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Problem Based Learning and Students' Motivation: The Case of an Electronics Laboratory Course*

BETO CATZ[1], NISSIM SABAG[2] and AHARON GERO[1]
[1] Department of Education in Technology and Science, Technion—Israel Institute of Technology, Haifa 32000, Israel.
E-mail: betoc@campus.technion.ac.il, gero@technion.ac.il
[2] Department of Electrical and Electronic Engineering, ORT Braude College, Karmiel 216100, Israel. E-mail: nsabag@braude.ac.il

Problem based learning is a student-centered pedagogy that often develops some of the skills required of engineering graduates, and an inquiry based laboratory might be an appropriate platform for its implementation. The study described in this paper focused on an inquiry based electronics laboratory offered to junior electrical engineering students at a leading college in Israel. It is the first course where students are exposed to problem based learning and experience how engineers work. In light of the course's unique characteristics, the study examined whether a change in the students' academic motivation has occurred as a result of the course. Fourteen electrical engineering students participated in the study which utilized quantitative and qualitative tools. The study found a decrease (small effect) in the students' relative autonomy index, which had been caused mainly by a decrease in their intrinsic motivation and an increase in their external regulation. This change could be explained by the findings, according to which, the students' need for competence was not met during the course. Possible causes for this lack of fulfillment are the difficulties experienced by most students to adjust to independent learning and to cope with the complexity of the problems studied on the course. Such difficulties are known in the literature as associated with problem based learning, and the paper offers various ways to overcome them.

Keywords: problem based learning; inquiry based laboratory; motivation; electronics laboratory courses

1. Introduction

Recently, studies indicate a gap between the skills of engineering graduates and those needed in the industry [1–3]. Therefore, the Accreditation Board for Engineering and Technology has determined that graduates of engineering programs need to possess applicable knowledge, technical skills and soft skills. Technical skills include, inter alia, the ability to identify, formulate and solve engineering problems, whereas soft skills refer, among other things, to the ability to function on teams and to communicate effectively [4].

Problem based learning (PBL) is a student-centered pedagogy that often develops the above skills [5–7], and an inquiry based laboratory (IBL) might be an appropriate platform for its implementation [8, 9]. However, research covering the use of IBLs in engineering education is very limited and focuses mainly on cognitive aspects [8, 10]. The affective domain which deals with academic motivation has not been a research focal point, although the importance of motivation in the learning process is considerable [11, 12], especially in the aspects of academic achievement [13, 14] and students' drop-out [15].

The study described in this paper focused on an inquiry based electronics laboratory offered at a leading Israeli college. This course is designed for electrical engineering students in their fifth semester, and is the first course where students are exposed to PBL and experience how engineers work. In light of the course's unique characteristics, the study examined whether a change in the students' academic motivation has occurred as a result of the course. The research findings and conclusions may expand the relatively meager body of knowledge covering the use of IBLs in engineering education [8, 10] and improve the training of engineering students.

The paper begins with an overview of the topics forming the study's theoretical foundation: PBL and IBLs, and motivation to study. Later, the inquiry based electronics laboratory course, the research goal and the methodology are described. After presenting and discussing the main findings, the conclusions are provided.

2. Theoretical background

2.1 Problem based learning and inquiry based laboratories

PBL is a learner-centered pedagogy in which students perform research combining theory and practice in order to find a solution to a given problem [16]. The main characteristics of this approach are [17]:

- Students are expected to solve a problem presented to them by the teacher. The problem should be complex and open ended but should also be realistic and suitable to the students' capability.

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- The problem is solved by a team, so that every student can independently study a specific aspect of the problem and contribute to its solution.
- The teacher's role is to serve as a facilitator assisting the students. The guidance provided is graduated, so that the support is more significant at the beginning and is reduced over time.
- The process ends in the students' reflection, which permits the construction of the knowledge.

The main goals of PBL cover several areas. From the cognitive and metacognitive aspect, PBL has the purpose of developing higher order thinking skills among the students, including the ability to study independently [2]. From the affective point of view, PBL intends to cultivate motivation to study [18], and in the social domain—to develop teamwork skills [6, 18].

