EURASIA Journal of Mathematics, Science and Technology Education
ISSN: 1305-8223 (online) 1305-8215 (print)
OPEN ACCESS
2018 14(4):1431-1451
DOI: 10.29333/ejmste/83680

Pre-service Science Teachers Learn a Science, Technology, Engineering and Mathematics (STEM)-Oriented Program: The Case of Sound, Waves and Communication Systems

Nayif Awad [1*], Moshe Barak [1]
[1] Ben Gurion University of the Negev, Beer Sheva, ISRAEL

Received 11 November 2017 ▪ Revised 2 January 2018 ▪ Accepted 2 January 2018

ABSTRACT

The current article about pre-service teachers (n=60) describes the implementation and evaluation of an innovative curriculum for teaching sound, waves and communication systems (SWCS). The study sought to investigate pre-service teachers' successes and difficulties in learning a science, technology, engineering and mathematics (STEM)-based program, to examine the program's influence on students' interest and self-efficacy beliefs about learning science and technology, and to explore the factors that affected their achievements and motivation. The participants were two groups of pre-service teachers who learned the course within their studies towards a B.Ed. degree in science teaching. Quantitative and qualitative data were collected by a final exam, a retention exam, a Motivation Questionnaire, final projects, class observations and interviews with the students. The findings revealed that the pre-service teachers successfully learned the new subject and were motivated in learning the course. The integration of science and technology studies, engaging the students in hands-on lab work and the use of ICT tools played a crucial role in promoting meaningful learning. However, the PBL part of the course contributed relatively little because the learners encountered difficulties in learning new subjects independently.

Keywords: ICT, pre-service teachers, project-based learning (PBL), STEM, sound waves

INTRODUCTION

Despite the many calls for combining the teaching of science, technology, engineering and mathematics (STEM), the pre-service teachers' classroom learning experience is probably replete with learning fragmented concepts and topics. STEM subjects such as physics, mathematics, biology, chemistry and technology are often taught separately, in isolation of one another, and without a coherent authentic context (Frykholm & Glasson, 2005; Kelley & Knowles, 2016).

In the conspicuous absence of studies presenting how a change can take place in teacher education programs, the current study has two purposes: first, to present a new curriculum designed to enrich the learning processes and introduce learners to STEM field; second, to conduct a research that examines the program's cognitive and affective influence on the participants.

Many elementary schoolteachers have a weak science content background (McDonnough & Matkins, 2010). This fact is not surprising since prospective teachers receive – if at all – only a partial or limited preparation in science and technology subjects; they often learn an inadequate number of courses either in content or pragmatic delivery of instruction (NRC, 1996). In addition, pre-service teachers often have negative attitudes towards science (Sherman & MacDonald, 2007), and might lack the adequate confidence and efficacy for teaching science (Bergman & Morphew, 2015). These factors might hamper students' STEM learning in schools (Nadelson et al., 2013). Hence, it is no wonder that STEM education in elementary schools is weak (Hechter, 2011; Hossain & Robinson, 2012).

✉ awad_nayif@yahoo.com **(*Correspondence)** ✉ mbarak@bgu.ac.il

Contribution of this paper to the literature

- This study describes the development, implementation and evaluation of an innovative STEM-oriented curriculum about sound, wave and communication systems.
- The study combines quantitative and qualitative tools to examine preservice teachers' achievements and motivation in learning STEM subjects.
- The study examines the science and technology integration as a mean to assist in learning advanced subjects.
- The study explores the use of ICT, hands-on lab work, and projects in learning STEM.

Moreover, teacher preparation programs often use the traditional teaching method (Jimoyiannis, 2010), and place information and communications technologies (ICT) at the center of the learning process merely to apply symbolic gestures or comply with educational trends (Barak, 2014). Little focus is given to student-based learning or to the use of advanced strategies such as inquiry, computer-assisted learning and project-based learning. Therefore, prospective teachers who come to teach classes tend to teach in the same way they learned as part of their training, usually based on a lecture or whole-class instructional techniques.

If so, it is crucial to impart prospective elementary schoolteachers with courses that: (a) offer an effective STEM knowledge of fundamental concepts that are central to teachers' understanding; (b) use ICT as a means to promote meaningful learning; and (c) present the use of advanced instructional methods such as project-based learning (PBL).

The current study describes the development, implementation and evaluation of an innovative curriculum for teaching sound, waves and communication systems in a rich ICT-based environment. The study sought to investigate pre-service teachers' successes and difficulties in learning a STEM-based program. It aimed at examining the program's influence on students' interest and self-efficacy beliefs about learning science and technology, and in determining the factors that affect their achievements and motivation. The main questions that guided the current study were:

1. How do pre-service teachers cope with learning sound, waves and communication systems (SWCS) subjects in an ICT-based environment? What are the factors that might contribute to or hinder their learning?
2. To what extent does learning the SWCS course affect pre-service teachers' motivation and self-efficacy in learning science and technology?

LITERATURE REVIEW

STEM Education: Definition and Objectives

Recently, the STEM acronym – science, technology, engineering and mathematics – has caught the attention of educational researchers and policy-makers as a framework for fostering scientific literacy learning in schools (Brown, Collins, & Duguid, 2011; ACSSO, 2010). The importance of STEM education is increasing in light of the growing necessity for interdisciplinary knowledge, which is essential to face the current challenges, such as brain science. In addition, the modern work today is characterized by interdisciplinary teamwork (Gero, 2016). Furthermore, the expectation is that interdisciplinary learning will contribute to the development of higher-order thinking skills (Field, Lee, & Field, 1994; Tsai, Chung, & Lou, 2017) and increase the motivation to study (Lattuca, Voight, & Fath, 2004).

The "STEM integration" concept carries different interpretations. According to Bybee (2013), "STEM literacy includes the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social and global issues." Vasquez et al. (2013) distinguish between four levels in STEM integration: disciplinary; multidisciplinary; interdisciplinary; and transdisciplinary. Satchwell and Loepp (2002) contend that STEM covers programs in which there is an explicit assimilation of concepts from two or more disciplines. Although the definition (of STEM integration) might vary significantly depending on who is being asked, researchers (Becker & Park, 2011; Schmidt & Fulton, 2016) emphasize the need to incorporate learners in integrated STEM programs. They claim that isolated learning in which each discipline is taught independently could lead to superficial learning and provide students with a misleading picture about the essence of science and technology learning.

The current study proposes a new curriculum about sound, waves and communication systems that spreads over physics, technology and computer disciplines. The study is designed to examine whether and how the new curriculum impacts pre-service teachers' achievements and motivation in acquiring STEM education, and to explore the factors that affect their engagement, successes or difficulties.

Preparing Elementary School Teachers to Teach STEM

The literature review shows that effective teaching of STEM contents is challenging. Nevertheless, it is crucial to increase elementary school students' awareness and understanding of STEM in order to meet the tremendous demand for STEM professionals (Augustine, 2005; NSF, 2007). Therefore, there is a need for qualified teachers who are acquainted with STEM subjects.

However, the research has shown that many elementary school teachers have a limited STEM education background. A main factor relating to a typical elementary school curriculum in science education suggests, if it indeed suggests, incomplete preparation for teaching the STEM curriculum (Teo & Ke, 2014). Due to limited preparation, teachers may not eagerly embrace the idea of teaching STEM content, and most of them are inclined to teach what they were taught (Deemer, 2004; Llinares & Krainer, 2006). To overcome the previous limitations, it is essential that future teachers engage in continuing education and professional development (Fore et al., 2015; Morrison, Raab, & Ingram, 2008; Nadelson et al., 2013; Tsai, 2006).

The program developed in this study proposes a semester-long course for second-year pre-service teachers specializing in elementary school science education. More details are presented later in this study.

Teaching about Sound, Waves and Communication Systems – an Overview of the SWCS Course

Why sound and waves?

A conceptual and practical understanding of the phenomena of sound and mechanical waves in general is a core piece within advanced physics and related disciplines. Areas such as acoustics, heat, light and electromagnetics are rooted in a deep understanding of the dynamics of wave disturbance propagation (Tongchai et al., 2009).

Numerous studies (Chang et al., 2007; Eshach & Schwartz, 2006; Pejuan et al., 2012; Sozen & Bolat, 2011; Wittmann, 2003) point to learners' difficulties with the conceptual understanding of sound. They also point to alternative ideas (misconceptions) and inaccurate scientific mental models. For example, the learners mistakenly thought that:

- Sound propagates through the travel of air particles
- Sound has a tendency towards materialistic properties
- A connection exists between frequency (pitch), amplitude (volume) and the distance that a wave travels
- Frequency depends upon the medium in which the wave propagates
- The speed of sound depends upon different parameters such as the speed of the sound source, frequency or amplitude (volume)

Only a few programs have suggested rich learning activities to address alternative ideas and impart acceptable scientific knowledge. The SWCS course highlights the need to provide pre-service teachers with wide scientific-technological knowledge and suitable preparation in order to be able to cope with the challenges arising from teaching the subject to elementary and middle school students.

