DESIGN-IMPLEMENT COURSES TO SUPPORT CHANGE IN ENGINEERING EDUCATION

Aderson Campos Passos, Humberto Henriques de Arruda, Marcelo F. Vasconcelos, Felipe Ferrari

Military Institute of Engineering (IME)

ABSTRACT

This article describes the results of well-succeeded design-implement courses developed at the Military Institute of Engineering (Rio de Janeiro, Brazil). The implementation of these courses is part of the ongoing transformation process in engineering education and considers simultaneously aspects from different CDIO standards, embedding active-learning methods and creating additional opportunities for integrated-learning experiences within the Institute. The article also describes important aspects of planning and execution, pedagogical results obtained and provides a benchmark for other teachers interested in implementing similar activities.

KEYWORDS

Change process, design-implement courses, PBL, project management, Standards: 5, 7, 8.

INTRODUCTION

The Military Institute of Engineering (IME) is a very distinct Brazilian engineering school that decided to follow the CDIO guidelines to enhance engineering education. In 2015, new strategic planning was initiated (Passos et al, 2017) and in 2016 the engineering education started to change. However, the implementation of these good practices suggested by the CDIO is very tough and requires some years of continuous effort. For this reason, we chose the creation of new design-implement courses as the first initiative to change engineering education. This article describes the conception and features of these courses, regarding the change process currently underway at the IME, besides providing some artifacts and a guideline to help other groups to initiate the same kind of course.

Regarding the experience brought from the Linköping University (LiU) and the Royal Institute of Technology (KTH) by two IME's teachers, it was decided to remove some courses from the existing curriculum to create the new design-implement courses (henceforth Introduction to Engineering Project I and II, with the acronym IEP I & II) in the 3rd and 4th semesters. The Scientific Theme (ST), previously taught in the 4th semester, was the main substitution. This course was science-focused, with its main learning outcomes linked to research skills, instead of planning, management and execution of projects. Historically, ST mostly provided poor learning results and generated demotivation of students and teachers. Clear evidence of this former statement was the difficulty to recruit themes to allocate all students during this semester. It should be emphasized that during the first 4 semesters, all the students belong to the Department of Basic Sciences and are not designated to any Engineering Department. So, this demotivation had a heavy impact on all departments.

The expected gains of IEP (the acronym for both courses) include the opportunity to develop skills and integrate multidisciplinary knowledge at the same set of activities, according to the CDIO motivations (Crawley et al., 2014) and industry requirements (McMasters, 2006). This is also aligned to the worldwide maker movement (Dougherty, 2012) with several implications and contributions to education (Halverson and Sheridan, 2014) that is especially valuable for the young engineer students, that are increasingly interested in practical activities and conscious about the importance of developing skills like oral and written communication and team working.

Beyond the Swedish benchmark mentioned above, we should also compare our work to other valuable experiences from other universities, that also used design-implement experiences to develop skills and integrate knowledge. The mature design-implement courses from Kanazawa Institute of Technology (KIT) and Vietnam-Japan Institute of Technology (VJIT) serves as the main pillar in the engineering curriculum integrating contents from other knowledge-based courses (Nguyen-Xuan et al., 2018). However, their main focus is the relationship between problem-solving and other disciplines. Similarly to IPE, teachers from the University of Piúra also selected *project management* as the core discipline to develop their design-implement experience and develop the skills mentioned above (Guerrero, Palma & Rosa, 2013). Some design-implement experiences benefit from the relationship with the industry to provide real projects for the students. That is an important feature of the FIRMA environment created by teachers from Turku University of Applied Sciences (Määttä, Roslöf & Säisä, 2017). In fact, the IPE framework provides to the students all the intended learning outcomes and opportunities described in the tutorial chapter about design-implement experiences in Crawley et al. (2014). Additionally, it is also interesting that we also face the same challenges described in this chapter. However, we still have several improvement opportunities for the courses.

This paper was divided into five parts, where the first part reviews relevant background involving the new courses, change management and CDIO implementation. The second part explains how changes have been implemented applying the 8-step model (Kotter, 1995). The third part describes IPE I and II and explains how they allow the development of desired skills. After, the fourth part shows the evaluation of the courses, that support the conclusions presented at the end.