The successful implementation of PBL involves a considerable number of challenges, for the student as well as the teacher. Thus, for example, the student is expected to cope with complex problems (such as engineering design problems) [19, 20] and become adjusted to independent learning, although he/she is generally not accustomed to doing these [21]. Additionally, the student is required to deal with the ambiguity and uncertainty that characterize this type of learning [22] and become adjusted to his/her role as a team member [23]. Finally, PBL requires students to dedicate a considerable amount of time compared to what is required of them in traditional learning [24]. As to the teacher, PBL requires him/her to abandon the instrumental approach [25] and adopt different guidance methods, such as the one based on scaffoldings [17]. Like the student, the teacher is also required to dedicate a considerable amount of time compared to traditional teaching methods [23]. It should be noted that successfully dealing with these challenges often leads to the achievement of the educational objectives specified above [17].

One possible platform for the implementation of PBL is the IBL. In IBLs, students independently design and conduct experiments to answer questions [9]. Therefore, the IBL is profoundly different from the traditional laboratory where students follow the instructions of the experiment brief, mostly to confirm predetermined results [26]. In IBLs, students experience, inter alia, problem solving, learning from mistakes and teamwork [7], and develop higher order thinking skills [9].

In spite of the potential that lies in the use of IBLs in engineering education, research in this area has been very limited, focusing mainly on the cognitive domain [7, 9]. Thus, for example, electrical and computer engineering students attending an IBL on signal processing reported improvement in their understanding and ability to design frequency filters [27]. Similarly, biomedical engineering students participating in an IBL attained significantly higher grades than their peers experiencing traditional learning [28]. It should be emphasized that these studies did not cover any affective aspects, such as motivation.

2.2 Motivation and self-determination theory

The term motivation relates to a person's desire to dedicate time and effort to a particular behavior, even when this involves difficulties or failures. Self-determination theory [29] is a prominent representative of the humanistic approach of motivational research. This approach, which also includes Maslow's hierarchy of needs [30], emphasizes the importance of human needs to the attainment of high quality motivation. Self-determination theory identifies three basic needs in the individual [31]: the need for autonomy—the need to feel that the behavior was not forced on the individual; the need for competence—the need to feel that the individual is capable of attaining challenging objectives; and the need for relatedness—the individual's need to be in contact with others and be part of a group. Satisfying these needs brings the individual to a high level of autonomous motivation permitting self-actualization.

In addition to identifying these needs, the theory describes the factors driving the individual across a continuum spanning between perceived autonomy at one end, characterized by a high degree of autonomous motivation, and perceived control (coercion) at the other end, characterized by a low degree of autonomous motivation [32]. The main motivational factors across this spectrum are described below in an increasing order of perceived control (and decreasing order of perceived autonomy). Intrinsic motivation stemming from interest and enjoyment derived by the individual from the behavior is the motivational factor with the lowest degree of perceived control and lies at one end of the continuum. Thus, for example, a student studying engineering because of his/her interest in studying the subject is a student driven by intrinsic motivation. The next factor is identified regulation which has as its source the identification of the importance of the behavior to the individual's values or goals. For example, a student who sees the importance of studying engineering because by that he/she can acquire a profession which is in high demand is a student driven by identified regulation. Introjected regulation is the next motivational factor on the continuum and represents the desire to attain appreciation from others for the behavior, or alternatively, the desire to avoid the feelings of guilt caused by the lack of such behavior. A characteristic example would be a student studying engineering in order to please his/her parents. The motivational factor characterized by the highest degree of perceived control is external regulation. This factor reflects the individual's desire to be compensated for the activity, or alternatively, his/her fear of punishment for not performing it. An example would be a student studying engineering in the fear that if he/she does not do so, he/she will be enlisted to the military. Self-determination theory views the last three factors as extrinsic motivation. However, identified regulation is perceived as relatively autonomous [33]. It should be noted that in addition to intrinsic motivation and extrinsic motivation (which includes a number of classes of regulation, as covered above), self-determination theory also defines a state of amotivation where the individual lacks any desire to act [29].