Course outline – contents and instructional method

The sound, waves and communication systems course was developed in order to provide learners with a conceptual understanding of real complex phenomena of sound waves. The SWCS course dealt with scientific concepts and ideas, such as:

- Vibrations cause waves
- Sound travels in waves
- Transitive and longitude waves
- Wave properties – period time (T), frequency (f), wavelength (λ), amplitude (A)
- Sound velocity (v)
- Sound propagation in different materials or states of matter
- Human hearing

The following relevant technological concepts were also included:

- Amplifying sound system
- Microphone – structure and work method

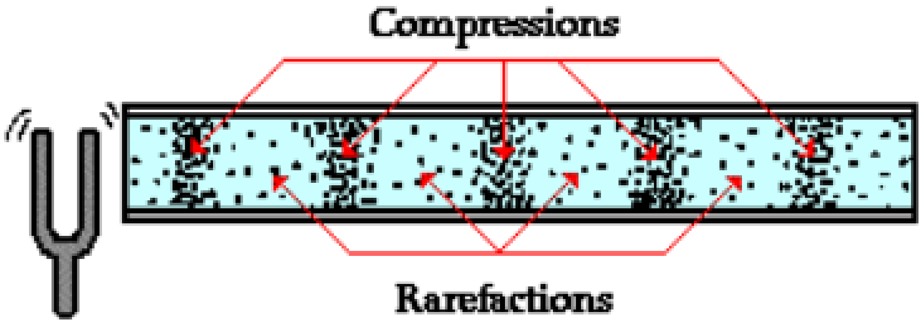

Figure 1. Simulation of a sound wave as particle vibration (Source: PhET interactive simulations)

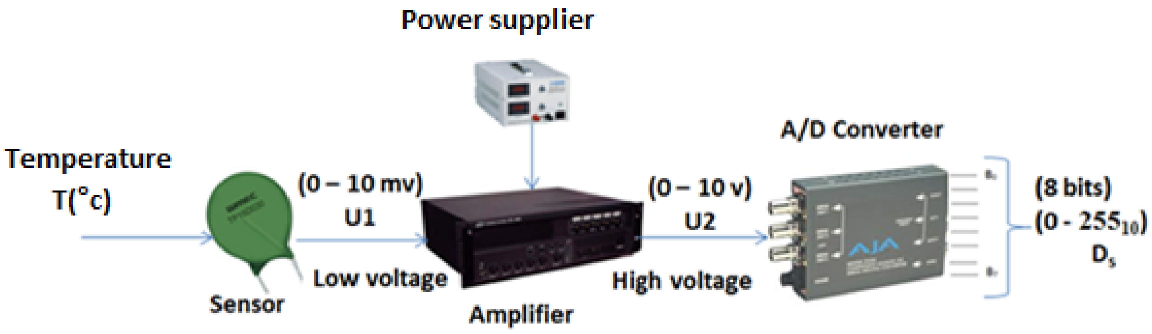

Figure 2. Conversion of temperature signal to digital value

- Speaker
- Amplifier
- Analog-to-digital conversion
- Digital sound

The scientific and technological subjects were taught in an integrated fashion without a formal distinction between science and technology. **Figures 1** and **2** show examples from the course contents: simulation of sound waves, and the conversion process of sound to digital data.

A significant part of students' activities included using ICT, such as the Audacity professional software for signal analysis. **Figure 3** presents an example of the Audacity window with three tones of different frequencies and/or amplitude. This example demonstrates how pre-service teachers used computers in order to generate, record and manipulate sounds, and consequently address their alternative ideas.

In the last part of the course, the students prepared mini-projects (final assignments) on different subjects such as "human hearing" and "Bluetooth communication."

More details of the application of the SWCS course for pre-service teachers are described in the following sections.

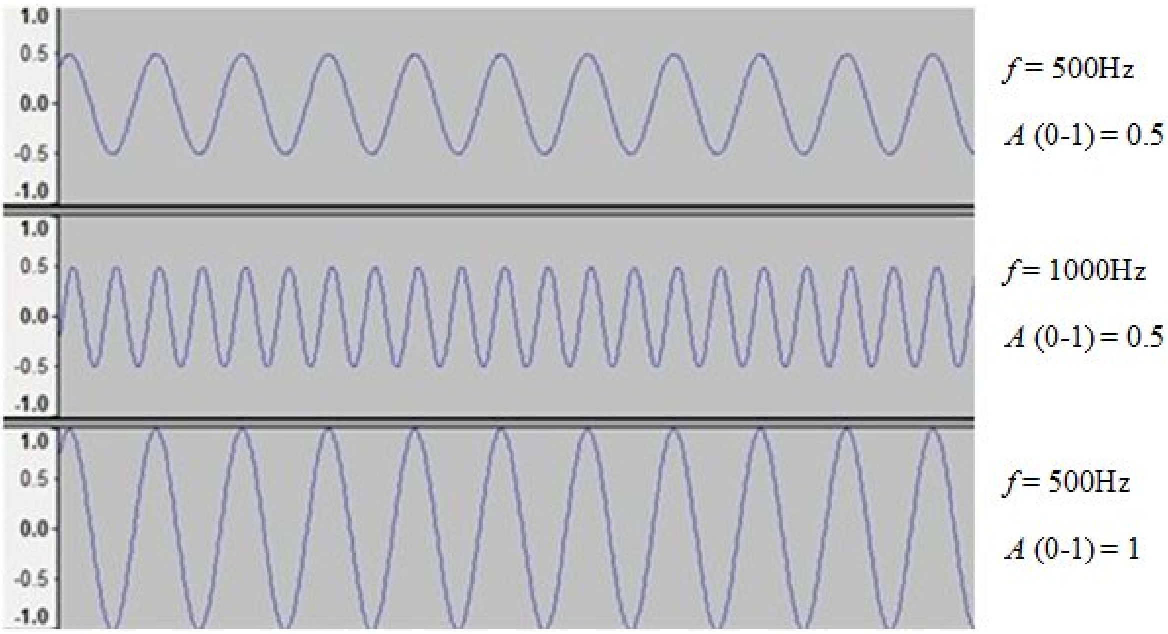

Figure 3. Example of using the Audacity program: three tones with different frequencies and amplitudes

Using ICT in Teaching and Learning STEM

Unfortunately, due to different constraints (time, expertise, materials, etc.), many teachers still practice teacher-centered and lecture-based instruction (Barak, Nissim, & Ben-Zvi, 2011; Bell, Maeng, & Binns, 2013); they rarely implement new practices or use advanced instructional methods such as information and communications technologies (ICT).

The rapid spread of ICT has given rise to the hope that new technologies would largely influence education. Skryabin et al. (2015) investigated how the national ICT development level and individual ICT usage will influence students' achievements in reading, mathematics and science. Analysis of large-scale international databases, including TIMSS 2011, PIRLS 2011 and PISA 2012, showed that the national ICT development level is a significant positive predictor for students' individual academic performance in all three subjects, while the national economic development level was controlled.

Professional use of ICT is defined as a cognitive and epistemic tool for processing data, finding solutions to emerging questions, generating knowledge and solving problems (Chai et al., 2014; Chen et al., 2017). Rogers and Twidle (2013) point out that the most significant products of teachers' professional development are the integration of ICT into the curriculum and the change in teacher's pedagogy towards teaching approaches that empower students to work more independently and reflectively. For ICT to become an integral component or tool for STEM learning, learners must develop an overarching conception of the subject matter with respect to technology and the meaning of studying with technology. To date, pre-service teachers often learn about technology in a more generic manner disconnected from subject matter courses or teaching and learning styles courses (Niess, 2005).

In the current study, ICT use lies at the heart of teaching and learning science, for example, using interactive scientific simulation and sound software. The evaluation concentrated on examining how pre-service teachers used ICT and the effects on the learners' cognitive and affective domains.

Integrating Project-Based Learning (PBL) into the Science Class

Project-based learning is a strategy placing a learner in meaningful learning that focuses on a solution to a problem taken from a real situation. The learner takes the initiative to construct knowledge and effectively develop a solution to a problem by providing the necessary resources, guidance and opportunities for exploration (Blumenfeld et al., 1991). Such a process not only builds a bridge between theory and the real world, but it also boosts the learner's conception of subject integration and application in addition to self-modification (Bilgin, Karakuyu & Ay, 2015).

Many researchers (Crismond, 2011; Thomas, 2000) agree that PBL is one of the best instructional methods for developing students' general skills such as independent learning, problem solving, creativity and teamwork.

However, Kirschner, Sweller, and Clark (2006) claim that minimally guided instructional methods are less effective than instructional approaches for guiding the students' learning process. According to Barak (2013), if the problems presented to students are too well structured, close-ended, simple, abstract or unrealistic, only little learning is achieved, and students are busy 'doing' with only little significant learning taking place (Barron et al., 1998; Blumenfeld et al., 1991; Dolmans et al., 2005). In addition, Capraro, Capraro, and Morgan (2013) claims that effective STEM PBL requires teachers to experience high-quality professional development in order to learn how to design high-quality experiential learning activities – something that is not taken for granted.

METHODOLOGY

Settings

The SWCS course lasted 15 sessions of two study hours weekly. In each of sessions 1 to 12, the lecturer (the researcher of the current study) presented the theory (20-30 minutes), and the pre-service teachers engaged in investigation and problem solving in the ICT environment (45-60 minutes).

