Electrifying Games: Teachers Implement STEM-Makers Learning in the Classroom

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משחקים מחשמליים: יישום למידת STEM-Makers בשגרת ההוראה

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Abstract

The purpose of this pilot study is to understand how Israeli science and technology teachers reflect on their learning and implementation of a unit, "Electrifying Games," developed by the Center for Educational Technology, for 8th graders, on the topic of electric circuits. The unit is based on mobile phone technology, Maker pedagogy, collaborative learning and problem-solving. The research questions focused on different aspects of teacher learning, teacher evaluation of the unit, and student learning. Twenty teachers participated in a 30-hour PD inservice and a WhatsApp Teacher Community. The teacher questionnaire included close-ended and open-ended questions. The findings show that the teachers expressed their overall satisfaction with the unit's pedagogical methods, its collaborative digital environment and use of Augmented Reality (AR), and the professional development learning model. Teachers found that the unit had a positive influence on various aspects of student learning in STEM, such as addressing diverse learners through learner choice, challenge, collaboration and control in the Maker pedagogy. The study also illuminated several issues that need further attention: (1) allocating adequate time for the students' building activities, (2) creating sustainable construction kits, (3) reinforcing conceptual learning in the Maker environments, and (4) developing student self-efficacy in these environments. The study demonstrates how Israeli science and technology teachers can be partners in developing STEM-Maker learning opportunities for their students, as part of their own professional development, and prepares the stage for more extensive development and implementation efforts, in the near future.

Keywords: teacher professional development, mobile-based learning, Augmented Reality.

Background and Rationale

How might 21st century learning be implemented in the STEM (Science, Technology, Engineering, and Math) disciplines? How might Israeli science and technology teachers become partners in creating this kind of learning for their students?

The term "21st century competencies" was coined in 2002 by an American non-profit organization (P21) that included representatives of the business community, education leaders, and policymakers. This work catalyzed the world-wide development of four student competencies in schools: communication, collaboration, critical thinking, and creativity (Boss, 2019; Kaufman, 2019; Pellegrino & Hilton, 2012). A recent review of the educational academic literature of the past 37 years (1980–2016), has shown that *Communication* is the most prominent digital literacy skill, followed by *Problem Solving* and *Collaboration* (Silber-Varod, Eshet-Alkalai, & Geri, 2019).

The purpose of this pilot study is to understand how Israeli science and technology teachers reflected on their learning and implementation of a STEM-Maker unit developed in the spirit of 21st century learning, based on a unique professional development model. The paper is organized into 4 parts: (1) a description of the unit and its components, (2) the study's research questions and methodology, (3) the study's findings, and (4) a discussion about relevant issues.

A Description of the Unit and its Components

The unit, "Electrifying Games", has two main objectives: (1) to develop 21st century competencies (especially collaborative learning and problem-solving), and (2) to teach students scientific knowledge about electricity and electric circuits, presented as part of the science and technology curriculum for middle school students in Israel.

The length of the unit is 6-8 hours (3-4 double lessons). The learning process is based on the students' use of their mobile phones, with two applications: (1) a social network digital environment (Courseline), designed to promote collaborative learning while conveying the unit's content and activities, and (2) an Augmented Reality (AR) application that allows students to plan, design and build electrical circuits using paper cards that represent 9 different components of electric circuits. When these cards are assembled properly on a flat surface, and are viewed by the AR Smartphone application, the image of a working electric circuit appears on the mobile phone's screen (See Fig. 1).

Figure 1. Mobile phone screen shots of Augmented Reality (AR) in "Electrifying Games".

After understanding how circuits work, the students build electric games, based on an "incremental Maker approach", choosing to build suggested games from a booklet (Fig. 2), or from their own imagination. In this way, students engage in the Maker approach, adapted for education, which has been described as "learning by constructing knowledge through the act of making something shareable"(Martinez & Stager, 2013, p. 21), i.e., "learning by making" and/or "making for learning".

