Creative Education, 2014, 5, 1959-1968
Published Online December 2014 in SciRes. http://www.scirp.org/journal/ce
http://dx.doi.org/10.4236/ce.2014.523220

Sound, Waves and Communication: Students' Achievements and Motivation in Learning a STEM-Oriented Program

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Received 5 October 2014; revised 30 October 2014; accepted 10 November 2014

Abstract

In this article, we present the case of developing an interdisciplinary curriculum for learning science and technology, its implementation in junior high schools and evaluation of students' achievements and attitude. The 30-hour course (15 two-hour sessions) includes subjects such as sound and waves, conversion of sound to electrical signal, amplification, sampling, and analog to digital conversion. Beyond teachers' short presentations, the students are engaged in problem solving and project-based learning, with strong emphasis on using information and computer technologies (ICT) tools such as simulation and sound editing software. One could see that the course design was guided by the following principles: contextual learning, integrated learning of science, technology and computer sciences; extensive use of information and computer technologies (ICT); and combining teacher's instruction with project based learning. The research aimed at exploring students' achievements and motivation to learn science, technology and computers. The participants in the pilot study were 40 junior high-school students in 7th grade (age 13). In the near future, the course will be updated and run once again among junior high school students and student teachers in a regional college. Data collection tools include: achievement tests, attitude questionnaires, interviews with teachers and students, and analysis of the students' assignments and projects. The findings indicate that the students manage to handle the subject fairly well and have good achievements in the final exam. The learners also succeeded in developing final projects in sound and communication systems, "The human ear" and "Bluetooth", and presented their projects to the parents.

Keywords

STEM, Interdisciplinary, ICT

How to cite this paper: Awad, N., & Barak, M. (2014). Sound, Waves and Communication: Students' Achievements and Motivation in Learning a STEM-Oriented Program. *Creative Education*, *5*, 1959-1968.
http://dx.doi.org/10.4236/ce.2014.523220

1. Introduction

Educators agree that one of the keys in fostering learning in school is linking subject matter and instructional methodology with students' real-life situations, experiences and interests (Dewey, 1963; Bruner, 1996). Technology offers powerful tools for the realization of these instructional concepts by means of simulating real-life situations or connecting classroom context to the outside world such as the community, business or practitioners in science and technology (Bransford, Brown, & Cocking, 2000).

Today's youth are living in a digital culture, making extensive use of advanced technological devices such as laptops and cell-phones in daily life. These technologies are all based on scientific, technological and mathematical knowledge. However, science and technology instruction in school is still mainly supported by laboratory experiments and the passive transfer of information from teacher to student. A viable and necessary change is that education should be connected directly to the real world outside the school (Roberson, 2011). For science and technology education to be successful, elements of the culture affecting students must be carefully considered and integrated into the curriculum.

Realization of these principles, with a strong emphasis on using information and computer technologies (ICT) tools such as simulation and sound-editing software may allow the establishment of an advanced scientific-technological environment having the potential to combine science, technology, mathematics and engineering, and linking them to the real world outside the school.

The current study presents a research focused on the development, implementation and evaluation of a science, technology, engineering, mathematics (STEM)-oriented curriculum for interdisciplinary learning in science and technology in an online environment. From the perspective of technology education, the students are engaged in constructing and testing technological artifacts, and learn technological concepts such converting sound to electrical signals, amplification, data sampling, analog-to-digital conversion and communication systems. Learning these subjects has to do with understanding central concepts in technology and engineering, for example system thinking and modeling. For example, in the "Concepts and Context in Engineering and Technology" (CCETE) study conducted by Hacker, de Vries, & Rossouw (2010), an international panel of experts identified the following three (out of 10) main concepts for engineering and technology education: 1) design (as a verb); 2) systems; and 3) modeling. Therefore, this case could be a good example of teaching technology under the wide umbrella of STEM or science and technology education.