IMPLEMENTING EDUCATIONAL CHANGES AT IME

Amongst several courses of action to start the transformation in engineering education (teacher training, improvement of engineering workspaces etc.) it was decided to adapt the curriculum of the Department of Basic Sciences to create new design-implement courses. These courses are part of the transformation process, that has been managed using John Kotter's 8-step model (Kotter, 1995).

Applying the 8-step model to this case

The 8-step model was used as a guideline and not as rigid process itself. Regarding this idea and considering the *implementation of the good practices in engineering education* as the change to be implemented, we present how this model has been used to support this change.

Step 1 - Create a sense of urgency

The necessity to improve engineer education is already clear within IME, despite the excellent results that our students and Institute obtain in national and international evaluations. This motivation for change originated from different sources, but mainly: a) students that returned from international internships proposing several improvements and b) teachers reporting student indifference within the classroom.

Step 2 - Building a guiding coalition

Regarding the problems mentioned above, the provost/commander selected some motivated teachers to discuss and address solutions for these problems.

Step 3 - Form a strategic vision and initiatives

The CDIO approach was selected as a reference to improve engineering education and two teachers were sent to Linköping University (Sweden) to live and learn about this set of good practices. After their return to IME, it was started a strategic planning to implement changes and some courses of action were prioritized, namely, a) the *Entrepreneurship Course* along Getúlio Vargas Foundation (Passos et al, 2018), b) the diffusion of active learning methods amongst faculty (ongoing activity) and c) the implementation of *new design-implement courses* in the Department of Basic Sciences.

Step 4 - Communicate the vision

The commander/provost used all the *resources available* to communicate this vision and motivate the faculty and students, but mainly lectures and videos produced by the *communication department*. The coalition group, selected in step 2, is very important to this step because they are local leaders that carry credibility to the change process.

Step 5 - Enable action by removing barriers

Focusing only on IEP *I & II*, it was necessary to *build a teaching group* to conceive the courses and after that discuss its implementation with IME's teaching advisory board. Regarding the course features some previous courses were excluded or merged into the current curriculum to avoid content repetition. At the same time, the new course benefits were widely discussed and several valuable contributions were provided by the teaching advisory board.

Step 6 - Generate short-term wins

The new courses generated great motivation among the students since the beginning. The using of active-learning methods to present the content represented a paradigm shift for the students. The discussion about skill development was emphasized, and it was possible to perceive the student's reaction taking care about their performance on presentations, reports and team working. Additionally, the competition of popsicle-stick bridges gave them the opportunity to put the knowledge in practice. All this energy and motivation was registered by the *communication department* in a very successful video, that reached more than 1 million views in the social networks (in YouTube, https://youtu.be/K1yNYUxOaak). This article itself represents a short-term win. The publication of these results in an international-reputed engineering education conference validates the courses.

Step 7 - Sustain acceleration

The second version of the courses was already planned. The difficulties and improvement opportunities were registered and the teaching team is working to enhance the course. The association of former students (Alumni IME) also provided financial support for the next project-based learning experiment: catapult commanded by Arduino. The successful use of active-learning methods, good project executions and, mainly, the student motivation empower the implementation of other engineering education good practices.

Step 8 - Consolidate change

The change consolidation will occur with teacher training on these engineering education fundamentals. The training contributes to disseminate good practices and prepare future teacher teams to continue and enhance these design-implement courses.

COURSES DESCRIPTION

IEP I & II were implemented in 2018. The core of both courses is the theory and practice of Project Management (PM). During these two semesters, the practices become increasingly complex, always considering the student's level and knowledge, as described below. Detailed information may be obtained in the website: www.iep.ime.eb.br.

Introduction to Engineering Project I (3rd semester)

Beyond the teaching of PM knowledge, IEP I also aims the improvement of oral and written abilities. The PM classes are taught using problem-based learning (PBL) method and, in 2018, oral presentation and written techniques were discussed with traditional lectures. Figure 1 provides an overview of IEP I & II.