The relative autonomy index (RAI) is a customarily used instrument permitting the individual's autonomous motivation to be estimated [34, 35]. The index is obtained through a linear combination of the different motivational factors with appropriate weights:

$$RAI = 3S_{Intrinsic} + S_{Identified} - S_{Introjected} - 3S_{External} \quad (1)$$

In definition (1), S_i is the score of motivational factor i as measured by an appropriate research tool. It can be seen that the index assigns higher weight in absolute terms to a particular factor when it is closer to one of the poles of the continuum. Additionally, the motivational factors characterized by relatively high perceived autonomy are assigned positive weight, whereas the ones characterized by relatively high perceived control are assigned negative weight.

It should be noted that self-determination theory is one of the leading motivational theories today, and has served as the theoretical framework for many studies in engineering education, both in high school [36, 37] and in higher education [38–40]. Therefore, it served as the theoretical framework for this study.

3. Inquiry based electronics laboratory

The inquiry based electronics laboratory course is a mandatory course for undergraduate electrical engineering students (fifth semester) at a leading Israeli college. The course lasts fourteen weeks (four hours per week) and provides two credit points. The course focuses on three areas: digital systems, analog electronics, and digital electronics. The subjects taught in each area are listed in Appendix A. The prerequisites for the course are courses in digital systems and analog electronics and a traditional laboratory course in electricity and analog electronics, where the students experience teamwork for the first time. Concurrently to studying the inquiry based electronics laboratory course, the students take a course in digital electronics.

At the end of the inquiry based electronics laboratory course, the student should be able to:

- Formulate an open-ended problem as engineering specifications.
- Design an electronic circuit that meets the specifications.
- Implement the circuit.
- Design and conduct experiments to test the circuit.
- Report in writing about the experiments, results and conclusions.

During the course the students engage in problem solving in teams of two-four students supervised by a teacher. The teacher is an electrical engineer with over thirty years of experience in the industry. Additionally, the teacher has academic training in education, including PBL. As customary in PBL, the instructor assists the students with questions and by providing feedback and guidance, which is more significant at the beginning and is reduced over time [17]. Additionally, at the beginning of the course the teacher explains how to formulate specifications and presents the structure of the final report.

On the course, the teams deal with two problems of increasing difficulty, with seven weeks dedicated to each problem. Each problem is complex and open ended but is also realistic and suitable to the students' capabilities, as required of problems of this sort [17]. The problems were written by the teacher and validated by two experts in electrical engineering education. The problems are given in Appendix B. For each problem, the teams perform the steps described in Table 1.

The equipment available to the teams consists of components (logic gates, counters, multiplexers, flip-flops, operational amplifiers, timers, and A/D and D/A converters) and measuring equipment (a

Table 1. Inquiry based electronics laboratory course—main activities

Week	Activities
1	Formulating the open-ended problem as engineering specifications
2–3	Designing an electronic circuit that meets the specifications and performing a simulation
4	Implementing the circuit
5–6	Designing and conducting experiments to test the circuit
7	Writing the final report

power supply, a function generator, an oscilloscope, and a multimeter). The team submits a final report after each problem is solved. The report contains a description of the problem and selected solution, the experiments conducted, an analysis of the results, and conclusions. Additionally, it contains personal reflection by each team member.

4. Research goal

The study focused on academic motivation in students attending an inquiry based electronics laboratory. The following research question was formulated: Has a change occurred in students' motivation to study electrical engineering as a result of the course?

5. Methodology

5.1 Participants

The participants were fourteen electrical engineering students in their fifth semester. These students attended the inquiry based electronics laboratory course described above, and had given their consent to participate in the study. The students' age range was 20–30. The students had prior experience in teamwork on a single traditional laboratory course but had no experience in PBL. The participants were representative of the junior electrical engineering students that normally take the course.

5.2 Procedure

The study utilized quantitative tools alongside qualitative ones, for the purpose of presenting different aspects of the phenomenon being studied and increasing the findings' trustworthiness [41]. At the beginning and end of the course, the students filled out an anonymous closed-ended questionnaire used for evaluating their academic motivation. At the end of the course, the students completed an anonymous open-ended questionnaire, and five semi-structured interviews were conducted with students. The open-ended questionnaire and interview focused on the degree to which the students' basic needs had been met on the course. The interviews were recorded and transcribed in full.