The participants comprised 60 pre-service teachers (from two successive cohorts) who enrolled in the SWCS course in the second year of their bachelor degree studies in teaching science and technology. The participants in both cohorts had similar initial backgrounds in terms of achievements and motivation. For example, there were no significant differences in pre-service teachers' admissions data to the college or in their grades in science courses in the first year. Additionally, most of pre-service teachers showed a preliminary high interest in learning the SWCS course.

About 95% of the overall participants were females aged 19-23 who majored in biology and chemistry in high school and had a relatively poor background in learning mathematics, physics and technology subjects. This fact reflects the general population enrolled in elementary school teacher training colleges in Israel, where high-achieving students often prefer to study medicine or engineering at the university.

Prior to this course, the participants had completed several biology and chemistry courses in college such as materials structure, the human body and cell structure, but only one physics course (mechanics).

Research Approach

The study adopted the mixed method research design, combining quantitative and qualitative methods. According to Creswell and Plano (2007), the combined use of quantitative and qualitative approaches provides a better understanding of research problems than either approach alone (Greene, 2005).

The main part in the current study comprised the quantitative research, which aimed at shedding light on the participants' achievements and motivation towards learning through exams, projects and the motivation questionnaire. In our case, the qualitative research based on class observation and interviews was relatively limited, and mainly aimed at completing or adding to the picture derived from the quantitative results. Therefore, among the four major types of mixed methods designs, the *Embedded Design* type was chosen to guide the current study.

Tools for Data Collection and Analysis

Final subject matter exam

Exams are considered effective tools for measuring students' understanding of basic principles (elementary knowledge), and examining the extent to which they recall facts, explain concepts and apply the main ideas. Such an evaluation is specifically essential before involving students in PBL, which might demand high-order thinking skills.

The exam content included the main subjects that pre-service teachers had learned throughout the course: sound waves, electrical amplification systems and digital sound. The exam contained 10 multiple-choice questions and five open-ended questions, all about factual, procedural and conceptual knowledge – 33% for each knowledge type.

To ensure the exam's validity, a panel of experts classified each question into its suitable knowledge type. The panel included three physics teachers having more than 10 years of experience in teaching science and technology in junior high school, a physics professor, and a science education professor having an extensive physics background. The questions' classification was based on majority opinions after conducting profound discussions.

Data analysis: The main researcher and co-author sat together and checked three final subject matter exams of low, middle, and high-achieving learners. Based on these discussions, they concluded how to evaluate the pre-service teachers' answers. Afterwards, the main researcher checked the remaining exams. An independent t-test was performed to compare the mean scores of the final subject matter exams between the first and second cohorts.

Mini-projects (final assignments)

As previously mentioned, in the last three course sessions, the pre-service teachers prepared a final assignment in which they had to choose a new topic related to sound, waves and communication systems, learn it well and prepare a presentation of about 8-12 slides. The projects' evaluation process was based on 'A+ PowerPoint Rubric' created by Vandervelde (2006) and used by Basturk (2008). The original scale consists of the following elements: research and note taking; pre-production planning – storyboard; introduction; content; text; layout; citations; graphics; sound and/or animation; and writing mechanics. The rubric was modified for the current research and comprised three main categories of 3-6 relevant components, as detailed below:

- Content (60%): information accuracy, information relevancy, STEM integration, ICT use, richness, sources (references)
- Structure (20%): suitable titles, main concepts, consistency and logical progression of ideas
- Graphic design (20%): text elements, layouts, animation

Each of the components above was evaluated and sorted to suitable performance level: fully accomplished, partially accomplished and unaccomplished.

Data analysis: In each cohort, the researcher and the supervisor evaluated four mini-projects together according to the detailed rubric (scale). For each assignment, they discussed the suitable performance level for each of the scale's categories until they reached a consensus. Based on these agreements, the researcher checked the remaining assignments. Each learner received a report of the evaluation process of his assignment.

Retention exam

One year after the end of the SWCS course, the second cohort's pre-service teachers were given an additional exam in order to examine the extent to which they understood what they had learned. The retention exam included 10 multiple-choice items and four open questions about factual, procedural and conceptual knowledge.

A physics lecturer (PhD) from the same college who had not been involved in this research before formulated the exam's questions. The lecturer also checked the exams and delivered the scores, as reported later in this study.

The Motivation Questionnaire

The questionnaire was administrated pre and post learning the course in order to examine the learners' motivation towards learning STEM. It comprised close-ended and open-ended parts, as detailed below:

a. The close-ended part of the questionnaire:

This section comprised 12 Likert-type items spread over three categories:

Items 1-4: Interest in learning science and technology, for example, "I am interested in studying science subjects."

Items 5-8: Self-efficacy beliefs about learning new topics, for example, "I can study alone and learn more science."

Items 9-12: Desire to learn in an ICT-based environment, for example, "I look for scientific information on the Internet in my free time."

The items mentioned above were based on questionnaires developed by Fortus and Vedder-Weiss (2014), Assor, Kaplan, and Roth (2002), Arbaugh (2000) and Joo, Bong, and Choi (2000).

To ensure the questionnaire's validity, the items were revised in several rounds according to comments from a panel of three academic researchers (PhD) in science and technology education. The prospective teachers marked their answers on a four-level Likert scale (1 = very low; 2 = low; 3 = high; 4 = very high). Half of the items in the questionnaire appeared in a negative form to avoid bias in the outcomes because of individuals' tendencies to answer questions positively. For example, "*It is difficult to learn new scientific subjects alone*." Answers to 'negative' items were converted to a positive scale in the data analysis. To check the reliability of the questionnaire's findings in terms of internal consistency, the Cronbach's alpha coefficient was performed. Results are presented in the Findings section.

Data analysis: A paired t-test was conducted to examine significant differences between mean scores pre and post the course and in comparison to the mid-scale value of 2.5.

b. The open-ended part of the questionnaire:

The open-ended part of the questionnaire aimed at enabling the learners to explain, give examples, or raise new issues that were not covered directly in the close-ended part of the questionnaire.

Data analysis: The principle of the content analysis method (Holsti, 1969) was used to analyze the pre-service teachers' responses. Specifically, we adopted the following four key steps: (a) reading learners' explanations to examine their compatibility with close-ended answers; (b) re-reading and sorting pre-service teachers' answers into meaningful short phrases (indicators); (c) conducting simultaneous and comparative reading of the pre-service teachers' answers in the pre and post questionnaires; and (d) classifying and quantifying the meaningful phrases into appropriate categories.

Class documentation and pre-service teachers' interviews

The main researcher documented the activities in the class. He made notes about the participants' difficulties, their motivation to learn and the use of ICT. In addition, the researcher conducted six semi-structured interviews of 10-15 minutes with small groups of 2-3 pre-service teachers in each cohort (a total of 12 interviews). Three interviews were held at the middle of the course and three at the end. The researcher asked the learners different questions about the learning in the course, investigating the students' cognitive, affective, and behavioral engagement. All the interviews were recorded and transcribed.

Data analysis: The analysis was conducted in three stages (Miles & Huberman, 1994): (a) data reduction; (b) data display; and (c) thematic interpretation, and aimed at identifying items, subcategories and main categories of the participants' answers. The questions in the structured part of the interview were derived from the educational theories (e.g., constructivism and self-efficacy beliefs), and this part of the analysis can be described as a top-down, deductive or theory-driven analysis. In comparison, the analysis of the learners' comments in the open or unstructured part of the interviews, as well as in the class documentation, was closer to the bottom-up, inductive or ground theory-oriented process. In practice, data analysis starts with coding; this is the basic activity in qualitative analysis (Punch & Oancea, 2014). Coding is the process of putting tags, names or labels against pieces of data. Later on comes the process of identifying main categories and subcategories in the data. In summary, the data analysis revealed three main categories comprising seven subcategories. The main categories were: (a) learning contents; (b) instructional methods; and (c) students' attitudes towards learning science and technology. In the next section, we present briefly some of these findings.

FINDINGS

The following section includes examples from the participants' outcomes related to:

a. Using simulation and animation.
b. Using the Audacity program for interactive sound measuring and analysis.
c. Conducting practical experiments.
d. Pre-service teachers' difficulties in learning SWCS subjects.
e. Pre-service teachers' achievements in the exams.
f. Pre-service teachers' work on mini-projects.
g. Pre-service teachers' motivation to learn STEM subjects

Using Simulation and Animation

During the course, the pre-service teachers answered four ICT class activities (the first three activities were mandatory and the fourth was optional). Most of these activities were replete with simulations and sound applets whereby pre-service teachers could, for example, change the sound frequency (f), amplitude (A) and velocity (v), and measure the wavelength (λ). The activity questions were composed in such a way as to confront particular difficulties in order to foster a conceptual change. In **Figure 4** (taken from a pre-service teacher's answers), for example, the learner explained about wavelength, wave propagation and medium particles movement. As illustrated, each material particle (for example, air or wood) vibrates around a constant point (see particle in circle) generating high-pressure regions – compression (where particles are compressed together) and low-pressure regions – rarefaction (where particles are spread apart). This example, for instance, shows how the participants confronted the common misconception that medium particles progress and travel along with the wave propagation.