In 2018, the practical activity of IEP I was the competition of popsicle-stick bridges, following the specifications provided by the teaching team. The student groups had to build their bridges in a limited period and soon after its construction, all the bridges were submitted to a destructive test to determine the maximum load supported by each bridge. The students practice PM knowledge carrying out the initial planning and executing the construction according to the specifications and the predetermined time. The teaching team of IEP I is multidisciplinary, composed of engineers from different specialties, administrators (both with PM knowledge) and language specialists.

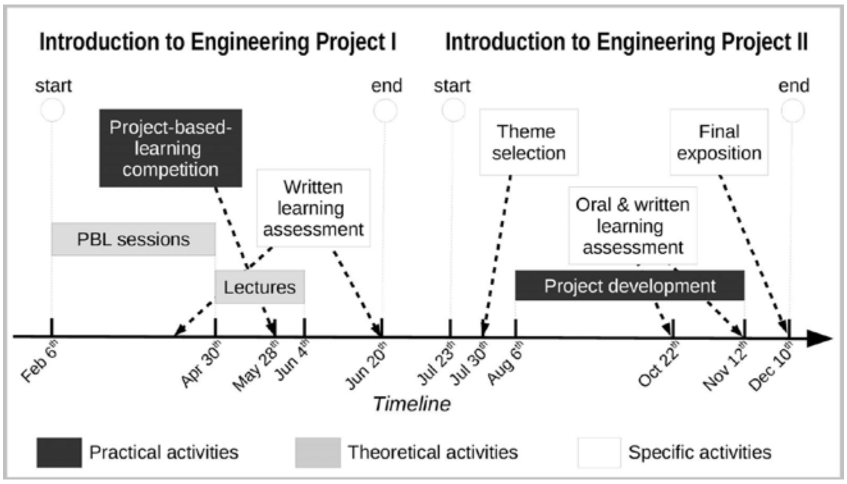

Figure 1- IEP Timeline

Introduction to Engineering Project II (4th semester)

In this course, the major focus was the practical application of the knowledge acquired in IEP I in a real engineering project.

The projects in IEP II were advised by 28 teachers from the Engineering Departments from IME. Despite most of the themes were proposed by teachers, some of them were proposed by students. These themes ranged from the implementation of mobile and web applications to the development of rocket models. Naturally, the complexity of the projects should be was adequate for the available time (14 weeks) and the students' knowledge. Considering the PM knowledge obtained in the previous semester, IEP II further develops the student's ability to work in teams and to carry out and execute planning. The oral and written learning assessment (depicted in Figure 1) play an important role in skill development. It is an opportunity for the students to practice the oral presentation and written techniques presented in the 3rd semester. The teaching team provided a rubric to guide the presentations (available on the website).

IME students choose the engineering program only in the 5th semester. For this reason, IEP is a great opportunity for students to get additional knowledge about the program which they want to choose. It is important to highlight the motivational character of this course since most of the courses of the Department of Basics Sciences (ranging from the 1st to the 4th semester) are strongly theoretical.

COURSES EVALUATION

The courses evaluation, detailed as follows, aims to compare IEP courses to others, that occurred simultaneously at IME. These surveys intend to check and foster the adoption of good practices by the teachers, including active-learning methods. This evaluation demonstrated that IEP achieved superior results comparing to other courses, using the same reference-questions.

As part of the IME internal evaluation process, it is requested to all students to fulfill a survey form to evaluate all the courses from all the engineering programs. The survey is very broad and intent to cover all courses formats in IME. The analysis presented in this work compares the results obtained in IEP with the other courses from IME. The survey consists of 12 objective questions presented using a five-point Likert scale (Likert, 1932), divided in three main areas: Course Questions (related to the course methodology and contribution with the engineer formation); Project Questions (related to complexity, timeline and theory, and practice alignment); Students Questions (related to students motivation and performance).