The quantitative data were statistically analyzed and the effect sizes (Cohen's *d*) were calculated. As the questionnaires were anonymous, the correlation between the motivational factor scores at the beginning of the course and the ones at the end could not be calculated. Therefore, the effect sizes provided a conservative estimation [42].

The qualitative data were coded by two independent experts and categorized through directed content analysis [43], based on self-determination theory and the challenges of PBL mentioned in the literature. Only information showing up at least three times via the different research instruments was included in this analysis.

5.3 Tools

The questionnaire used for evaluating the motivational factors driving the students to study electrical engineering was a five level Likert-like questionnaire, ranging between "highly agree" to "highly disagree". The questionnaire was based on the Self-Regulation Questionnaire—Academic (SRQ-A) scale [34]. It contained twenty statements reflecting the four motivational factors mentioned in Section 2.2. Thus, for example, the statement "I am studying electrical engineering because I think the studies are interesting" expresses intrinsic motivation; the statement "I am studying electrical engineering because I think working in electrical engineering would be a good job for me" reflects identified regulation; the statement "I am studying electrical engineering because my parents want me to do so" reflects introjected regulation; and the statement "I am studying electrical engineering because I do not have a choice" represents external regulation. The statements were validated by two engineering education experts. Cronbach's alphas (0.78-0.86) indicate good internal consistency. A sample of the statements is provided in Appendix C. Samples of the open-ended questions and the interview questions are provided in Appendices D and E, respectively.

6. Findings

Table 2 presents the relative autonomy index (mean *M* ranging between –16 and +16 and standard deviation *SD*) calculated based on the answers to the closed-ended questionnaire at the beginning of the course (pretest) and at its end (posttest). It can be concluded that at the beginning as well as the end the index was a little below the third quartile, and that a decrease has occurred accompanied by a small effect size.

In order to understand the factors leading to the decrease in the relative autonomy index, Fig. 1 presents the mean score (between 1 and 5) for each of the four motivational factors at the beginning and end of the course. It can be seen that both at the beginning and the end, the intrinsic motivation score was the highest of all motivational factors, the identified regulation score was in second place,

Table 2. Relative autonomy index (beginning and end of course)

Test	*M*	*SD*	*d*
Pretest	7.39	3.16	–0.22
Posttest	6.67	3.28	

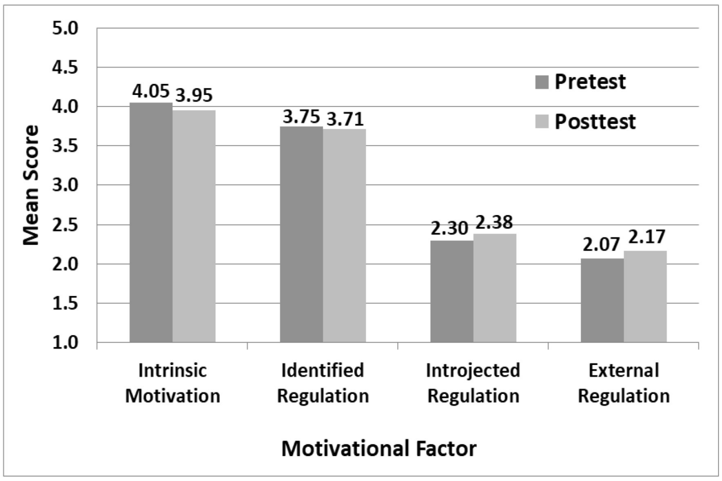

Fig. 1. Mean motivational factor scores (beginning and end of course).

close to the first place, the introjected regulation score was in third place, close to the last place, and the external regulation score was the lowest. It is evident that a decrease has occurred in the factors characterized by relatively high perceived autonomy (intrinsic motivation and identified regulation) alongside an increase in the factors characterized by relatively high perceived control (external regulation and introjected regulation).

Table 3 shows the score for the different motivational factors and the corresponding effect sizes. It can be seen that the changes in intrinsic motivation and external regulation were small while the changes in the other factors were very small.

