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Project-based learning in international teams composed of excelling high-school and first-year engineering students: high-school students' perspective

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ABSTRACT: Studies indicate a considerable gap between the skills of engineering graduates and those required in the industry, especially regarding soft skills. As a partial solution, a unique educational programme focusing on project-based learning in international teams (iPBL) was recently developed. These teams consist of excelling high-school students majoring in science and engineering (Israel) and first-year engineering students (Yale University, USA). The project deals with design and manufacturing iterations for potential products and takes place over five days at the Yale Centre for Engineering Innovation and Design in the USA. The study described in this article aimed to characterise iPBL from the high-school students' perspective. In-depth interviews were conducted with high-school students who attended the programme. Content analysis identified different components in students' attitudes. From the cognitive aspect, students claim that iPBL develops soft skills, as well as technical skills that are not taught in Israel. However, at the same time, they report difficulties in teamwork stemming from the heterogeneity of the team. Affectively, students think that iPBL is interesting and enjoyable, mainly due to the exposure to different cultures and different ways of thinking. From the behavioural viewpoint, students strongly recommend their peers to participate in similar programmes.

Keywords: Project-based learning, international teams, high-school students, engineering students

INTRODUCTION

Along with the ongoing lack of engineers in many parts of the world [1], studies indicate a considerable gap between the capabilities of engineering graduates and those required in the industry [2]. Therefore, the Accreditation Board for Engineering and Technology (ABET) has published the skills required of engineering graduates. These abilities encompass both technical skills, e.g. carrying out engineering design, and soft skills, such as effective communication and teamwork [3]. According to the literature, the abovementioned gap is particularly noticeable when it comes to soft skills [4], which are recommended to be cultivated in early stages, namely, high school [5].

Project-based learning, i.e. learning in a team setting where students are involved in executing a project under guidance [6], often develops technical and soft skills [7]. Moreover, project-based learning carried out in international teams (iPBL) better prepares students for the global labour market, which is characterised by heterogeneous teamwork [8]. At the same time, project-based learning involves challenges, both for the student and the instructor [9], and these challenges are amplified in the case of international teams [10].

In light of the above, a unique educational programme that focuses on iPBL was recently developed. In this case, the teams consist of 11th-12th grade high-school students from Israel and first-year engineering students from Yale University, USA. The high-school students are excelling students who intend to study engineering in academia. These students major in Robophysics - an interdisciplinary approach to studying mathematics, physics and engineering based on robotics and other advanced technologies. This approach puts an emphasis on physical modelling of artefacts [11]. It is important to note that both the high-school and the first-year engineering students had previous experience in project-based learning in homogeneous teams. The project at the centre of the programme deals with design and manufacturing iterations for potential products and takes place over five days at the Yale Centre for Engineering Innovation and Design (CEID), USA.

The aim of the study described in this article was to characterise iPBL from the high-school students' perspective. The research findings make a contribution to the body of knowledge dealing with iPBL and may improve the training of high-school and engineering students.

The article opens with a concise review of project-based learning in general and of iPBL in particular. Then, the educational programme is presented. Next, the research goal and methodology are described. Finally, the main findings are discussed and solutions suggested to overcome the identified challenges.

PROJECT-BASED LEARNING

As mentioned, project-based learning is active learning in a team setting, where students are involved in carrying out a project under the guidance of an instructor [6]. As part of this learning, the students experience problem solving, decision making and design. Students are given the opportunity to work relatively independently over extended periods of time, and the learning ends in building a product that may be tangible or virtual [12]. Project-based learning may be limited to a designated course (e.g. sophomore projects or capstone projects) [13][14] or may take place throughout the entire engineering programme [15].

The theoretical basis of project-based learning is in the constructivist approach, according to which the individual builds his/her knowledge through processes of assimilation and accommodation [16]. Later, project-based learning was influenced by social constructivism, emphasising the construction of knowledge in a social environment [17]. Finally, according to constructionism, effective learning occurs when the individual builds a product that can be shared with others [18].