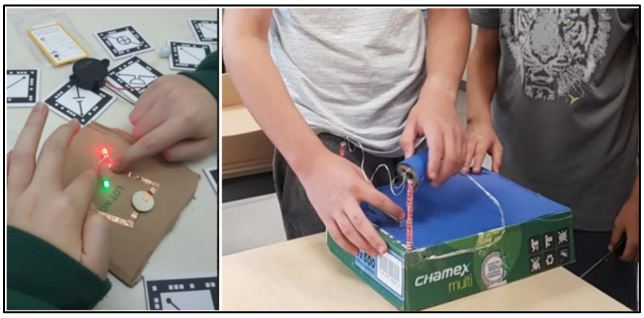

Figure 2. Building Electric Games. Students created suggested games or invented their own.

The teacher Professional Development (PD) model includes a 30 hr. inservice, given by an expert on the Maker approach to guide teachers to (1) use the digital environment (Courseline) to implement the unit's lessons, and (2) use the unit's construction kit and game-making booklet to build electric games (Fig. 3), as well as (3) implement the unit with their students. The PD model also includes a Community of Practice WhatsApp group, moderated by the inservice instructor, and a learning model (independent learning, a hands-on approach using digital tools, planning and building a product reflection on the learning/teaching process and peer review. (See Fig. 4). The PD model thus integrates teacher experiential learning about the pedagogical and technical innovations and teacher classroom implementation of these innovations.

Figure 3. Instruction Page from the Unit's Game-Making Booklet

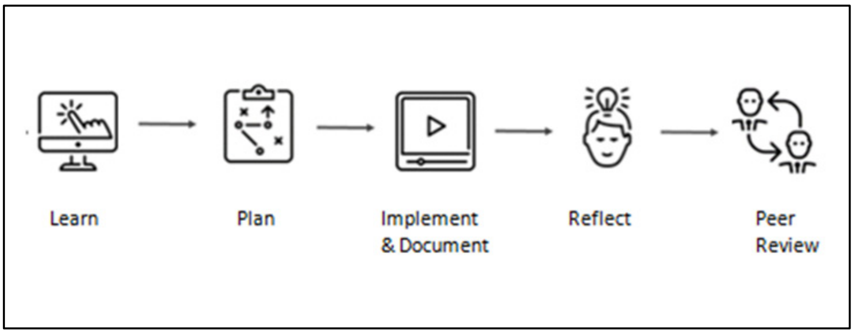

Figure 4. The Learning Model of Teachers in their Professional Development.

Research Questions and Methodology

The research questions focused on two areas, based on teacher perceptions: (1) teacher learning and teacher evaluation of the unit, and (2) student learning:

1. Regarding the first area, what was the teacher response to their own learning process? To the inservice and the learning model? To the unit's components? To their time allocation in the unit? What was their overall satisfaction level?

2. Regarding student learning, what was their knowledge acquisition? Their skill acquisition and self-efficacy? Their motivation and curiosity to learn? How did the unit address diverse learners?

The teacher questionnaire included 48 questions (39 close-ended questions, based on a 5-point Likert scale and 5 open-ended questions), based on the above research questions.

Twenty teachers participated in the 30-hour inservice. The teachers had taught for an average of 12 years (range: 3-27 years, with a standard deviation of 6.75 years). The questionnaire was answered by 18 (90%) of the teachers.

Regarding data analysis for the close-ended questions, the percentage of the teachers who answered 4 or 5 was calculated for each question. These percentages are listed for each of the teacher question's scores in Tables 1 and 2. The questions are listed in descending score value for each numbered topic. In the data analysis for the open-ended questions, the answers were coded according to category.

Findings

The scores for teacher learning and evaluation of the unit are shown in Table 1. The scores for the student learning are shown in Table 2. Summaries of these two data sets follow, listed according to the numbered topics; some representative teacher responses to the open-ended questions are included in these summaries. Following these summaries are teacher responses regarding what they recommend to keep in the unit and what they recommend as improvements.