A content analysis of the data collected at the end of the course (Table 4) shows that most of the students' need for relatedness was satisfied on the course, but the need for competence was not met. It seems like the need for competence was not met due to difficulties in adjusting to independent learning and in coping with the complexity of the materials being learned, as described in Table 5.

Table 3. Motivational factor scores and effect sizes (beginning and end of course)

Motivation	Regulation	Test	*M*	*SD*	*d*
Intrinsic		Pretest Posttest	4.05 3.95	0.50 0.45	–0.21
Extrinsic	Identified	Pretest Posttest	3.75 3.71	0.60 0.53	–0.07
	Introjected	Pretest Posttest	2.30 2.38	0.96 0.78	0.09
	External	Pretest Posttest	2.07 2.17	0.67 0.68	0.15

Table 4. Partial fulfillment of needs (end of course)

Need	Frequency (%)	Examples	Interpretation
Competence	64	"The lesson was very difficult mentally. We saw that the circuit was working correctly in the simulation, but during our entire lab period we were trying to understand why the wired circuit was not working and were unable to identify the problem." (questionnaire) "It is difficult when something we have worked on does not work out. We unsuccessfully tried to find the problem and I actually gave up." (questionnaire)	The need for competence was not fulfilled on the course
Relatedness	57	"In my opinion, we are a good team. Although we argue a lot, we can reach an agreement . . . All in all, I'm very happy with the team." (questionnaire) "The opportunity to work with people that you normally do not communicate with daily and to achieve good collaboration, as occurring on the course, is incredibly beneficial." (questionnaire)	The need for relatedness was fulfilled on the course

Table 5. Difficulties associated with problem based learning

Difficulty	Frequency (%)	Examples	Interpretation
Difficulty to adjust to independent learning	50	"It is possible that the approach of 'throwing a child into the water so he/she can learn to swim' works, but in my opinion, it is not the right thing to do where learning is concerned. . . I personally expect to be provided with a detailed explanation in class and assistance while working." (questionnaire) "I think that at the beginning [of the course] the [instructor's] presence should be more dominant... At the beginning we were lost and did not know what to do." (interview)	Students find it difficult to adjust to independent learning
Difficulty to cope with the complexity of the problems being studied	42	"The course was difficult because it was the first time we were given complex problems." (questionnaire)	Students find it difficult to cope with complex problems to which they are not accustomed

7. Discussion

Based on the quantitative findings, both at the beginning and the end of the course the intrinsic motivation score was the highest of all motivational factors, the identified regulation score was in second place, close to the first place, the introjected regulation score was in third place, close to the last place, and the external regulation score was the lowest. The distribution of motivational factor scores obtained in this study is similar to the distribution among sophomore electrical engineering students at a research university [44, 45].

The study found that a decrease in the students' relative autonomy index had occurred on the course, accompanied by a small effect size. This change was caused by a decrease (small effect) in the factors characterized by relatively high perceived autonomy (intrinsic motivation and identified regulation) alongside an increase (small effect) in the factors characterized by relatively high perceived control (external regulation and introjected regulation). In light of self-determination theory [29, 31], the change could be explained by the qualitative findings, according to which, the students' need for competence was not met on the course, while their need for relatedness was satisfied. The failure to fulfill one basic need on one hand, but the satisfaction of another basic need on the other, have probably led to a small decrease in the students' relative autonomy.

The findings indicate two possible causes for the failure to fulfill the students' need for competence. The first cause is the students' difficulty to adjust to independent learning, and the second is their difficulty to cope with complex problems to which they were not accustomed. These difficulties are known in the literature as associated with PBL [19–21]. Thus, for example, electrical engineering students experiencing PBL for the first time felt uneasy about the considerable independence and demanded further support from the teaching faculty [46]. Similarly, mechanical engineering students found it difficult to perform a complex design task characterized by ambiguity [47].

The fulfillment of the students' need for relatedness on this study could possibly be assigned to the students being accustomed to teamwork as a result of the traditional laboratory course in which they had participated prior to the current course. Based on the literature, lack of former experience in teamwork often leads to difficulties among students experiencing PBL [23].