Results of three different surveys are showed, students in 3rd (225 answers, 76% of the total students) and 4th (160 answers, 57% of the total students) semesters and teachers in the 4th semester (27 answers, 96% of the total teachers). The questions applied to the students are presented below:

1) Does the teaching process relate the theory to engineering practice?
2) Does the teacher relate the theory to the engineering practice in the EVALUATION process?
3) Does the teacher appropriately use various technologies such as overhead projector, Internet, among others, in a way that favors INTERACTION and student LEARNING?
4) Does the teacher use suitable teaching techniques to present the course - directed study, case study, lectures, group work, among others, in a way that favors students' INTERACTION and LEARNING?
5) How does the teacher classes promote student's MOTIVATION for course?
6) Does the RELATIONSHIP between teacher and students contribute to learning?
7) Does the teaching provided in the classroom EFFECTIVELY contributes to learning?
8) Can the teacher COMMUNICATE clearly what should be learned during the course?
9) Is the teacher AVAILABLE to clarify students' questions?

10) The content in the evaluations CORRESPONDS to what was taught during the course?
11) Does the difficulty of the tests CORRESPONDS to what was taught during the course?
12) Does the teacher establish relationships between his / her course with other areas of knowledge, favoring multidisciplinarity?
The questions applied to the teachers are presented below:

1) What is your opinion about the use of PM methodology in IEP II?
2) What is your opinion regarding the time available for the project development (14 weeks)?
3) What is your opinion regarding the organization of the course activities?
4) What is your opinion about the comparison of the students' learning results in IEP II and in the Scientific Theme (ST)?
5) What is your perception about the contribution of the course to the formation of the future engineer?
6) What is your opinion regarding the complexity of the work offered to the students?
7) Do you consider that the PROJECT can relate theory to engineering practice?
8) What is your opinion whether the project EVALUATION contributed to the engineering practice?
9) How much time did you have for this project?
10) What do you think about the students' results on the project?
11) What is your perception regarding students' motivation in the project?
12) To which extent your relationship with the students contributed to the project success?

Evaluation of IEP I and IEP II

Figure 2 and Figure 3 present students' evaluation to IEP I and IEP II, compared with remaining courses that occur in same semesters. The vertical axis presents the average of the answers and the horizontal axis indicates the question number presented to the students. The gray line shows the results of all IME students for each of the 12 questions. In Figure 2, the orange line shows the results for all the courses considering only the 3rd semester, that is, the courses that occur simultaneously to IEP I. Similarly, in Figure 3, the orange line indicates the results for all the courses that occur simultaneously to IEP II during the 4th semester. The blue line shows the results for IEP I & II in both figures.