The participants worked in pairs; they discussed the questions together and submitted their written answers (doc file) to the lecturer through the course site in the Moodle system. More than 80% of the learners carried out the class's activities. About 50% managed to complete the last activity (fourth) before the course end.

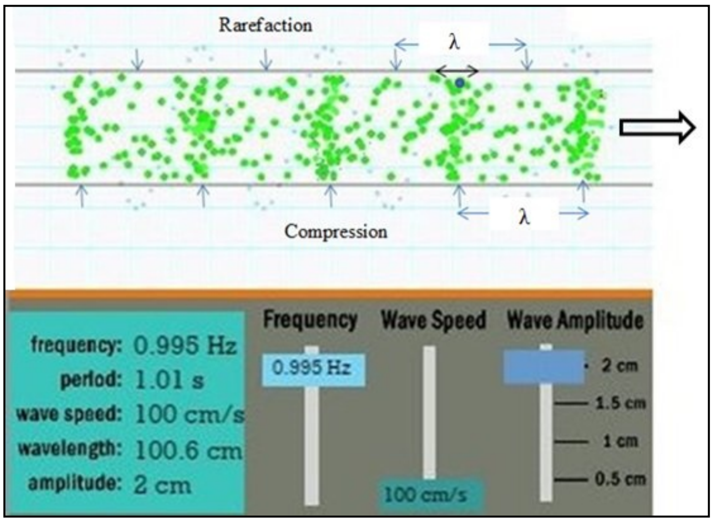

Figure 4. Control over parameters of sound as vibrations of a medium's particles that transport energy and create compression and rarefaction regions

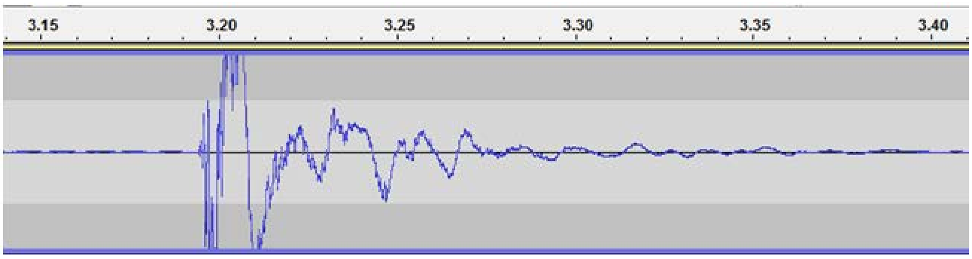

Figure 5. A single knock on table, recorded by Audacity (time in seconds)

Figure 6. Three slow knocks recorded by Audacity (time in seconds)

In each of the ICT class activities, the lecturer checked randomly about 20% of the pre-service teachers' work. He wrote notes and comments, and discussed them with the learners in the subsequent session.

Using the Audacity Program for Interactive Sound Measuring and Analysis

Audacity is a free, open-ended professional sound software. The learners connected microphones to the computer's audio inputs and used the program to measure their sounds and other real sounds in their surroundings. Figure 5 presents a sound recorded from knocking once on a wood table. Figures 6 and 7 show the signals obtained from three slow knocks and three quick knocks, respectively.

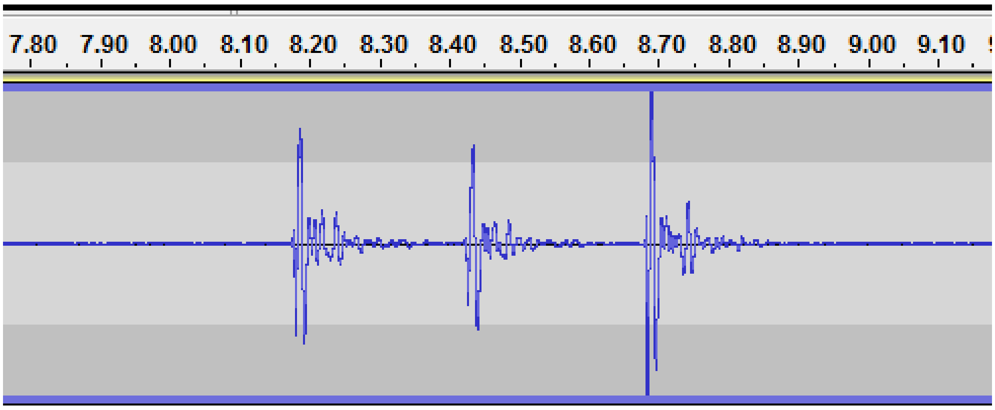

Figure 7. Three quick knocks recorded by Audacity (time in seconds)

The Audacity software helped in measuring the period time and frequency in each case and provided the opportunity to deal with different questions such as:

- How many vibrations occur (approximately) during 0.05 seconds (according to **Figure 5**)?
  (Answer: 5)
- What is the period time of the knock's sound?
  (Answer: T=0.05/5=0.01sec)
- What is the frequency of the knock's sound?
  (Answer: f=1/T=1/0.01=100Hz)
- What does the recording tell us about knock amplitude (volume)?
  (Answer: The knock amplitude decreases gradually)
- How would putting a heavy pot on the table affect knock frequency?
  (Answer: The frequency will decrease)
- At which precise times were slow and quick knocks measured?
  (Answer: Slow – 2.20, 3.20, 4.20; Quick – 8.20, 8.40, 8.70)
- What were the time intervals between knocks?
  (Answer: Slow – 1.00 sec; Quick – 0.20sec, 0.30sec)
- Calculate the frequencies of the slow and quick knocks. How do they differ from the frequencies calculated before?
  (Answer: f_{slow}=1.00Hz; f_{quick}=3.33-5.00Hz; the current frequencies describe the rate of the knocks (rhythm) while the previous frequencies describe the tone of the sound itself)

This example demonstrates how the course under discussion utilized the technological environment (microphone, computer and professional sound software) for engaging the participants in real-life STEM-oriented measurements and experiments. The participants are exposed to the meaning of the terms time period T(sec) and frequency f (Hz) in the context of real sound (100 Hz) and knocks on the table (1 Hz, 5 Hz)

It was observed that the Audacity program brought a great of dynamics to the class sessions and motivated pre-service teachers to help and support one another. Many pre-service teachers who used to work independently (or in pairs) in "regular" ICT class activities joined together and worked cooperatively in large groups of 3-5 participants.

Conducting Practical Experiments

It is widely agreed that many kinds of hands-on experiments and activities related to connecting things to the real world may be effective in promoting (or retaining) positive interest in STEM contents and careers.

In the current study, each pair of pre-service teachers was asked to prepare a practical experiment about one of the course topics and present it in front of the class. Below are examples of experiments that the learners performed:

- Demonstrating vibrations using a tuning fork: the students showed how knocking on a tuning fork caused water particles (inside a closed glass) to vibrate. In addition, they showed that the vibrations of one tuning

Figure 8. Examining feedback audio in a sound system

fork caused another similar tuning fork to vibrate at the same frequency, which is known as the resonance phenomenon.

- Blowing out a candle with a music sound: the students checked different sounds (in terms of frequencies and amplitudes) in order to examine which sound might blow out a lit candle. Their conclusion related to sounds of low frequency and high amplitude.
- Producing sounds by whistles: the students made three different whistles that generated different sounds by cutting drinking straws into different lengths.
- Building a magnetic microphone: the students built a simple magnetic microphone. To check the microphone's function, the students connected it to the computer's audio input and used the Audacity program to record sound, amplify the recordings and hear the recorded sound.
- Following a sound source: the students presented a robot to their classmates, explained about the robot's sound sensor and the program they prepared to force the robot to follow a sound source.
- Generating sounds by musical instruments: the students brought a violin and flute, and used the Audacity program to demonstrate the differences between the instruments' sounds.
- Examining a sound produced by feedback: **Figure 8** shows a student bringing a microphone closer to a speaker and then distancing it in an attempt to explain how the feedback sound's frequency depends on the distance between the microphone and the speaker.

All of the participants completed the task, which comprised 10% of the course's final grade. More than half of the pre-service teachers planned the experiments according to films on the YouTube site and implemented the experiments using materials and instruments they borrowed from their schools. Upon the experiment's completion, the participants were asked about the benefit they had gained. Most of the learners commented that the task contributed to their skills in performing real experiments and they felt more confident in dealing with the subject.

Participants' Difficulties in Learning the SWCS Course

Based on qualitative data derived from class documentation and learners' interviews, we can point to a number of difficulties the pre-service teachers encountered while learning the course, for example:

- Understanding the relationship between the intrinsic properties of sound and the way we hear them; about half of the learners barely distinguished between concepts such as amplitude, frequency, period, wavelength, and hardly realized their effects on sound.
- Imagining how sound might propagate through a solid medium such as a concrete wall.
- Connecting sound concepts to the way in which sound devices work, for example, how frequency and amplitude are expressed in the speaker's work.
- Grasping basic technological concepts such as voltage, current, resistor, and resolution; most of the learners had inadequate prior knowledge in the technology field.
- Dealing with advanced technological topics such as amplification and sampling, the learners had an incomplete picture of how processes are performed (electronically) in practice.