Table 1. Teacher Responses regarding Teacher Learning and Evaluation of the Unit

Topics	Teacher Questions	Score
1. Teacher response to the their learning process	1.1 The teacher community in the WhatsApp group contributed to your learning.	78%
	1.2 The length of the PD inservice was sufficient for you to acquire the teaching skills based on the Maker approach and to experience the cooperative learning.	78%
	1.3 The reflective process advanced your learning in the PD inservice.	72%
2. Teacher response to the inservice and learning model	2.1 You would recommend to other teachers that they take an inservice using a similar learning model (independent learning, hands-on approach, building a product and reflection on the learning/teaching process).	94%
	2.2 You are satisfied with the implementation support presented to the teachers for use in the classroom (the construction kit, the course's digital environment, and the PD inservice).	94%
3. Teacher response to the unit’s components	3.1 The combination of the construction kit and the digital environment contributed to the learning.	94%
	3.2 The possibility to create a teaching and learning process gradually in the digital environment contributed to experiential learning.	94%
	3.3 The instructions in the construction kit and in the digital environment were clear.	78%
	3.4 The use of the construction kit and the AR (Augmented Reality) were simple for the students.	72%
	3.5 It is possible to reuse the same construction kit.	28%
	3.6 The use of the mobile phones in the classroom disturbed the lessons.	28%

Topics	Teacher Questions	Score
4. Teacher response to time allocation	4.1 The time you spent during the unit's lessons was used appropriately.	50%
	4.2 During the lessons you succeeded in helping the students in the unit "Electrifying Games".	44%
	4.3 The time budgeted for the unit was sufficient for teaching it to the students.	6%
5. Overall teacher response to the unit	5.1 You would recommend to other science and technology teachers to teach the topic of electric circuits via this unit.	100%
	5.2 You connect with the Maker approach as a way to bridge content and skills in teaching.	94%
	5.3 You would like other similar units to be developed for other topics in the curriculum.	94%
	5.4 You would like other units to be developed via the digital environment, to advance cooperative learning.	94%
	5.5 The digital environment makes it possible for the teachers to guide the learning process.	89%
	5.6 Also in the future, you would prefer to teach about electric circuits via the construction kit and the digital environment.	89%
	5.7 You enjoyed learning about the topic of electricity via the construction kit and the digital environment.	83%

Summary of Findings on Teacher Learning and Evaluation of the Unit

1. Teacher response to the learning process. The teacher community via the WhatsApp group and the reflective process contributed to the teachers' learning process. The length of the inservice was sufficient to acquire the necessary teaching skills.

2. Teacher response to the inservice and learning model. Almost all the teachers were very satisfied with the learning model – based on independent learning, hands-on approach, building a product and reflection on the learning/teaching process – and would recommend other teachers to take part in a similar learning model.

3. Teacher response to the unit's components. The combination of the construction kit and the digital environment greatly contributed to student learning. The use of mobile phones during the unit did not disrupt this learning. Most of the teachers felt that the construction kit cannot be reused.

4. Teacher response to time allocation. Nearly all teachers felt that the time allocated for the unit (8-10 hours) does not match the time required to cover it. Half of the teachers felt that the available time was well-spent during the lessons, and about half felt that they were able to adequately respond to their students during this time.

5. Overall teacher response to the unit. All the teachers would recommend other teachers to teach the unit. Almost all the teachers are very satisfied with the various components of the unit, including the Maker problem-solving pedagogy and the cooperative approach of the digital environment.

