum that support the interdisciplinary teaching and learning in science (18 of 20).

Challenges to achieving STEM education:

When asked about the challenges that they anticipate to achieve interdisciplinary STEM instruction at schools, they responded that the lack of understanding of STEM philosophy and approach is the main challenge (18 of 20). They mentioned that STEM is a new approach to most teachers, therefore they need awareness and intensive professional development opportunities on STEM philosophy and how to implement it at schools. They also emphasized that the STEM approach requires a huge shift in both teachers' and students' thinking to be able to recognize and appreciate the new way of science teaching.

In the same route, many participants commented on the need to have flexible science and math curricula to facilitate the adoption and implementation of the STEM approach. Such flexibility requires a new design of integrated science curricula that connects science with technology, engineering, and Mathematics.

Teachers also discussed the lack of time to collaboratively plan for STEM instruction (18 of 20). They commented that most of the time all science subjects' teachers are busy during the school day and is hard for them to collaborate during the day. According to them, having such time would enable them to exchange their learnings and experiences with others and give them opportunities to generate new ideas for projects to implement in their teaching. Finding such time for collaboration becomes further complicated due to the variation in the lengths of science class periods among all science classes within each school.

Another challenge that participants reported is related to the physical and technological readiness of schools (15 of 20). They argued that most of their schools have limited spaces and science equipment that are needed to support the implementation of STEM instruction. Although the training program stressed using cheap and available equipment and resources, participants argued that most schools allocate limited annual budgets for science labs that are insufficient to match what is required to implement STEM education at schools.

Another barrier that teachers also reported is the intensive science curricula that require so much time to be covered (20 of 20). They discussed that STEM projects need a long time to finish and that time is not always available. Although they learned to cover many connected science concepts in each STEM project, they believe that still reflecting on each concept addressed during the project requires more time from the class meeting.

An additional challenge discussed by all teachers (20 of 20) was the impact of national and international standard examination. They argued that they are required to prepare students for the country-wide national standard exams that are administered throughout the school year. The Ministry of Education administers several national academic achievement tests for middle and secondary school students for quality assurance and those tests put a lot of pressure on both students and teachers. Preparing students for those exams distract teachers from adopting STEM education in their teaching of science. Such pressure could be alleviated by rethinking the way academic achievement is being measured. The existing educational mindset believes in focusing on evaluating students' content learning and ignores evaluating students' skills and attitudes that are as important as learning science content. The new assessment mentality calls to pay more attention to the use of multiple assessment performance-based assessment strategies and procedures to better assess students learning in all three essential domains of learning: cognitive, psychomotor, and affective.

Supports needed to implement STEM at schools

To cultivate teachers' ideas on ways to support them in implementing STEM in their teaching, teachers insisted that allocating time for science teachers to collaborate and plan for STEM projects is the most needed support from school administration (18 of 20). Better organization of school schedule is also needed (17 of 20). This could be achieved by scheduling the weekly science classes to be successive to each other so teachers will be able to finish their STEM projects in one session.

Additionally, more professional development (PD) opportunities are required to develop teachers' capacities to teach STEM (19 of 20). These opportunities need to be continuous and focused on enabling teachers on how to connect several science and mathematics concepts in one STEM project. Such PD opportunities should also provide teachers with workable examples of teaching units and lesson plans that could be easily implemented in every school setting. Some teachers also suggested providing on-site PD for schools to make it more customized and tailored to each school's context.

Teachers also requested allocating more time in the school schedule to allow both science and mathematics teachers to collaborate and exchange their experiences. That collaboration would be highly beneficial to strengthen the capacities of both subjects' teachers to use the STEM approach in their teaching. Providing needed technology and resources is also another important support that teachers require from school administration. As they discussed, STEM education needs specific resources to allow students to do several learning projects throughout the year. Therefore, schools' administrations should allocate enough budget to fulfill that need.

Discussion:

Some teachers mentioned that they lacked critical knowledge of content and standards of other STEM Subjects. Because an integrated STEM approach focuses on core ideas and major crosscutting concepts that connect many subjects, support is continuously needed to support teachers with diverse instructional approaches that organize and potentially rearrange/reduce knowledge around central ideas, crosscutting concepts, and major themes (Stohlmann et al., 2012).

Teachers always want to participate in PD that is carefully designed using integrated STEM approaches, so that they could experience how to learn through STEM and become good STEM teachers. The interviewed teachers had an idea of how to begin working towards designing and teaching an integrated STEM approach but realized that they need more support, collaboration, modeling, experience, and mentoring. Therefore, more CPD opportunities are needed to continuously enhance teachers' skills in implementing STEM approach in their teaching.

Many critiques have been offered to STEM professional development programs as they are short and not continuous which leads to becoming ineffective (Wilson, 2011). Therefore, STEM PD programs should consider that to design continuous CPD programs that are built on teachers' prior understandings and skills to address the specific needs of every teacher (Wilson, 2011). According to Avery and Reeve (2013), a "one-size-fits-all" approach to STEM teacher education may not be productive for teachers of varying backgrounds and experiences, specifically in core academic subjects such as mathematics.

Although most of the participants commented on the significance of utilizing a design-based science approach in teaching science, some of them argued that the successes with using engineering challenges to teach science are limited in their applicability to engineering classrooms for some reasons such as; classroom culture and its effect on the degree to which students connect their design work to the desired science concepts.

Another concern that the participants addressed is the challenge of covering the learning outcomes stated in the national science curriculum and finding relevant design-based activities to fulfill those outcomes. While learning goal in engineering design classrooms emphasizes "engineering habits of mind", this emphasis should be reflected in the national science curricula to help teachers implement it in their classrooms.

Although these concerns are valid and might limit teachers' capacity to implement design-based science instruction in their classes, I argue that the engineering design context offers the flexibility to address many related Math and Science concepts that are directly in the path of the design work. However, overcoming such limitations in teachers' abilities requires further training and field support to help them design their engineering activities and cover the learning outcomes stated in the national science curricula. Future research is needed to examine classroom enactments of such an approach inside the classroom, focusing on understanding both whether students apply math and science concepts to their design work and why they do so (or not).

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Dr. Ahmad Qablan is currently a visiting professor of science education at the University of Alberta, Canada. He earned his PhD degree in science and sustainability education from Florida State University, USA in 2005 and worked for more than a decade at the college of educational science at the Hashemite University in Jordan and 6 years as a senior program manager at Queen Rania Teacher Academy, Jordan. He has conducted several research projects in education with UNESCO, UNICEF, EU and USAID. Dr. Qablan has published more than 60 books, book chapters and journal articles in local and international publishing houses.