Table 1. Scores in the final and retention exams

	Final subject matter exam (n=57)		Retention exam (n=27)	
	Mean score (0-100)	**Standard deviation (SD)**	**Mean score (0-100)**	**Standard deviation (SD)**
Factual knowledge	73.05	17.20	75.49	20.15
Procedural knowledge	80.00	25.18	77.00	28.20
Conceptual knowledge	75.27	20.12	70.30	24.18
Total score	76.02	13.00	73.86	11.50

However, the lecturer tried to address these challenges by adding explanations, demonstrations and illustrations, enriching the class learning activities, and performing more practical experiments. The exam findings, shown below, shed light on the students' achievements.

Pre-service Teachers' Achievements in the Final Subject Matter Exams

As mentioned in the Methodology section, the learners completed a final subject matter exam at the end of the course that aimed at assessing the extent to which the learners understood the course contents. The scores of the pre-service teachers in the two cohorts were quite similar, and a t-test for independent samples showed no statistically significant difference between the mean scores. Hence, the two cohorts were treated as one large group (n=60).

In addition, a retention exam was performed one year after the end of the course in order to examine the learners' knowledge about the SWCS subjects after a long duration. **Table 1** presents the scores in both exams.

Table 1 shows that the learners' grades in the retention exam were similar to the scores in the exam that took place during the course. This indicates that pre-service teachers internalized what they had learned in the course.

Pre-service Teachers' Work on Mini-Projects

As previously mentioned, projects might increase pre-service teachers' interest in learning science and technology, and integrate them in solving real life problems. Hence, in this part of the SWCS course, we aimed at examining whether the PBL strategy involved the pre-service teachers in investigating new subjects and contributed to their development as independent learners.

The pre-service teachers worked in pairs to prepare mini-projects on subjects that relate to sound, waves and communication systems, for example:

- Analog and digital technologies: digital music, data compression, MP3 technology
- Application of sound editing/analysis programs: Audacity, Praat, Wave-pad
- Sound instrumentation: home sound systems, sonar, ultrasound, musical instruments

Figure 9 presents an example from a project on "Electromagnetics waves – X-ray." The students explained about the x-ray (in comparison to the sound wave), and how the X-ray device – with which they had become familiar in the panoramic dental photography clinic – works.

Most of the learners asked for the lecturer's help in choosing their work's subject. About half of them preferred dealing with contents relevant to biology, humans and the environment. For example, "sound communication among animals," "human hearing" and "noise pollution and health effects."

The mini-project final scores related to the following categories: content (60%), structure (20%) and graphic design (20%). For example, the content category consisted of the following components: information relevancy; accuracy; STEM integration (inclusion of a minimum of two disciplines); ICT use (video, simulation, application/computer software); richness (images/graphs/data and statistics); and sources and references (quality and variety).

The distribution of students' scores related to the content, structure and graphic design of the final project at three levels: fully accomplished; partially accomplished; and not accomplished. This showed that the participants managed to learn techniques quickly and were able to apply the formalistic requirements.

Most of the students used the main concepts they had learned during the SWCS course to show the connection between the project subject and the SWCS course. However, they had difficulties in dealing with the mini-project's content, especially in the cases where they needed to learn new subjects. The main challenges the pre-service teachers faced were: (a) dealing with relatively complicated subjects; (b) presenting a meaningful use of ICT in the project work; and (c) detecting suitable sources and resources. In addition, many students who tried to cover the requirement of "STEM integration" presented a shallow connection between the disciplines in the context of the investigated subject. Most of those learners focused on biology and technology; only a few referred to mathematics or engineering.

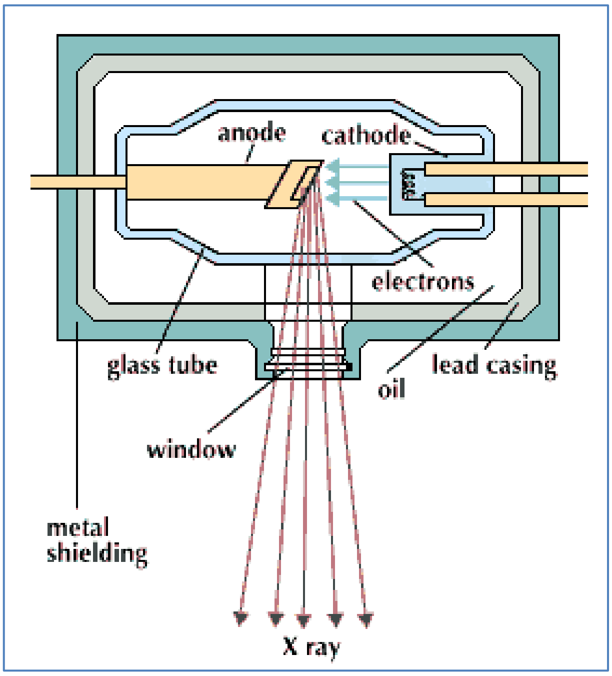

Figure 9. An example from a project about "Electromagnetics waves – X-ray"

Table 2. Findings from the Motivation Questionnaire that pre-service teachers answered pre and post the course (n=55) (scale: 1 = very low; 2 = low; 3 = high; 4 = very high)

					t – test (Pre – Post)	
	Pre/Post	**Cronbach's Alfa**	**Mean**	**Std. Deviation**	**t**	**Sig.**
Interest in learning science and technology	Pre	0.682	3.5875#	.29553	-0.127	.900
	Post	0.799	3.5750#	.41438		
Self-efficacy beliefs	Pre	0.884	2.4625	.51475	-1.126	.274
	Post	0.707	2.3000	.50393		
Desire to learn in an ICT-based environment	Pre	0.742	2.9000	.39236	4.067	.001*
	Post	0.730	3.3000#	.48395		

# $p<0.05$: Deviation from the mid-scale value 2.5 * $p<0.05$: relative to pre-post differences

In summary, the prospective teachers were exposed to new subjects and had the opportunity to tackle the SWCS concepts that they had learned in the course in a new context. However, the learners encountered difficulties in learning and understanding the subject at a deep level, as previously explained. To a large extent, we could note that the prospective teachers' difficulties were similar to those middle school students faced in developing the project.

Pre-service Teachers' Motivation towards Learning STEM Subjects

To examine the effects of learning the SWCS course on the learners' motivation in learning STEM subjects, the close-ended part of the Motivation Questionnaire contained three categories: interest in learning science and technology; self-efficacy beliefs; and desire to learn in an ICT-based environment. Each category included four items (a total of 12 items). In addition, more findings emerged from the content analysis of the open-ended part of the Motivation Questionnaire.

Findings from the close-ended part of the Motivation Questionnaire

Table 2 shows that the findings' reliability in both the pre and post phases measured by the Cronbach's Alfa coefficient was in the range of 0.682-0.884, which is acceptable. A compression of students' answers to the questionnaire in the pre and post phases showed a significant difference only in the category "desire to learn in an ICT-based environment." It is also worth mentioning that the mean score of students' answers was significantly higher than the mid-scale value of 2.5 (natural position) only in the pre and post course answers to the category "interest in learning science and technology" and the post course answers to the category "desire to learn in an ICT-based environment."

Findings from students' answers in the open-ended part of the Motivation Questionnaire and the interviews

As previously mentioned, the Motivation Questionnaire also included an open-ended part in which 32 students wrote comments before taking the course and 36 students wrote comments after the course. Among them, 24 students answered the questionnaire at both times. In the pre-course questionnaire, many students expressed fear and hesitation about learning physics and technology, as seen in the following examples:

> *"I like biology and chemistry. If it is a physics course, my chances to survive are small."*

> *"It seems like it is going to be an all-inclusive course about physics, technology and computers… you [an appeal to the lecturer] have to give us the exam in advance otherwise the situation will be difficult."*

> *"I have never felt comfortable with technological stuff… even the basic concepts of this field are strange for me."*

In the post-course questionnaires, most of the students (about 80%) had positive comments about learning the course, such as:

> *"The course encouraged me to think profoundly about phenomena in our daily lives."*

> *"I started to think how different technological and digital systems work, for example, the electronics screen at the bus station."*

> *"I enjoyed learning physics, technology and computers all together."*

Nevertheless, a few students still expressed feelings of disquiet and unease about learning sound and waves, which are mainly about physics and technology.

In the interviews held with the students at the middle and end of the course, the interviewees were asked, inter alia, about ICT use. For example, "How do you evaluate the role of computer simulation or sound software in your learning process?" or "To what extent did using ICT contribute to understanding the SWCS subjects?" Out of the 24 interviewees from the two cohorts, 20 students said that ICT played a central role in the course, as demonstrated below.

> *"The simulation showed me exactly what happens in sound phenomena… it helped me clearly identify between a particle's movement and a wave's propagation."*

> *"This simulation took me gradually step-by-step from a sinus signal (analog sound) to a binary signal (digital sound). Without the simulation, it was difficult for to me to see that."*

> *"When I have a good simulation, I don't need to make special efforts in order to imagine how things look."*

On the other hand, about a quarter of the prospective teachers had reservations, difficulties and doubts concerning the intensive use of ICT. They indicated that ICT might distract students' attention in class, and distance the lecturer and the students from one another. Specifically, the learners commented that they would prefer receiving more help in completing the ICT class activities.

DISCUSSION

In this section, we discuss the findings of the study related to preparing new teachers to teach STEM, and the SWCS course in particular, in light of the literature reviewed earlier in this work.