2. Conceptual Framework for Teaching "Sound, Waves and Communication" Concepts

The conceptual framework for the proposed schooling consists of four main ingredients: contextual learning, interdisciplinary learning, project-based learning and technology-supported learning, as illustrated in **Figure 1** and discussed in the following sections.

2.1. Contextual Learning

The term contextual learning has to do with learning that relates to a learner's diverse life contexts such as at home, during leisure time, social or environmental activities, or in the students, having opportunities to make meaning of their disciplinary knowledge and solve problems within a real world context (Karweit, 1993). For the student to be able to develop the required elements in problem-solving process: procedural fluency, conceptual understanding, strategic competence, adaptive reasoning and productive disposition (Schunn & Silk, 2011), he must be involved in well-designed problems.

2.2. Interdisciplinary Learning

Interdisciplinary learning is about providing students with opportunities and space for learning beyond subject boundaries and making connections between different areas of learning (Rowntree, 1982).

STEM—science, technology, engineering and mathematics

The term STEM (science, technology, engineering and mathematics) has caught the attention of educational research as a framework for fostering science and technological literacy learning in schools. STEM recognizes the importance of science and mathematics, and places special emphasis on technology and engineering as fields that affect our lives, and is especially important to society interested in constant renewal (Bybee, 2010).

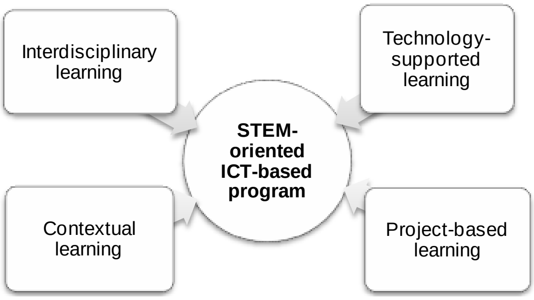


Figure 1. Major principles of the learning environment examined.

Katehi, Pearson and Fidir (2009) argue that technology and engineering should be given their appropriate places in school's programs in order to ensure interest and creativity.

2.3. Project-Based Learning

Educators are increasingly recognizing that project-based learning (PBL) is considered a natural framework for the implementation of constructivist learning, and a good platform for fostering the student's cognitive skills. The application of PBL in science and technology aims at placing the learner in an active role where he investigates or solves a major real life problem that is driven by a research question and consists of a number of tasks (Savery, 2006; Barak & Shachar, 2008).

2.4. Technology-Supported Learning

Technology can help in the scientific learning process because of its potential to support activities such as data collection, visualization, meaningful thinking, problem solving and reflection. Special emphasis was placed on using simulation and animation, which has emerged as one of the most popular instructional tools for delivering quality instruction. The use of realistic simulation often requires students to apply newly acquired skills while motivating them toward advanced learning (Hsu & Thomas, 2002; Lewis, Stern, & Linn, 1993; Moreno & Mayer, 2007; Weller, 2004).

3. The Sound Waves and Communication Systems Course

The course is designed for junior high school students and consists of three phases as described in **Figure 2**.

Following are examples of material taken from the basic level: **Figure 3** is an animation showing that sound is cyclical fluctuations of particles; **Figure 4** shows a chart of a sound system; **Figure 5** describes the major phases of the analog-to-digital conversion process; and **Figure 6** illustrates a simulation carried out for sampling a signal where students can control the sampling frequency and watch the signal obtained.

3.1. Instruction Method

1) *Teacher's presentation and demonstrations*

At the beginning of each lesson, the teacher presented basic principles of theoretical material to the students for 20 - 30 minutes using rich presentations with animations. Moreover, he introduced his students to different electronic systems such as radio and bell entrance (**Figure 7(a)**).

2) *Student's experimentation by simulations and interface with the computers*

Following the teacher's short presentation, the students were engaged in problem-solving tasks, with strong emphasis on using information and computer technologies (ICT) tools such as simulation and sound-editing software. At the end of the lesson, the students sent their answers to the teacher. Aside from the computer activities, the students learned scientific concepts in experiential ways. For example, in order to learn the frequency concept, the students produced different voices trying to demonstrate a high tone and a low tone. They played musical instruments such as a flute, drum and xylophone, and entered websites, connected headphones, controlled the frequency of the signal and heard how the sound changed (**Figure 7(b)**).