In the cognitive aspect, project-based learning generally improves students' thinking skills, including systems thinking [13]. In the affective domain, this type of learning often increases students' intrinsic motivation [19][20]. In the social realm, project-based learning usually develops soft skills, such as effective written and oral communication, and teamwork [7]. However, from the student's point of view, this learning takes place in a complex environment characterised by ambiguity, uncertainty and time pressure [21]. Moreover, the student is required to adapt to independent learning that demands many resources [22]. Finally, the student is exposed to teamwork that requires interpersonal communication and negotiation skills, which the student, for the most part, is not skilled in [23].

As for the instructor, project-based learning is often enjoyable and interesting and allows him/her to become a constant learner, since he/she is exposed to new ideas. However, alongside these advantages, this type of learning poses considerable challenges to the facilitator, such as time management and difficulties in instruction and assessment [19][24].

When project-based learning occurs in international teams, the difficulties may be exacerbated, due to cultural, language and knowledge gaps [10][25]. At the same time, iPBL may expose students to other ways of thinking and prepare them better for the global labour market [8].

EDUCATIONAL PROGRAMME

The educational programme takes place at the Yale Centre for Engineering Innovation and Design (CEID), USA. This complex serves the entire university community as an academic makerspace, where engineering projects can be developed and realised. The centre includes a lecture hall, meeting rooms, a metal machine shop, a wood shop, a wet laboratory to support chemical and biological projects and a studio for the production of prototypes, equipped, among other things, with 3D printers [26]. One of the on-going activities is a two-month summer programme *From Project to Product*, in which, first-year engineering students examine the possibility of turning the team-based projects they were engaged in during the school year into commercial products.

In the programme that is the subject of the present study, outstanding Israeli high-school students (11th-12th graders) were involved in the above activity. These students majored in Robophysics, mentioned in the introduction. Before arriving at the CEID, the students were exposed to the design carried out by the first-year engineering students for three potential products: a device to detect the contact of a tennis ball with the court, a virtual bass and a device to measure the velocity of a barbell that is lifted in a gym. Based on the preliminary design in a team setting (one team for each product, comprised of two-three high-school students) under the guidance of a teacher, the high-school students built a physical model and an emulator (based on LEGO® MINDSTORMS® EV3) for each potential product. For example, Figure 1 shows the emulator for a tennis ball contact detection device.

Figure 1: Emulator for a tennis ball contact detection device.

When the high-school students arrived at the CEID, they presented the physical models and emulators they had built to the first-year engineering students. Later, over five days, the high-school students engaged together with the engineering students in design and manufacturing iterations of the three products mentioned above, which included, among other things, market testing. The activity took place in three international teams (one team for each product) that each consisted of the original Israeli team and two-three American rising sophomore students who worked on the relevant project during their first academic year. Each team was supervised by a facilitator from the CEID. During the week, relevant trainings were integrated, such as an Arduino workshop, an abstract painting workshop and a presentation on manufacturing products in China. At the end of the week, each team presented a report on its progress.

RESEARCH GOAL AND METHODOLOGY

The study characterised, from the high-school students' perspective, project-based learning in international teams composed of high-school students and beginning engineering students.

The study involved five Israeli high-school students who took part in the educational programme described earlier. As explained, before arriving at the CEID, the students had experience in project-based learning in homogeneous teams, which were composed of students of their own class.

At the end of the educational programme, semi-structured interviews were conducted with the high-school students, which focused on their attitudes toward iPBL. The interviews were recorded and transcribed in full. A sample of the interview questions is given in the Appendix.

The qualitative data were classified into categories based on a directed content analysis performed by two experts in engineering education. The analysis was based on the tri-component attitude model. Only information that occurred at least three times was included in this analysis.

FINDINGS

The content analysis identified cognitive, affective and behavioural components of the high-school students' attitudes toward iPBL. In the cognitive domain, the students argue that iPBL develops technical skills, as well as soft skills.