Integration of Science and Technology Learning in the SWCS Course

We have seen that STEM is widely accepted as a suitable platform for discussing complex cross-discipline issues. Many researchers (Bybee, 2013; Katehi, Pearson & Feder, 2009) argue that a true STEM education might increase students' understanding of how things work, provide a better picture of the applicability of science and technology, and improve learners' use of technologies.

In the current study, the prospective teachers learned a range of scientific and technological subjects related to waves and communication systems. Special emphasis was placed on choosing authentic context, and the pre-service teachers coupled theoretical concepts with real-world applications, for example, learning about home sound systems, and devices such as a microphone and speaker. In the interviews, most of the pre-service teachers expressed their satisfaction from the interdisciplinary approach and cited its advantages in comparison to the 'traditional' (disciplinary) approach with which they were familiar (Section 4.7).

Tackling the Sound Waves Subject

One of the main objectives of teaching the current course for pre-service teachers was to promote an understanding of the scientific and technological aspects of sound, waves and communication systems (SWCS) concepts. Many researchers highlighted a number of misconceptions and difficulties in learning about sound waves among secondary school students (Caleon & Subramaniam, 2010; Tongchai et al., 2009), prospective teachers (Linder, 1993, Wittmann, 2003), or even undergraduate learners (Pejuan et al., 2012).

The present findings showed that at the beginning of the course, pre-service teachers also encountered difficulties in perceiving main concepts such as frequency, amplitude, wavelength and sound propagation in solid materials. Some of the misconceptions, mentioned in Section 4.4, were common among part of the school students. For example, the connection between frequency (pitch), amplitude (volume) and distance that a wave travels in a given time, and the dependence of frequency on the medium in which the wave propagates.

Moreover, the pre-service teachers had difficulties in learning technological aspects such as amplifying and analog-to-digital conversion due to their poor disciplinary knowledge. Nevertheless, the prospective teachers' achievements in the final subject matter exam at the end of the course were relatively good, indicating initial acquisition of conceptual knowledge. Furthermore, the learners maintained their achievements in the retention exam conducted one year afterwards, which might reinforce our conclusion about the pre-service teachers' understanding of the SWCS subjects. These findings indicate that choosing an instructional method that combines theoretical instruction, hands-on lab work and meaningful use of ICT might help learners overcome difficulties and acquire the accepted scientific knowledge. This conclusion goes hand-in-hand with findings of several studies (Jaakkola, Nurmi & Veemans, 2011; Olympiou & Zacharia, 2012), which showed that the integrative use of both actual and virtual environments might significantly enhance the learners' conceptual knowledge acquisition.

Pre-service Teachers' Motivation to Learn STEM

As previously mentioned, the SWCS course aimed at helping prospective teachers develop positive attitudes toward STEM, which might in turn affect school students' interest to learn STEM (Deemer, 2004; Duschl, Schweingruber, & Shouse, 2007; Osborne & Hennessy, 2003). Aspects of pre-service teachers' motivation were examined, as described below.

Interest in learning science and technology

In the literature review section, we mentioned that many researchers (Blumenfeld et al., 1991; Bruner, 1996; Hmelo-Silver, 2007) agree that learners' motivation towards learning is affected positively when science knowledge becomes relevant and learners have the opportunity to link science knowledge with their life. In addition, Smeets (2005) asserts that ICT provides opportunities to access an abundance of information, thus fostering the authenticity of the learning environment.

In the current study, the participants' answers in the Motivation Questionnaire pre and post learning the course and in the interviews showed a substantial increase in their interest in learning science and technology. Three factors contributed to the learners' high interest: the course's authentic contents; the integrative approach between disciplines; and the flexible integration between teachers' instruction, hands-on lab work and use of ICT.

Self-efficacy beliefs about learning new subjects

In the current study, we examined the course's impact on pre-service teachers' self-efficacy beliefs about learning new subjects in science and technology. For example, one of the items in the Motivation Questionnaire the participants answered was "It is easy for me to learn new scientific subjects independently."

The findings from the questionnaire showed that pre-service teachers' self-efficacy was relatively low in both the pre and post course answers (Section 4.7). Observations in the class and discussions with the students showed that these results had to do with the fact that the students answered the post course questionnaire very close to starting their work on the final project in the course (see Section 5.5 below). As is well known, the beginning of the project work is often identified by learners' difficulties, doubts, worries and uncertainties. Hence, it was hard to see how students could achieve Bandura's (1997) four essential resources for strengthening self-efficacy beliefs, for example, 'active mastery of successful personal experience' and 'vicarious experience.' However, towards completion of the project, the students were more confident and expressed some improvement in self-efficacy. It should be noted that a major part of the prospective teachers' difficulties in developing a high extent of self-efficacy is related to insufficient preparation provided to learners about the project work.

The Role of Using Information and Communications Technology (ICT)

An essential part of the learning-teaching method in the course under discussion was based on ICT use. While many researchers (Dori & Belcher, 2005; Park, Khan, & Petrina, 2009) claim that using ICT in STEM subjects might promote learners' conceptual understanding, others (Chiu, Chen, & Linn, 2013; Jimoyiannis, 2010) point to difficulties in learning with ICT and criticize the ICT's techno-centric and tokenistic use in science and technology.

During the course, the pre-service teachers used the ICT resource in two forms, as detailed below.

Using simulations for conceptual understanding

The pre-service teachers were engaged in class activities supported by simulation-based inquiry. For example, changing variable values, observing effects to form scientific conclusions and answering open-ended questions. In interviews with 12 students (Section 4.7) that took place towards the end of the course, a vast majority of the participants valued the contribution of simulations to learning about SWCS, although few pre-service teachers commented that using simulation distanced learners from real science. Findings from the Motivation Questionnaire that students answered pre and post the course also indicated an increase in learners' desire to learn with ICT. These results could be related to using interactive simulations (Hoffler & Leutner, 2007; Mayer, Heiser, & Lonn, 2001), adding verbal explanations to simulations (Kaberman & Dori, 2009; Najjar, 1998), and using the simulation in conjunction with the study of basic knowledge.

Using interactive open-ended sound software

A unique aspect of utilizing ICT in the current study relates to the use of the professional Audacity software (https://sourceforge.net/projects/audacity/) for sound editing and analysis. The pre-service teachers recorded and analyzed their voice and other sounds in the surrounding area. Actually, the prospective teachers were able to see, hear and handle different sounds. This open-ended sound program, in comparison to structured software, enabled a human-computer interaction with physical-sensory intervention, and connected the learners to their environment. Nowadays, in an era of mixed-reality technology, physical interactions are used to control digital environments. Many researchers (De Jong, Linn, & Zacharia, 2013; Liu, 2006) claim that combining physical and virtual labs helps students gain a better understanding of certain science topics compared to either virtual or physical labs alone. Barak and Ziv (2013) assert that many free programs might be used to enhance exploratory learning and student-centered learning.

Preparing Mini-Projects

Because of time and laboratory limitations, the learners' final task was reduced to preparing a mini-project that bore the central principles of PBL. Special emphasis was placed on examining the pre-service teachers' capability in tackling new advanced subjects autonomously, and specifically, the skills of integrating STEM and using ICT meaningfully. The students prepared mini-projects on subjects such as human hearing, sonar technology, electromagnetic waves and noise pollution.

Despite the wide consensus in the literature about the advantages of PBL over traditional schooling, educators are increasingly aware of the difficulties and limitations of applying these methods in the regular school context. The literature presents several key features needed for the implementation of an effective project-enhanced environment. For example, Dolmans et al. (2005) and Polman (2000) posit that in order to stimulate students towards constructive and contextual learning, realistic, open-ended or ill-structured problems must fit with students' prior knowledge. These authors also write that PBL curricula should consist more of tutor guidance at the beginning through shared guidance of both the students and the tutor, and move to more student guidance at the end. Kirschner et al. (2006) argue that 'minimal guidance' during discovery, problem- or project-based teaching may impose excessive demands on limited cognitive resources. Mayer (2004) also indicated that instruction using minimal guidance might not enhance learning because students do not receive support in selecting relevant information from the learning environment.

The findings of the present study revealed that few learners showed high proficiency in investigating their topics and developed their learning skills, which is in line with the findings of Barak and Dori (2005). In addition, the findings revealed initial indicators regarding learners' endeavors to combine scientific and technological aspects of the subjects investigated as expressed in the real world. However, this integration was not deep enough. More than half of the pre-service teachers found the task too challenging and completed it only partially. The majority of participants also had difficulties in applying meaningful use of ICT for presenting the new topic. Interestingly, while the learners enjoyed working with structured ICT class activities during the course sessions, they did not develop their skills to detect and use new ICT resources by themselves.

Overall, the students' relatively limited achievements in incorporating the projects could be interpreted by: (a) a lack of students' basic knowledge on complex topics, for example, students who tackled the "electromagnetic waves" subject required a broader knowledge base, beyond what they had learned in the course; (b) a lack of sufficient time – the class time for working on the project (last three sessions) was not enough for the pupil-teacher interaction and guiding process; and (c) focusing only on the project's theoretical aspects without any reference to practical work aspects.