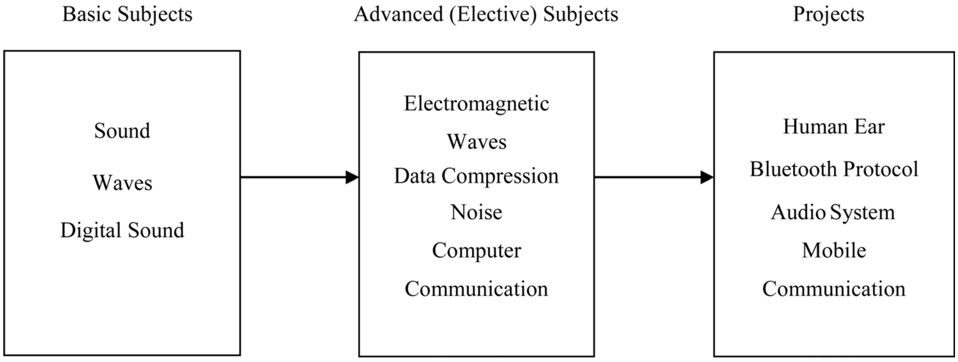


Figure 2. The course design.

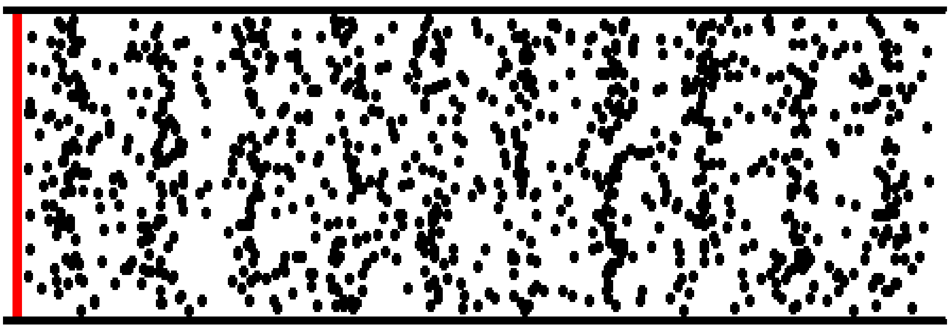


Figure 3. Sound as a movement of particles.

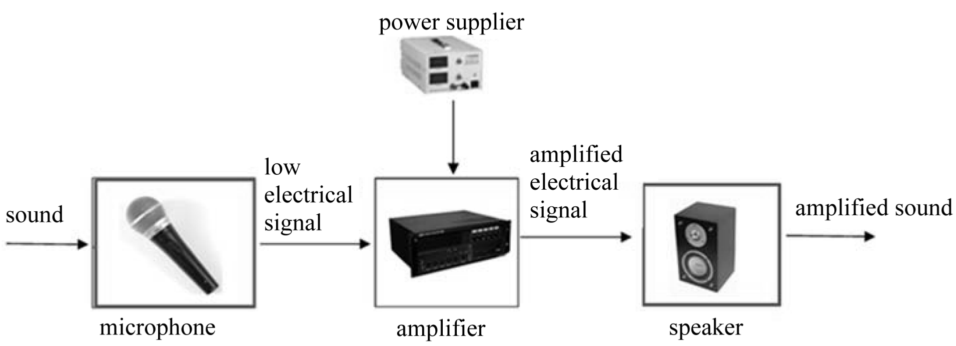


Figure 4. Sound amplification system.