Regarding the former, the students refer to the development of new abilities, ones that are not taught in Israel, such as market testing: *…We took the prototype* [developed as part of the tennis ball contact detection project], *and went to a real tennis court* [on campus]. *You put it* [the prototype] *on the court and see real tennis players using it. It is the first time I have seen a prototype that I participated in its development come into real use by real customers. They do not teach it* [market testing] *at all in school* [in Israel]. *I learnt how to turn a prototype into a product. I realised that there are more things in the process beyond development. …I saw the project* [I worked on] *become useful in real life and not just in theory. I learnt how to test* [a prototype in the field] *at a professional level.*

The students also refer to hands-on skills: *…I learnt how to solder. This is something new that I was not exposed to before. There was practical work on a prototype and not just theory. This is not done in Israel. …There is not enough hands-on work in Israel. There is a lot of theory and less practical work. At Yale they* [engineering students] *learn, for example, how to solder. There is a huge room for practical work, which in Israel is considered the work of technicians.*

In addition, the students claim that iPBL promotes systems thinking: *…We learnt how to deal with errors, how a product changes throughout the stages of the project. We learnt system engineering. …On the tennis court* [in the field experiment] *there were disturbances that caused the LED to turn on* [false positive]. *We played with the sensitivity setting, so that they* [disturbances] *would not have an effect. We raised the threshold in Arduino* [software], *so that the* [tennis] *ball did not activate the LED either, and then we slowly started lowering the threshold so that only the ball and not the disturbances would turn on the LED.*

As for soft skills, the students note that iPBL develops written and oral communication skills in general and in foreign languages in particular: *…My ability to make a* [written] *presentation at a high level has improved. And also my* [foreign] *language because you speak English all the time. …I learnt how to speak and lecture at an academic level. My English improved a lot.*

At the same time, the students point to difficulties in working in heterogeneous teams, arising from knowledge gaps between the team members: *…They* [engineering students] *were much more advanced than us, they only gave us simple things and did not let us go deep. Sometimes, we were like apprentices. There is a knowledge gap between an engineering student and a high-school student. That is why some high-school students thought they could not contribute to the project. …There was not really full cooperation with the engineering students. They* [engineering students] *told us to cut some fabric or solder boards, or do insignificant things. During this time, they really worked. It is because we are high-school students* [who know less than the engineering students]. *This* [lack of cooperation] *was not caused by language difficulties.*

From the affective aspect, the students think that iPBL is interesting due to the exposure to another culture: *…It was interesting to see an American university. I felt like I was in a movie about an* [American] *college. Seeing people walking around with* [Greek] *letters on their shirts* [student fraternities and sororities]. *…It was interesting. I thought* [before I arrived] *that Yale was a closed compound like a school and at the end I realised that it is actually a city.*

In addition, iPBL is interesting due the exposure to other ways of thinking: …*It was interesting to work with someone foreign, certainly on foreign soil. You see different work methods, how you did the project and how he or she* [an American student] *did it, in which direction he or she chose to go. It is really interesting to see that there is a similar line of thought and it is very special to see that two other sides of the world have a similar line of thought. …It was interesting to see how they* [engineering students] *think, how they see things differently, especially since there are quite a few knowledge gaps between engineering students and us* [high-school students].

The students also argue that iPBL is enjoyable: …*It was a lot of fun, talking with American students and also with people on campus. …A great social experience. A once-in-a-lifetime experience.*

Behaviourally, the students strongly recommend their peers to participate in iPBL: …*I unequivocally recommend participating* [in similar programmes]. …*I definitely recommend participating* [in similar programmes] *and suggest expanding it to other fields, such as chemistry or biology*. Figure 2 summarises high-school students' attitudes toward iPBL.