In view of the failure to meet the students' need for competence, it is recommended to take actions to try to fulfill it. Thus, for example, independent learning periods should be integrated into earlier stages of engineering programs [46], and students should be exposed to problems that are challenging, but not too complex [45]. Another suggestion is to lengthen the inquiry based electronics laboratory course (into an annual course) in order to allow the students to become adjusted to independent learning [48]. Alternatively, it is proposed to have the course focus on one problem rather than two. These actions are necessary in light of the importance of high autonomous motivation in programs developing higher order thinking skills, such as engineering programs [49].

The study has two major limitations: a relatively small number of participants and a lack of a control group. The first limitation was mainly caused by the laboratory size and the number of students that can safely be taught. Additionally, the number of electrical engineering students who were in their fifth semester (during which the study was conducted) was small. Therefore, it was impossible to form a control group of a reasonable size. In order to overcome these limitations and increase the findings' trustworthiness, qualitative instruments were used alongside quantitative ones [41].

The study's theoretical contribution is in characterizing the change occurring in the motivation to study electrical engineering in students attending an inquiry based electronics laboratory. To our knowledge, this characterization was done here for the first time. The study's practical contribution may be reflected in the implementation of its findings to reinforcing the autonomous motivation of students on this type of courses. Such contributions are validated by the potential use of IBLs in engineering education [8, 9] and by the limited body of knowledge on the subject [10].

8. Conclusions

The study described in this paper focused on academic motivation in students attending an inquiry based electronics laboratory. The study, which utilized quantitative and qualitative tools, found a decrease (small effect) in the students' relative autonomy index during the course. This change was the result of a decrease (small effect) in the motivational factors characterized by relatively high perceived autonomy (intrinsic motivation and identified regulation) alongside an increase (small effect) in the factors characterized by relatively high perceived control (external regulation and introjected regulation). The change could be explained by the findings, according to which, the students' need for competence was not met during the course, whereas the need for relatedness was fulfilled. A possible cause for the failure to fulfill the need for competence is the difficulty experienced by most students to adjust to independent learning and deal with the complexity of the problems studied on the course. The fulfillment of the need for relatedness could possibly be assigned to the students being accustomed to teamwork after attending a traditional laboratory course prior to the current course.

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Appendix A: Inquiry based electronics laboratory course—main topics

Following are the subjects that were the focus of the inquiry based electronics laboratory course described in Section 3.

A1. Digital systems

- Combinational logic: logic gates, counters, multiplexers
- Sequential logic: flip-flops, Moore machine, Mealy machine

A2. Analog electronics

- Differential amplifiers
- Operational amplifiers

A3. Digital electronics

- A/D converters
- D/A converters
- Function generators

Appendix B: Inquiry based electronics laboratory course—inquiry problems

Following are the two problems presented to the teams on the inquiry based electronics laboratory course. The problems were mentioned in Section 3.

B1. Problem I

The management of a bank wants to prevent the possibility to break into a safe at a certain branch. The security officer determined that in order to open the safe, five employees would be required to type a personal code consisting of four binary digits. Three of the employees work at the bank's main headquarters and two at the particular branch. Entering the personal codes will be done according to a predetermined order for each day, in two rounds, so that each employee would be required to type his/her code twice. Design and implement a system that meets the above requirements.

B2. Problem II

A packing house sorts peaches for export. The export standards are as follows: the fruit's diameter must be 4–6 cm and its weight 80-90 grams. Sorting is currently performed manually, and the packing house is interested in mechanizing the process. In the mechanized process, the fruit will travel on a conveyor belt with two analog weight sensors and one digital diameter sensor installed along it. The weight sensors provide voltage output proportional to the weight. The first sensor provides voltage output proportional to the weight of the fruit with its attached spray, and the second sensor provides voltage output proportional to the weight of the spray after its separation from the fruit. The diameter sensor provides a binary combination representing the fruit's diameter. If the fruit does not meet the export criteria, an arm driven by a motor is activated and removes the fruit from the conveyor belt. Design and implement a system that meets the above requirements.