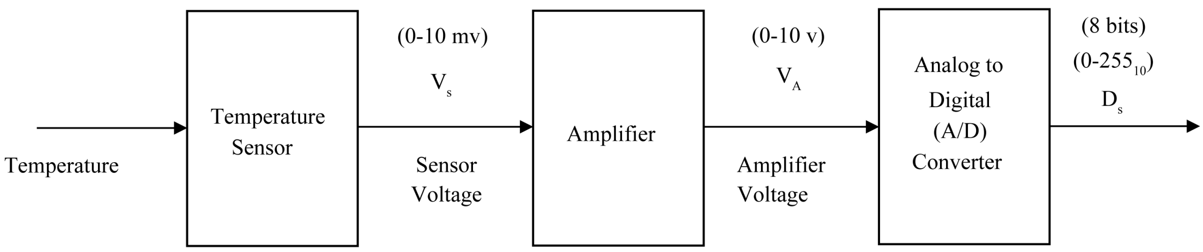


Figure 5. Sampling and analog-to-digital conversion process.

3) *Artifacts construction*

Some lessons were devoted to experiential learning during which students were engaged in creating accessible products. For example, students of one group built a model of a simple speaker from basic components. A second group built a simple radio using an electronics kit (**Figure 7(c)**).

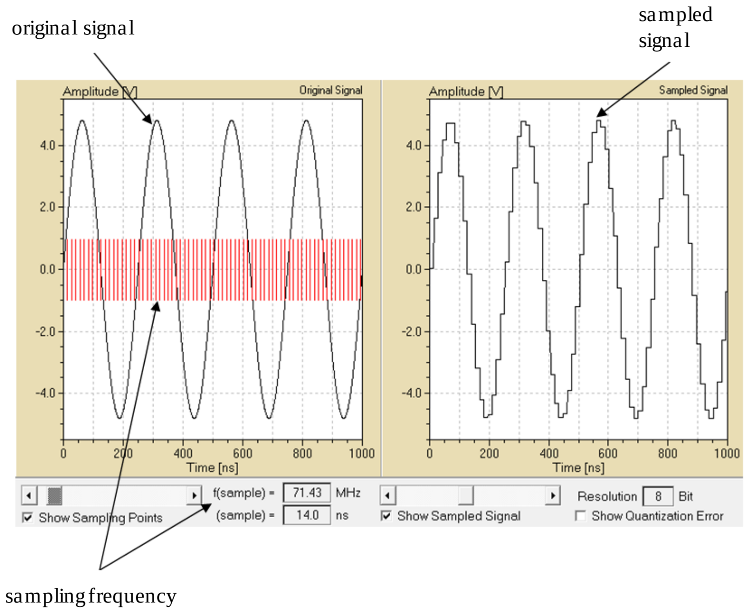
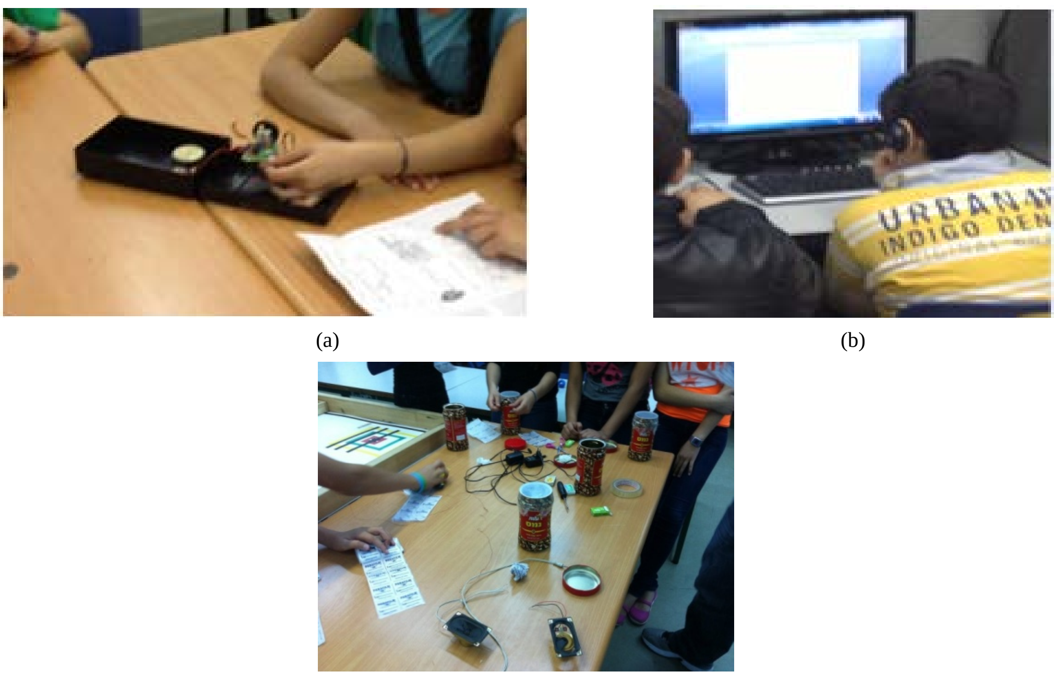