Table 2. Teacher Responses regarding Student learning

Topics	Teacher Questions	Score
6. Student knowledge acquisition	6.1 The students acquire the necessary knowledge about electric circuits during their experience with the construction kit and the digital environment.	83%
	6.2 You will need to strengthen the students' knowledge about electric circuits in additional lessons.	44%
7. Student skill acquisition	7.1 The students acquire the foundation for skills of collaborative problem-solving during their experience with the construction kid and the digital environment.	94%
	7.2 The students acquire the foundation for cooperative learning during their experience with the construction kid and the digital environment.	89%
8. Student efficacy	8.1 Student learning via the construction kit and the digital environment contributed to their confidence about learning the material.	72%
	8.2 Student confidence in the learning process was strengthened by their use of the construction kit and the digital environment.	61%
	8.3 The students approached the problems presented to them by the construction kit and the digital environment with greater confidence than the regular lessons in science.	33%
9. Student motivation and curiosity to learn	9.1 The AR (Augmented Reality) contributed to an experiential introduction of the students to the topic of electricity.	94%
	9.2 Constructing a product (experiential learning) contributes to an experiential introduction of the students to the subject matter.	89%
	9.3 Experience with the construction kit and the digital environment increased student curiosity in regard to the subject matter.	78%

Topics	Teacher Questions	Score
	9.4 Student motivation during the lessons with the construction kit and the digital environment was greater in comparison to regular lessons in science.	72%
10. Addressing diverse learners	10.1 Learning by the Maker approach makes it possible to address diverse learner differences.	78%

Summary of Findings on Student Learning

6. Student knowledge acquisition about electricity. Most teachers think that their students have acquired the required knowledge about electrical circuitry, but almost half of them estimate that they will need to reinforce this knowledge with additional lessons.

7. Student skill acquisition regarding problem-solving and cooperative learning. The teachers felt that the students acquire a good foundation for problem-solving and collaborative learning skills. As one teacher wrote: "Student interaction with a partner, while working on a common task, leads to mutual fertilization of ideas and doubles success."

8. Student self-efficacy. About two-thirds of the teachers feel that the use of the construction kit and the digital environment contributed to students' confidence in the subject matter and the learning process. However, two-thirds of the teachers think that their students have less confidence engaging in the unit's Maker activities than they do engaging in regular lessons.

9. Student motivation and curiosity to learn. Most teachers believe that the students' experience with the construction kit and the AR has contributed to students' experiential introduction with the subject matter, to increasing their curiosity, and to increasing their motivation to learn the subject matter. One teacher wrote: "In my opinion, learning in this way is very motivating for both students and the teacher." Another teacher wrote: "The course environment is very experiential and motivating for learning. When a student answers on the cooperative board, and sees the other students' answers as well, this contributes to the emotional side of the student, whose answers are meaningful even if they are incorrect. The possibility of students learning from each other's answers is important."

10. Addressing diverse learners. More than three-quarters of the teachers reported that the Makers approach allows for addressing diverse student differences in the classroom. As one teacher wrote: "This type of learning is new and unconventional. It allowed the weaker students to participate more in the learning and construction process and be more active."

Teacher Suggestions about What to Keep and What to Improve in the Unit

Teachers were asked to indicate what is important to keep in the unit. Most of them included the Artificial Reality (AR) cards used by the students to create virtual electric circuits, the digital environment, and the construction kits. Also, most of the teachers pointed out the importance of collaborative work and students sharing answers.

Teachers were asked to suggest what to improve the unit. Most teachers noted a technical problem with some of the components of the construction kit (e.g. making proper electric contact in building the circuits). The teachers also noted the need for more precise instructions in the booklet, as well the need to make allow users to "go back" in the Courseline environment.

Discussion

This pilot study focuses on teacher responses to their implementation of a STEM-Maker unit in their classrooms, focusing on their own Professional Development (PD) learning, their evaluation of the unit, and student learning. Although only 18 teachers answered the questionnaire, for a unit that was allotted only 6-8 hours of classroom time, the detailed analysis of the teachers' responses illuminates several important issues that, in turn, might illuminate 21st century digital learning in STEM.