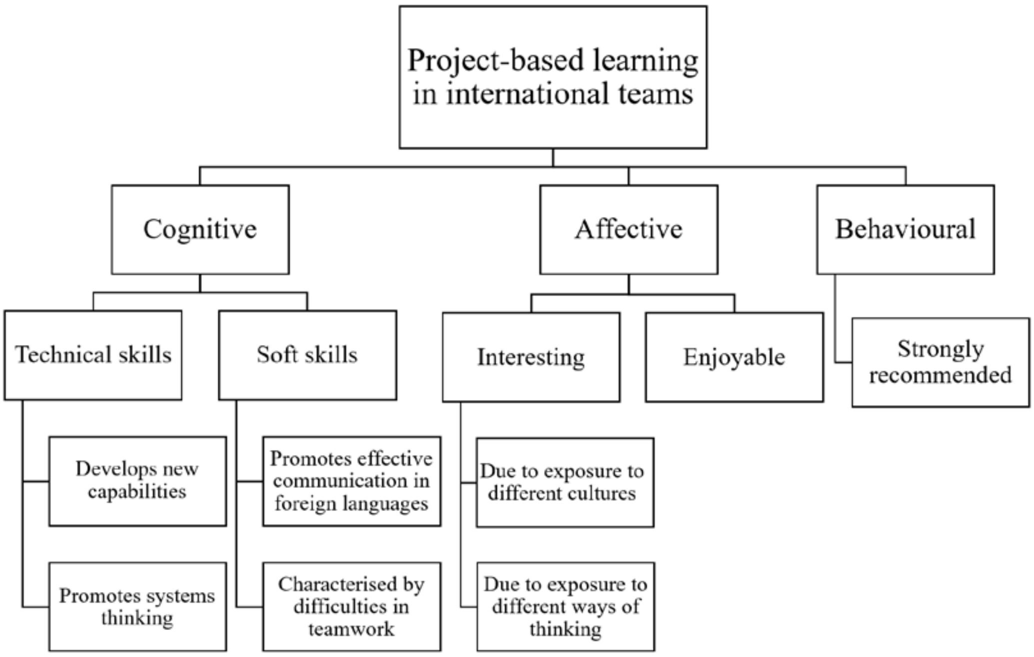

Figure 2: High-school students' attitudes toward iPBL.

DISCUSSION

According to the findings, iPBL advances systems thinking, similar to standard project-based learning (where team members share the same nationality) [13][19]. The high-school students claim that the added value of iPBL is in the development of new technical skills, ones that are not taught in Israel, such as market testing. In addition, similar to standard project-based learning, iPBL promotes written and oral communication skills [8]. However, the unique contribution of the latter, according to the students, is in fostering communication skills in foreign languages.

Along with these contributions, the students also point to challenges in working in heterogeneous teams, which, according to them, results from knowledge gaps between the team members. The authors believe these difficulties may have also stemmed from the status differences between the students and the fact that the programme took place in a foreign country. The above finding is consistent with the literature, arguing that when project-based learning occurs in international teams, difficulties may be exacerbated, due to differences in culture, language and knowledge [10][25].

Affectively, the students find interest in iPBL and think it is enjoyable. The interest originates from two factors, exposure to other cultures and exposure to different ways of thinking.

In light of self-determination theory, it can be concluded that the students are driven by intrinsic motivation and identified regulation (arising from the recognition of values inherent in the activity). This diagnosis is of great importance, since these motivational factors are autonomous, and as such, allow the individual to persist in the activity over time [27].

Finally, in the behavioural domain, the students highly recommend their peers to participate in iPBL. This component is in line with the other two attitude's components.

As a possible solution to the abovementioned challenges in working in heterogeneous teams, the authors recommend: 1) providing the participants with preliminary training on teamwork in general and heterogeneous teamwork in particular; and 2) holding a virtual meeting, before the high-school students' arrival at the CEID, with the participants of the international team members and the facilitators. The meeting would focus on getting to know each other, coordinating expectations and defining work procedures.