Figure 6. Simulation of sampling a sound signal.



(a) (b)

(c)

Figure 7. Examples of classroom activities for students. (a) Examining an electronic system; (b) Listening to sounds on a computer; (c) Building a speaker.

3.2. Project

In the second part of the course, the students were engaged in project-based learning on topics that interested them, such as "digital music", "mobile communications", and "the human ear and hearing". Students were guided in searching information and data from various sources to understand their subject matter in depth. Their task was to prepare 8 - 10 pages including the following chapters: introduction, body—a description of three to four main points, results and conclusions, sources, and personal reflection. At the end of the course, the students presented their projects to their class and during parents' day.

4. The Research

4.1. Research Questions

The current research, which aimed at exploring students' achievements and motivation to learn science, technology and computers, was guided by the following questions:

To what extent can junior high school students learn an advanced scientific-technological subject such as sound, waves and communication systems? What factors contribute to or hinder their success in learning the subject? What is the impact of studying the subject on students' in relation to:

a) Motivation and interest in learning science and technology.

b) Self-efficacy perception of studying scientific-technological subjects.

c) Desire to learn in an online environment.

4.2. Participants and Setting

The study took place in a regional enrichment educational center, and the students came from four different cities in northern Israel. The participants comprised two separate groups of 20 students each (7th grade, age 13 - 14) for a total of 40. Each group studied for two periods a week over 15 weeks.

4.3. Data Collection

The study adopted a mixed method, combining quantitative and qualitative methods, aimed at shedding light on as many aspects as possible of students' activities in the class, their achievements and their attitudes toward the course. The quantitative tools included a closed-ended attitude questionnaire and an achievement exam; the qualitative tools were an open-ended questionnaire, observations, interviews and analysis of the students' work. More specifically, the data collection included:

- Documenting students' activities in the class. The researcher attended the course and documented comments about the students' motivation and success in performing the class activities, the students' statements and special events.
- Analyzing the outcomes of a 90-minute exam that students answered at the end of the course.
- Administering a semi-structured attitude questionnaire distributed to all students before and after the course.
- Conducting 10 interviews with groups of 2 - 3 students at the end of the lessons.
- Interviewing six parents on parents' day at the end of the course.
- Analyzing class activities and final projects that the students had submitted.

5. Findings

5.1. Students' Achievements in Learning Scientific-Technological Subjects

We used a 1 - 1.5 hour exam to assess the knowledge acquired by the students. The final version of the exam was validated by science and technology teachers having extensive experience who are studying for an MA degree in science and technology education at Ben-Gurion University of the Negev.

The exam consisted of one question about declarative knowledge, two questions about procedural knowledge and two questions about conceptual knowledge. Below are examples of exam questions about each knowledge type:

- Regarding declarative knowledge, the students were asked about facts such as the speed of sound in air, human hearing range, etc.
- Regarding procedural knowledge, the students were required, for example, to calculate the velocity of the wave (using the formula $v = \lambda * f$).
- **Figure 8** shows an exam question of conceptual knowledge where VA represents the input signal to the amplifier while VB represents the output signal. The students were asked to identify the amplifier's amplification, draw a graph that describes the relationship between VA and VB, and calculate the overall amplification of two amplifiers connected in series.