CONCLUSIONS

The current study describes the development, implementation and evaluation of an innovative curriculum for teaching sound, waves and communication systems in a rich ICT-based environment to prospective science teachers. The study aimed at examining the pre-service teachers' successes and difficulties in learning the program. It also aimed at examining how the program affected the pre-service teachers' achievements and motivation in terms of interest and self-efficacy, and at exploring the major factors behind this.

The research findings confirmed the necessity to design the courses around main concepts or themes to emphasize the realistic and authentic context of the contents, and to provide richly connected ideas and learning experiences. In this regard, the SWCS course might serve as a model for developing courses to promote STEM learning in teacher education programs.

Notably, the instructional method played a crucial role in achieving the study goals. Effective use of integrating simulation and programs for sound editing and analysis, real (hands-on) experiments, and theoretical/traditional teacher teaching might assist learners' conceptual learning on the physics of sound waves and contribute to their success and motivation.

However, the project-based learning was utilized only partially. The main factors of students' difficulties stem from a lack of exposure to PBL during previous studies and from dealing with complicated subjects with a limited prior background knowledge. To assist in the realization of the PBL potential, it is recommended to adopt gradual learning processes; learners should start with practice (basic exercise) and move to open-ended small-scale tasks before they deal with ill-structured or complex projects.

ACKNOWLEDGEMENTS

I deeply acknowledge the EURASIA Journal of Mathematics, Science and Technology Education and its staff for their support and generosity. This article was published with the financial support of the EURASIA Journal of Mathematics, Science and Technology Education for doctoral students.

REFERENCES

Arbaugh, J. B. (2000). Virtual classroom characteristics and student satisfaction with internet-based MBA courses. *Journal of Management Education, 24*(1), 32-54. https://doi.org/10.1177/105256290002400104

Assor, A., Kaplan, H., & Roth, G. (2002). Choice is good, but relevance is excellent: autonomy-enhancing and suppressing teacher behaviors predicting students' engagement in schoolwork. *British Journal of Educational Psychology, 72*(2), 261-278. https://doi.org/10.1348/000709902158883

Augustine, N. R. (2005). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, DC: National Academy Press.

Australian Council of State School Organizations (ACSSO) (2010). *Australian Education Digest, STEM Education Special*. Retrieved from http://www.acsso.org.au/AED100923.pdf

Bandura, A. (1997). *Self-efficacy: the Exercise of Control*. New York, W. H. Freeman and Company.

Barak, M. (2013). Teaching engineering and technology: cognitive, knowledge and problem-solving taxonomies. *Journal of Engineering, Design and Technology, 11*(3), 316-333. https://doi.org/10.1108/JEDT-04-2012-0020

Barak, M. (2014). Closing the gap between attitudes and perceptions about ICT-enhanced learning among pre-service STEM teachers. *Journal of Science Education and Technology, 23*(1), 1-14. https://doi.org/10.1007/s10956-013-9446-8

Barak, M., & Dori, Y. J. (2005). Enhancing undergraduate students' chemistry understanding through project-based learning in an IT environment. *Science Education, 89*(1), 117-139. https://doi.org/10.1002/sce.20027

Barak, M., & Ziv, S. (2013). Wandering: a web-based platform for the creation of location-based interactive learning objects. *Computers & Education, 62*(2), 159-170. https://doi.org/10.1016/j.compedu.2012.10.015

Barak, M., Nissim, Y., & Ben-Zvi, D. (2011). Aptness between teaching roles and teaching strategies in ICT-integrated science lessons. *Interdisciplinary Journal of E-Learning and Learning Objects, 7*, 305-322. https://doi.org/10.28945/1526

Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: lessons from research on problem-and project-based learning. *Journal of the Learning Sciences, 7*(3-4), 271-311. https://doi.org/10.1080/10508406.1998.9672056

Basturk, R. (2008). Applying the many-faceted Rasch model to evaluate PowerPoint presentation performance in higher education. *Assessment & Evaluation in Higher Education, 33*(4), 431-444. https://doi.org/10.1080/02602930701562775

Becker, K. H., & Park, K. (2011). Integrative approaches among science, technology, engineering and mathematics (STEM) subjects on students' learning: a meta-analysis. *Journal of STEM Education: Innovations and Research, 12*(5/6), 23-37.

Bell, R. L., Maeng, J. L., & Binns, I. C. (2013). Learning in context: technology integration in a teacher preparation program informed by situated learning theory. *Journal of Research in Science Teaching, 50*(3), 348-379. https://doi.org/10.1002/tea.21075

Bergman, D. J., & Morphew, J. (2015). Effects of a science content course on elementary pre-service teachers' self-efficacy of teaching science. *Journal of College Science Teaching, 44*(3), 73-81. https://doi.org/10.2505/4/jcst15_044_03_73

Bilgin, I., Karakuyu, Y., & Ay, Y. (2015). The Effects of Project Based Learning on Undergraduate Students' Achievement and Self-Efficacy Beliefs towards Science Teaching. *Eurasia Journal of Mathematics, Science & Technology Education, 11*(3), 469-477. https://doi.org/10.12973/eurasia.2014.1015a

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M. & Palincsar, A. (1991). Motivating project-based learning: sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398. https://doi.org/10.1080/00461520.1991.9653139

Brown, J. L., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42. https://doi.org/10.3102/0013189X018001032

Bruner, J. (1996). *The Culture of Education*. Cambridge, MA: Harvard University Press.

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. Arlington, VA: National Science Teachers Association.

Caleon, I., & Subramaniam, R. (2010). Development and application of a three-tier diagnostic test to assess secondary students' understanding of waves. *International Journal of Science Education, 32*(7), 939-961. https://doi.org/10.1080/09500690902890130

Capraro, R. M., Capraro, M. M., & Morgan, J. R. (2013). *STEM Project-based Learning*. Rotterdam: Sense Publishers. https://doi.org/10.1007/978-94-6209-143-6

Chai, C. S., Koh, E., Lim, C. P., & Tsai, C.-C. (2014). Deepening ICT integration through multilevel design of technological pedagogical content knowledge. *Journal of Computers in Education, 1*(1), 1-17. https://doi.org/10.1007/s40692-014-0002-1

Chang, H. P., Chen, J. Y., Guo, C. J., Chen, C. C., Chang, C. Y., Lin, S. H., … Tseng, Y. T. (2007). Investigating primary and secondary students' learning of physics concepts in Taiwan. *International Journal of Science Education, 29*(4), 465-482. https://doi.org/10.1080/09500690601073210

Chen, F., Gorbunova, N. V., Masalimova, A. R., & Birova, J. (2017). Formation of ICT-competence of future university school teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(8), 4765-4777.

Chiu, J. L., Chen, J. K., & Linn, M. C. (2013). Overcoming deceptive clarity by encouraging metacognition in the web-based inquiry science environment. In R. Azevedo & V. A. Aleven (Eds.), *International handbook of metacognition and learning technologies* (pp. 517-531), Springer, New York. https://doi.org/10.1007/978-1-4419-5546-3_33

Creswell, J. W., & Plano, C. V. L. (2007). *Designing and Conducting Mixed Methods Research*. Thousand Oaks, California: SAGE Publications.

Crismond, D. P. (2011). Scaffolding strategies for integrating engineering design and scientific inquiry in project-based learning environments. In M. Barak & M. Hacker (Eds.) (pp. 235-255). *Fostering Human Development through Engineering and Technology Education*, Rotterdam: Sense Publishers. https://doi.org/10.1007/978-94-6091-549-9_13

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*(6130), 305-308. https://doi.org/10.1126/science.1230579

Deemer, S. (2004). Classroom goal orientation in high school classrooms: revealing links between teacher beliefs and classroom environments. *Educational Research, 46*(1), 73-90. https://doi.org/10.1080/0013188042000178836

Dolmans, D. M., de Grave, W., Wolfhagen, I. P., & van der Vleuten, C. M. (2005). Problem-based learning: future challenges for educational practice and research. *Medical Education, 39*(7), 732-741. https://doi.org/10.1111/j.1365-2929.2005.02205.x

Dori, Y. J., & Belcher, J. (2005). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *Journal of the Learning Sciences, 14*(2), 243-279. https://doi.org/10.1207/s15327809jls1402_3

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. Washington, DC: National Academies Press.