Appendix C: Closed-ended questionnaire

The closed-ended questionnaire used for evaluating the motivational factors driving the students to study electrical engineering (Section 5.3) was a five level Likert-like questionnaire based on the Self-Regulation Questionnaire – Academic (SRQ-A) scale [34]. The questionnaire contained twenty statements. Following is a sample of the statements. Statements 1 and 8 reflect intrinsic motivation, statements 3 and 6 express identified regulation, statements 2, 4, 5 represent introjected regulation, and statement 7 expresses external regulation.

1. I am studying electrical engineering because I think the studies are enjoyable.
2. I am studying electrical engineering because I want people to think I am smart.
3. I am studying electrical engineering because I think working in electrical engineering would be a good job for me.
4. I am studying electrical engineering because my parents want me to do so.
5. I am studying electrical engineering because my friends are studying electrical engineering.
6. I am studying electrical engineering because it will benefit me in the future.
7. I am studying electrical engineering because I do not have a choice.
8. I am studying electrical engineering because I think the studies are interesting.

Appendix D: Open-ended questionnaire

Following is a sample of the questions asked on the open-ended questionnaire mentioned in Section 5.3:

1. What is your opinion of the course?
2. Describe your teamwork during the course.
3. What was the most interesting lesson on the course? Explain.
4. Did you feel you were able to express your abilities on the course? Explain.
5. What, in your opinion, is the teacher's contribution to studying on the course? Explain.

Appendix E: Interview

Following is a sample of the questions asked on the interview mentioned in Section 5.3:

1. Describe the learning atmosphere on the course.
2. What was the most interesting lesson on the course? Explain your answer.
3. What is your opinion about the level of difficulty on the course? Were you able to cope with it? How?
4. What, in your opinion, is the teacher's contribution to studying on the course? Explain.
5. What, in your opinion, is the best thing about the course?
6. What, in your opinion, is the worst thing about the course?

Beto Catz holds a BSc in Electrical Engineering and a BSc in Technology and Science Education (Summa Cum Laude), both from the Technion—Israel Institute of Technology. In addition, he has an MBA (Cum Laude) from the University of Derby, UK. Mr. Catz has many years of experience in electronics design and has served in technological and management positions in leading companies. He is an adjunct lecturer in the Department of Electrical and Electronic Engineering at Ort Braude College (Israel) and serves as the coordinator for the promotion of PBL programs at the College's Teaching and Learning Center. Currently, Mr. Catz is a graduate student in the Department of Education in Technology and Science at the Technion.

Nissim Sabag is a Senior Lecturer and the Head of the Department of Electrical and Electronic Engineering at ORT Braude College, Israel. He has served as the Chair of the Collegial Committee of Academic Affairs and as the Head of Academic Administration. Dr. Sabag holds a BSc in Electrical Engineering and BSc, MSc, and PhD in Technology and Science Education from the Technion—Israel Institute of Technology. His research focuses on engineering education. Dr. Sabag has published over 45 papers in refereed journals and international conference proceedings (as coauthor). Between 2004 and 2016, Dr. Sabag received fourteen prizes for being an outstanding member of the academic staff.

Aharon Gero holds a BA in Physics (Summa Cum Laude), a BSc in Electrical Engineering (Cum Laude), an MSc in Electrical Engineering, and a PhD in Theoretical Physics, all from the Technion—Israel Institute of Technology. In addition, he has an MBA (Cum Laude) from the University of Haifa, Israel. Dr. Gero is an Assistant Professor in the Department of Education in Technology and Science at the Technion, where he heads the Electrical Engineering Education Research Group. Before joining the Technion, he was an instructor at the Israeli Air-Force Flight Academy. Dr. Gero's research focuses on electrical engineering education and interdisciplinary education that combines physics with electronics, at both the high school and higher education levels. Dr. Gero has received the Israeli Air-Force Flight Academy Award for Outstanding Instructor two times and the Technion's Award for Excellence in Teaching eleven times. In 2006 he received the Israeli Air-Force Commander's Award for Excellence, and in 2016 was awarded the Yanai Prize for Excellence in Academic Education.