The teacher and the researcher checked four exams together and concluded how to evaluate the rest. After

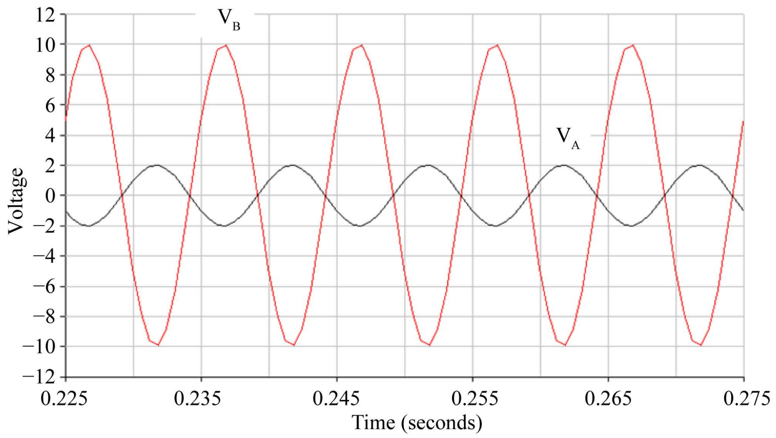


Figure 8. An exam question requiring conceptual knowledge.

checking the exams separately, they decided each student's score together. The average total score (on a scale of 0 - 100) was 82 (n = 36, SD = 12.7). The highest score was 100 and the lowest was 60. More specifically, the average score for the declarative knowledge questions was 80 (SD = 22.17), for the procedural knowledge questions 85 (SD = 36.2) and for the conceptual knowledge questions 80 (SD = 29.18). These outcomes reflect the fact that science and technology teachers often emphasize learning procedural knowledge. The findings show that students were more capable of dealing with questions based on procedural knowledge such as calculating physical quantities using formulas. Moreover, the good achievements of the students regarding questions based on conceptual knowledge show that they acquired significant knowledge on scientific-technological topics studied in the course.

5.2. Findings from the Students' Questionnaires

One objective of the sound, waves and communication systems course was to bring students closer to the world of science and technology, and foster their interest in this field. To explore students' viewpoints in this regard, a structured questionnaire was administrated in the classes before and after the course. The questionnaire included 12 items spread over three categories:

1) Motivation and interest in learning science and technology. For example, I am interested in studying science subjects.

2) Desire to learn in an online environment. For example, I look for information on the Internet in my free time.

3) Self-efficacy beliefs about learning new topics. For example, I can study alone and learn more about science.

The students marked their answers on a Likert scale (1 = very low; 2 = low; 3 = high; 4 = very high). Half of the items in the questionnaire appeared in a negative form, for example, "It is difficult to learn new scientific subjects alone," to avoid bias in the outcomes because of individuals' tendencies to answer questions positively. Answers to "negative" items were converted into a positive scale in the data analysis. The questionnaire also included an open-ended section: several empty lines were left next to each item in which the students were asked to explain or give examples of their answers in their own words. Most of the students wrote relevant things, and the researchers learned additional valuable information about the students' viewpoints in the questions discussed. In addition, the students' authentic answers indicated whether they had answered the closed-ended questions carefully. Twenty-nine students answered the questionnaire before the course, and 31 students answered it after the course.

To check the reliability of the questionnaire findings in terms of internal consistency, Cronbach's alpha test was performed. The results were 0.67 for motivation and interest in learning science and technology, 0.53 for the desire to learn in an online environment, and 0.58 for self-efficacy beliefs about learning new topics. The findings of the three categories of the questionnaire before and after the course are presented in **Figure 9**.