Eshach, H. & Schwartz, J. L. (2006). Sound stuff? Naïve materialism in middle-school students' conceptions of sound. *International Journal of Science Education, 28*(7), 733-764. https://doi.org/10.1080/09500690500277938

Field, M., Lee, R., & Field, M. L. (1994). Assessing interdisciplinary learning. *New Directions for Teaching and Learning, 1994*(58), 69-84. https://doi.org/10.1002/tl.37219945806

Fore, G. A., Feldhaus, C. R., Sorge, B. H., Agarwal, M., & Varahramyan, K. (2015). Learning at the nano-level: accounting for complexity in the internalization of secondary STEM teacher professional development. *Teaching and Teacher Education, 51*, 101-112. https://doi.org/10.1016/j.tate.2015.06.008

Fortus, D., & Vedder-Weiss, D. (2014). Measuring students' continuing motivation for science learning. *Journal of Research in Science Teaching, 51*(4), 497-522. https://doi.org/10.1002/tea.21136

Frykholm, J., & Glasson, G. (2005). Connecting science and mathematics instruction: pedagogical context knowledge for teachers. *School Science and Mathematics, 105*(3), 127-141. https://doi.org/10.1111/j.1949-8594.2005.tb18047.x

Gero, A. (2016). Development of interdisciplinary lessons integrating science and engineering in heterogeneous teams: education students' attitudes. *IJEP, 6*(2), 59-64. https://doi.org/10.3991/ijep.v6i2.5683

Greene, J. C. (2005). The generative potential of mixed methods inquiry. *International Journal of Research & Method in Education, 28*(2), 207-211. https://doi.org/10.1080/01406720500256293

Hechter, R. P. (2011). Changes in pre-service elementary teachers' personal science teaching efficacy and science teaching outcome expectancies: the influence of context. *Journal of Science Teacher Education, 22*(2), 187-202. https://doi.org/10.1007/s10972-010-9199-7

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: a response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99-107. https://doi.org/10.1080/00461520701263368

Hoffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: a meta-analysis. *Learning and Instruction, 17*(6), 722-738. https://doi.org/10.1016/j.learninstruc.2007.09.013

Holsti, O. R. (1969). *Content Analysis for the Social Sciences and Humanities*. Reading, Mass: Addison-Wesley Pub. Co.

Hossain, M. M., & Robinson, M. G. (2012). *How to Motivate US Students to Pursue STEM (Science, Technology, Engineering and Mathematics) Careers*. Online submission. Retrieved from http://eric.ed.gov/?id=ED533548

Jaakkola, T., Nurmi, S., & Veermans, K. (2011). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. *Journal of Research in Science Teaching, 48*(1), 71-93. https://doi.org/10.1002/tea.20386

Jimoyiannis, A. (2010). Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers' professional development. *Computer Education, 55*(3), 1259-1269. https://doi.org/10.1016/j.compedu.2010.05.022

Joo, Y. J., Bong, M., & Choi, H. J. (2000). Self-efficacy for self-regulated learning, academic self-efficacy, and Internet self-efficacy in web-based instruction. *Educational Technology Research and Development, 48*(2), 5-17. https://doi.org/10.1007/BF02313398

Kaberman, Z., & Dori, Y. J. (2009). Metacognition in chemical education: question posing in the case-based computerized learning environment. *Instructional Science, 37*(5), 403-436. https://doi.org/10.1007/s11251-008-9054-9

Katehi, L., Pearson, G., Feder, M. A., Committee on K-12 Engineering Education. National Academy of Engineering & National Research Council (U.S.). (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. National Academies Press, Washington DC.

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

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching? *Educational Psychologist, 41*(2), 75-86. https://doi.org/10.1207/s15326985ep4102_1

Lattuca, L. R., Voight, L. J., & Fath, K. Q. (2004). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *The Review of Higher Education, 28*(1), 23-48. https://doi.org/10.1353/rhe.2004.0028

Linder, C. J. (1993). University physics students' conceptualizations of factors affecting the speed of sound propagation. *International Journal of Science Education, 15*(6), 655-662. https://doi.org/10.1080/0950069930150603

Liu, X. (2006). Effects of combined hands-on laboratory and computer modeling on student learning of gas laws: a quasi-experimental study. *Journal of Science Education and Technology, 15*(1), 89-100. https://doi.org/10.1007/s10956-006-0359-7

Llinares, S., & Krainer, K. (2006). Mathematics (student) teachers and teacher educators as learners. In A. Gutierrez & P. Boero (Eds.), *Handbook of Research on the Psychology of Mathematics Education*, Rotterdam, The Netherlands: Sense

Mayer, R. E. (2004). Should there be a three – strikes rule against pure discovery learning? *American Psychologist, 59*(1), 14-19. https://doi.org/10.1037/0003-066X.59.1.14

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: when presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187. https://doi.org/10.1037/0022-0663.93.1.187

McDonnough, J. T., & Matkins, J. J. (2010). The role of field experience in elementary preservice teachers' self-efficacy and ability to connect research to practice. *School Science and Mathematics, 110*(1), 13-23. https://doi.org/10.1111/j.1949-8594.2009.00003.x

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*. London: Sage.

Morrison, J. A., Raab, F., & Ingram, D. (2008). Factors influencing elementary and secondary teachers' views on the nature of science. *Journal of Research in Science Teaching, 46*(4), 384-403. https://doi.org/10.1002/tea.20252

Nadelson, L., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: inquiry-based STEM professional development for elementary teachers. *Journal of Educational Research, 106*(2), 157-168. https://doi.org/10.1080/00220671.2012.667014

Najjar, L. J. (1998). Principles of educational multimedia user interface design. *Human Factors, 41*(2), 311-323. https://doi.org/10.1518/001872098779480505

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

National Science Foundation. (2007). *A National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering, and Mathematics Education System*. Retrieved from http://www.nsf.gov/nsb/edu_com/draft_stem_ report.pdf

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: developing a technology pedagogical content knowledge. *Teaching and Teacher Education, 21*(5), 509-523. https://doi.org/10.1016/j.tate.2005.03.006

Olympiou, G., & Zacharia, Z.C. (2012). Blending physical and virtual manipulatives: an effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education, 96*(1), 21-47. https://doi.org/10.1002/sce.20463

Osborne, J., & Hennessy, S. (2003). *Literature Review in Science Education and the Role of ICT: Promise, Problems and Future Directions*. Bristol: Future lab.

Park, H. R., Khan, S., & Petrina, S. (2009). ICT in science education: a quasi-experimental study of achievement, attitudes toward science, and career aspirations of Korean junior high school students. *International Journal of Science Education, 31*(8), 993-1012. https://doi.org/10.1080/09500690701787891

Pejuan, A., Bohigas, X., Jae□n, X., & Periago, C. (2012). Misconceptions about sound among engineering students. *Journal of Science Education and Technology, 21*(6), 669-685. https://doi.org/10.1007/s10956-011-9356-6

Polman, J. L. (2000). *Designing Project-Based Science: Connecting Learners through Guided Inquiry*. New York, NY: Teachers College Press.

Punch, K., & Oancea, A. (2014). *Introduction to Research Methods in Education*. Thousand Oaks, California: SAGE Publications.

Rogers, L., & Twidle, J. (2013). A pedagogical framework for developing innovative science teachers with ICT. *Research in Science & Technological Education, 31*(3), 227-251. https://doi.org/10.1080/02635143.2013.833900

Satchwell, R. E., & Loepp, F. L. (2002). Designing and implementing an integrated mathematics, science, and technology curriculum for the middle school. *Journal of Industrial Teacher Education, 39*(3), 41-66.

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. https://doi.org/10.1007/s10956-015-9594-0

Sherman, A., & MacDonald, L. (2007). Preservice teachers' experiences with a science education module. *Journal of Science Teacher Education, 18*(4), 525-541. https://doi.org/10.1007/s10972-007-9049-4

Skryabin, M., Zhang, J., Liu, L., & Zhang, D. (2015). How the ICT development level and usage influence student achievement in reading, mathematics, and science? *Computers & Education, 85*, 49-58. https://doi.org/10.1016/j.compedu.2015.02.004

Smeets, E. (2005). Does ICT contribute to powerful learning environments in primary education? *Computers & Education, 44*(3), 343-355. https://doi.org/10.1016/j.compedu.2004.04.003

Sozen, M., & Bolat, M. (2011). Determining the misconceptions of primary school students related to sound transmission through drawing. *Procedia - Social and Behavioral Sciences, 15*(5), 1060-1066. https://doi.org/10.1016/j.sbspro.2011.03.239

Teo, T., & Ke, K. (2014). Challenges in STEM teaching: implication for preservice and in-service teacher education program. *Theory into Practice, 53*(1), 18-24. https://doi.org/10.1080/00405841.2014.862116

Thomas, J. W. (2000). *A Review of Research on Project-Based Learning*. San Rafael, CA: Autodesk Foundation.

Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2009). Developing, evaluating and demonstrating the use of a conceptual survey in mechanical waves. *International Journal of Science Education, 31*(18), 2437-2457. https://doi.org/10.1080/09500690802389605

Tsai, C. C. (2006). Reinterpreting and reconstructing science: teachers' view changes toward the nature of science by courses of science education. *Teaching and Teacher Education, 22*(3), 363-375. https://doi.org/10.1016/j.tate.2004.06.010

Tsai, H.-Y., Chung, C.-C., & Lou, S.-J. (2017). Construction and Development of iSTEM Learning Model. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(1), 15-32. https://doi.org/10.12973/ejmste/78019

Vandervelde, J. (2006). *A+ PowerPoint Rubric*. Retrieved on 6 September 2005 from http://www.uwstout.edu /soe/profdev/pptrubric.html

Vasquez, J. A., Sneider, C. I., & Comer, M. W. (2013). *STEM Lesson Essentials, Grades 3-8: Integrating Science, Technology, Engineering, and Mathematics*. Portsmouth, NH: Heinemann.

Wittmann, C. M. (2003). Understanding and affecting student reasoning about sound waves. *International Journal of Science Education, 25*(8), 991-1013. https://doi.org/10.1080/09500690305024

http://www.ejmste.com