The main limitation of the study is its low number of participants, which resulted from the small number of high-school students who took part in the programme. However, the authors believe that the research has both theoretical and practical contributions. The theoretical contribution is in expanding the body of knowledge dealing with iPBL. The practical contribution may be expressed in improving the training of high-school and engineering students. These contributions are validated in view of the considerable gap between the skills of engineering graduates and those needed in the industry, especially with regard to soft skills, which are recommended to be cultivated in early stages [5].

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BIOGRAPHIES

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, Haifa, Israel. 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. His research interests also include quantum optics and atomic physics. Dr Gero has received the Israeli Air-Force Flight Academy Award for Outstanding Instructor twice and the Technion's Award for Excellence in Teaching 16 times. He received the Israeli Air-Force Commander's Award for Excellence (2006), the Yanai Prize for Excellence in Academic Education (2016) and the Technion's Award for Continuing Excellence in Teaching (2022). Dr Gero is an Associate Editor of IEEE Transactions on Education.

Vincent Wilczynski is the Deputy Dean of the Yale School of Engineering and Applied Science and the James S. Tyler Director of the Yale Centre for Engineering Innovation and Design. As the Deputy Dean, he helps plan and implement all academic initiatives at the School. In addition, he manages the School's teaching and research resources and facilities. As the James S. Tyler Director of the Centre for Engineering Innovation and Design he leads the School's efforts to promote collaboration, creativity, design and manufacturing activities at Yale's academic makerspace. His professional interests in mechanical engineering are in the areas of data acquisition/analysis and mechanical design. He is the Co-Chair of the Executive Advisory Board of the FIRST Foundation and is a Fellow of the American Society of Mechanical Engineering. Previously, he was the Dean of Engineering at the U.S. Coast Guard Academy and has had fellowships at the MIT Charles Stark Draper Laboratory, the Harvard School of Public Health and with the American Council on Education. He has also served as the Vice President of Public Awareness for the American Society of Mechanical Engineers and was the 2001 Baccalaureate College Professor of the Year by the Carnegie Foundation, the only national award that recognises outstanding college teaching. He is active in STEM outreach as the Treasurer of FIRST and an Advocate for FIRST Global.

Nira Krumholtz holds a BSc in mathematics and physics education, an MSc in science education, and a PhD in computer science education, all from the Technion - Israel Institute of Technology, Haifa, Israel. She founded and served as the head of IDEA Centre for research, development and implementation of computer science teaching based on the constructivist pedagogy approach. The IDEA Centre was affiliated to the Department of Education in Technology and Science at the Technion and was supported by the Israeli Ministry of Education. Later, she developed and managed the Media+ national project, invited and funded by the Ministry of Education. The project involved the development of a theoretical model for integrating computer technologies with the constructivist approach to learning and teaching science. Currently, she develops learning materials and teacher guides in computer science, computer control and technology education, for elementary, middle and high-school students, invited by LEGO, KNEX, LASY and SPIN-MASTER toy companies.

Ofer Danino is a high-tech entrepreneur who developed Robophysics - an educational methodology for teaching science and engineering to high-school students by combining robotics and other advanced technologies. He serves as a supervisor of student projects at the Viterbi Faculty of Electrical and Computer Engineering at the Technion - Israel Institute of Technology, Haifa, Israel. Mr Danino holds a BSc and an MSc in technology and science education from the Technion.

APPENDIX

Below is a sample of the interview questions:

- Describe the work of the international team you were a member of. Did you experience difficulties? Explain.
- Describe the most interesting part of iPBL you have experienced. What was interesting about it? What did you learn?
- Describe a case in iPBL where you felt your abilities in the scientific/engineering field were manifested. Specify which capabilities. What made you feel that way?
- What do you think was the best thing about iPBL you experienced? Explain.
- What do you think was the worst thing about iPBL you experienced? Explain.
- Would you recommend your friends to participate in a similar activity? Explain.