The average score of students' answers to the questionnaire after the course was slightly higher than that before the course in all three categories, although these differences are not statistically significant. A possible

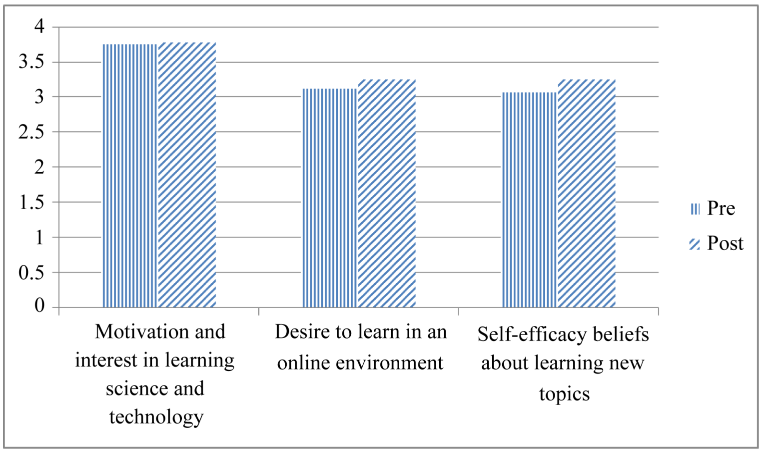


Figure 9. Average scores of students' answers to the attitude questionnaire. Scale: 1 = very low; 2 = low; 3 = high; 4 = very high.

explanation for these results is that the students were interested and motivated to learn new subjects before they learned the course under discussion.

5.3. Findings from the Students' Final Projects

As previously mentioned, project-based learning may contribute to fostering learning skills among students. However, the implementation of this method in school is not easy and requires considerable effort from both the teachers and the students (Barak & Shachar, 2008). In this study, the students prepared projects on subjects in the field of sound, waves and communication systems during the final four weeks of the course. The students worked in pairs and chose topics that interested them as shown in **Figure 10**.

For their projects, the students were required to prepare a presentation or a website of 8 - 10 pages including the following chapters: introduction, body, results and conclusions, sources, and personal reflection. The students received an explanation and a detailed document about the structure and scope of each chapter from their teacher.

Figure 11 presents partial content of projects developed by two students on "Bluetooth communications". The students explained how two devices using Bluetooth can create a network that prevents the penetration of other devices into the network by randomly changing the frequency 1600 times.

In the students' reflections regarding the project development process, many expressed their satisfaction and interest in learning new subjects. Some noted difficulties they had encountered and methods of overcoming them.

Using technology as tool for learning

As the students worked on their projects, they invested serious efforts in seeking new sources, making an appropriate use of keywords in the search for and utilization of web-based information. They downloaded digital books on issues relevant to their subject matter and used diverse computer software (such as MS Paint, Word, PowerPoint, Screen Capture and Audacity) to prepare and present their projects. Five students managed to learn Google sites platform by themselves and presented their project through a website that they developed.

5.4. Findings from Observations in the Class and Interviews with Students and Parents

The researcher attended nearly all of the class lessons in both study groups and prepared a detailed diary of special events, activities and responses of the students. Ten interviews with groups of 2 - 3 students were carried out after class lessons throughout the course. The interviews were recorded, transcribed and analyzed. Because of the limited scope of this article, we present below only a few examples from these findings.

The researcher asked the students questions such as: "What is the difference between learning in the course and learning in school in general?" Students answered:

"It is different from the school class... There we learn only theoretical things throughout most of the year."

"Here we learn about practical communication… In school, we only learn words."