Regarding the specific unit under study, with a few exceptions, the teachers expressed their overall satisfaction with its *pedagogical methods* (focusing on collaborative learning and problem-solving skills, implemented with an experiential Maker approach), its *digital and physical components* (the unit's digital environment as well its construction kit) and the *PD model* (the teacher inservice, the accompanying learning model, and the WhatsApp teacher community). This combination and integration of pedagogical, digital, physical and PD elements is important to take into account in all forms of 21st century learning in general (Bull, Thompson, Schmidt-Crawford, Garofalo, Hodges, & Spector, 2016) and in STEM learning in specific, where investigation and design are central (NAS, 2019; NAS, 2015, NRC, 2006).

The teachers also related positively to the effect that the unit had on student learning in STEM, in terms of student knowledge acquisition, skill acquisition, motivation and curiosity to learn, and addressing diverse learners. The latter finding relates to prior research that Maker activities appeal to a great diversity of learners (Sahin, & Mohr-Schroeder, 2019); this may be because Maker activities are often connected to increasing learner choice, challenge, collaboration, and control, variables linked to increasing intrinsic motivation (Schwartz, 2019). The unit's explicit "incremental Maker approach" – that provides both instructions for a variety of electronic games, as well as an open-ended option to create original ones – is consistent with these variables, especially given the tension that exists between the Maker movement's original informal grassroots origin and the context of formal education (Rosenfeld, et al., 2019).

The study suggests that several issues need further attention in 21st digital learning environments: (1) allocating adequate time for student building activities, (2) creating sustainable construction kits, (3) reinforcing conceptual learning in the Maker environment, and (4) developing student self-efficacy in these environments.

Teacher response to time allocation (topic 4 in Table 1) clearly shows that the teachers felt that not enough time was available for implementing the unit and providing timely assistance to the students. One explanation for this finding is that student building activities took more time than expected by the developers. Another explanation may be that the teachers were relatively inexperienced with the Maker pedagogy and were not as efficient in helping their students, as more experienced teachers could have been. Changing the perception of the teacher's role is a process that takes time. In order for teachers to adopt the role of guide and facilitator, they need many opportunities to engage in 21st Century learning environments. Teachers who engage repeatedly in these learning environments will be more likely to the change the perception of their role as teachers (Bull, et al, 2016).

Creating sustainable construction kits was another challenge that surfaced in the study and is relevant for 21st century learning in general. One possible solution is to develop low-cost replacement kits for the consumable items.

Reinforcing conceptual learning in the Maker environment is another challenge. As seen in this study, while over 80% of the teachers felt that their students learned the necessary scientific concepts involved with electric circuits, almost half of the teachers felt that they needed to "strengthen the students' knowledge about electric circuits in additional lessons."

Developing student self-efficacy in Maker environments is another issue that needs to be further addressed. Only 33% of the teachers felt that the students "approached the problems presented to them by the construction kit and the digital environment with greater confidence than the regular lessons in science." According to Bandura (1994), there are four sources of self-efficacy: (1) mastery experiences, (2) vicarious experiences provided by social models, (3) social persuasion, and (4) a reduction of stress reactions. The lack of student self-efficacy in this study likely reflects the lack of student experience in Maker activities. Perhaps the above sources of self-efficacy can be employed to empower the students in these Maker environments.

In conclusion, this pilot study presents an example of 21st century STEM-Maker learning that is currently being developed; plans are to expand the implementation and study of teachers and students using "Electrifying Games" in more classrooms, this school year. The pilot study also demonstrates how Israeli science and technology teachers can serve as partners in creating this kind of learning for their students, as part of their own PD.

It is important to note that this pilot study is only a start. No rigorous evaluation of student learning was made during or after the unit. It is important to note that the digital environment does not allow teachers and students to follow and measure student progress in meeting the challenges they are asked to face in the unit, and does not allow for the retrieval of a student performance report. The teachers felt that the students developed a good foundation for the skills of cooperative problem-solving and cooperative learning. These skills have not been fully measured in this evaluation, but the teachers' perceptions are a preliminary exploration of the potential for impact in this area.

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