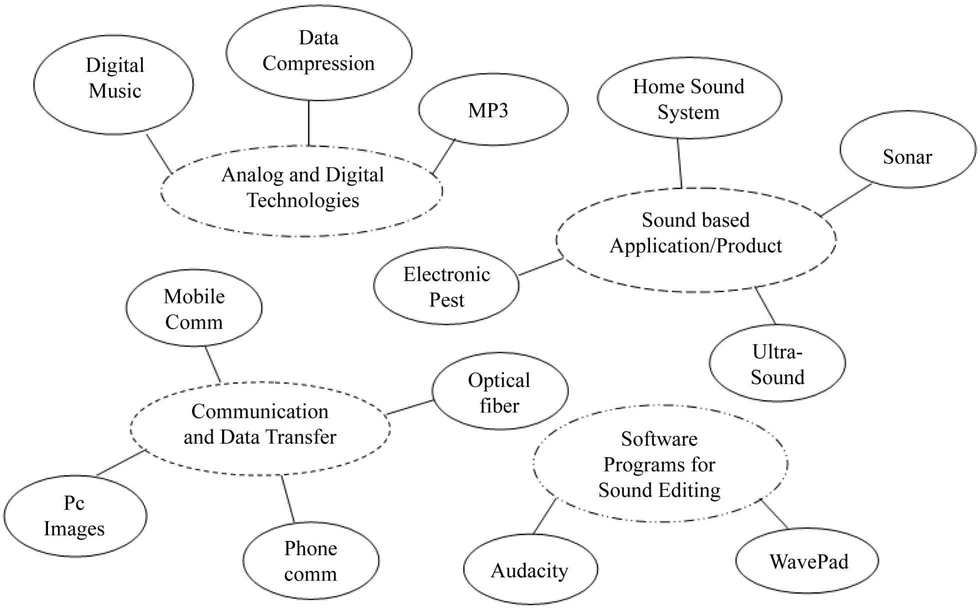


Figure 10. Examples of projects that students chose.

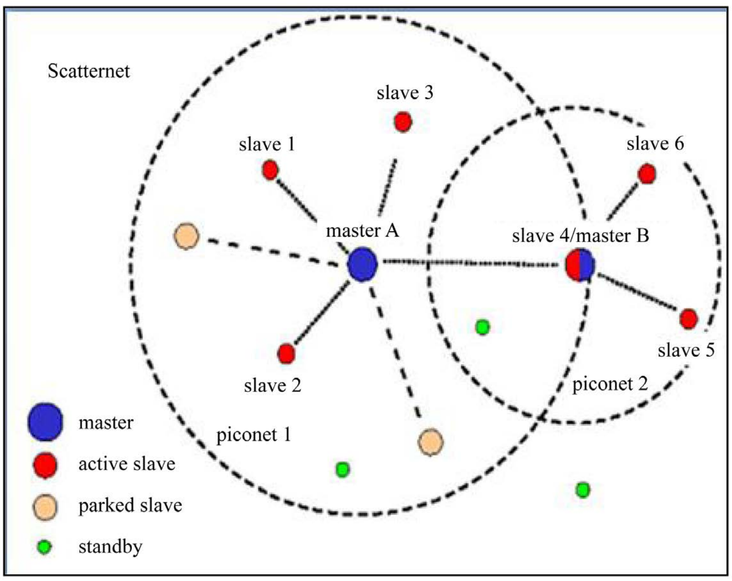


Figure 11. A slide from a project about Bluetooth communications.

Other students declared that working on a real product helped them understand the major role that theoretical subjects play in practical reality. For instance:

"To make the speaker work, we tried magnets of different sizes with various coils of the copper wires."

"The beauty is that I can see immediately if things work or not."

6. Conclusion

The findings of this study indicate that students at this age can deal successfully with learning a relatively complex and interdisciplinary subject that spreads over a number of areas in science and technology. According to the students' perspective, it is not essential to define whether a subject belongs to physics, electronics, computer science or mathematics. The main factors that contributed to learning were the combination of the teacher's explanations (traditional teaching), students' learning in a rich technological environment, and the projects they prepared. Choosing topics related to the students' world such as sound amplification systems and digital sound was a key factor in creating motivation in learning the theory and preparing the final projects. Using computers and ICT technologies, not only for teaching the subject but also for documenting the learning process and presenting the project to class members and parents, contributed greatly to students' motivation throughout the course.

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