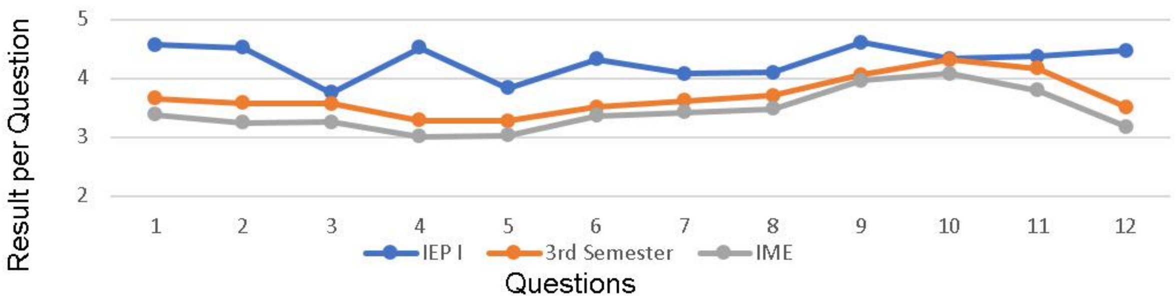

Figure 2 - IEP I Student Survey

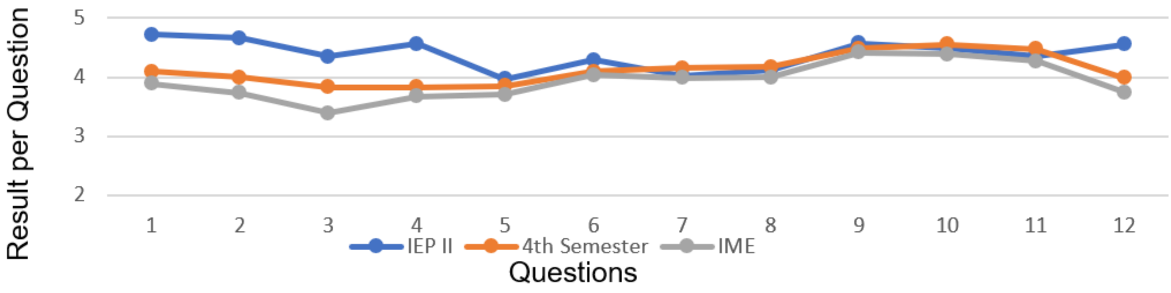

Figure 3 - IEP II Student Survey

In Figures 2 and 3, comparing the results of all the courses from IME (gray line) with the results of the 3rd and 4th semesters (orange line), it is possible to verify that these semesters results present the same behavior as all the courses from IME.

Comparing the overall result of IEP I in Figure 2 (blue line) with the 3rd-semester courses (orange line) and all courses from IME (gray line), the results of IEP I were higher for all questions and very higher in several questions. It is important to mention that questions 1 and 2 (the relationship between theory and practice), question 4 (teaching techniques), question 6 (teacher-student relationship) and question 12 (multidisciplinarity) presents the higher positive difference for IEP I.

Comparing the overall result of IEP II in Figure 3 (blue line) with the 4th semester courses (orange line) and all courses from IME (gray line), the results of IEP II were higher for almost all questions, except questions 7, 8, 10 and 11 and very higher for questions 1, 2, 3, 4 and 12.

Considering the results analyzed above three aspects must be emphasized: the students' perception about the relationship between theory and practice, using active-learning techniques and multidisciplinarity. The competition of popsicle-stick bridges in the 3rd semester and the project development in the 4th semester were successful in providing significant learning experiences for the students. The use of PBL in the 3rd semester provided a different teaching experience for the students and was very welcome. The project development in the 4th semester, mixing disciplinary knowledge with project management in a real (or almost real) situation, was a valuable multidisciplinary activity.

Figure 4 presents the teacher survey results after the 4th semester. The vertical axis presents the average of the answers and the horizontal axis presents the questions presented to the teachers. The orange bar shows the Course-related Questions. The blue bar shows the results for Project Questions. The gray bar shows the results of Student-related questions.

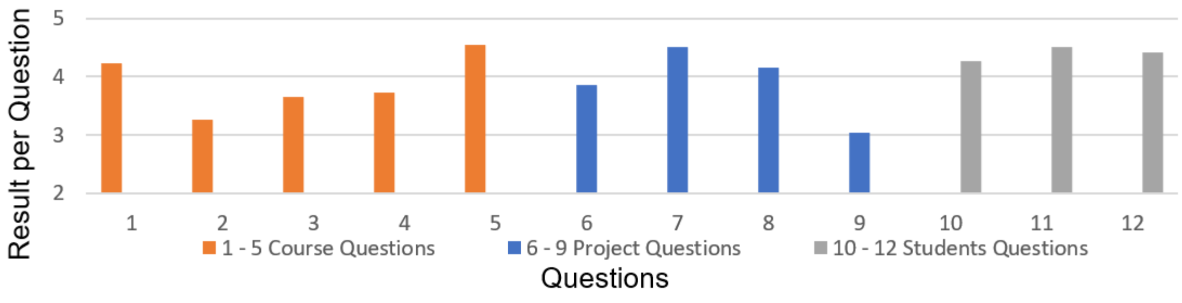

Figure 4 - IEP II Teachers Survey

In Figure 4, the highest numeric value (4.56) was obtained in question 5 (contribution of IEP II to the formation of future engineers). The second highest values presented in Figure 4 (4.52) represents questions 7 (the relationship between theory and practice) and 11 (students' motivation). These results are very important for the teaching team and for the change process in general. It demonstrates that a broader set of teachers recognize the discipline value and may amplify the coalition group.

Questions 2 and 9 in Figure 4 presents the lowest results in teachers survey. Both questions are related to the available time. It is important to be careful during the themes selection in order to give an appropriated scope to the time available.

Qualitative evaluation of team working skills

The students had two valuable opportunities to work in teams during both semesters: first, with the competition of popsicle-stick bridges. After that, with the IEP II project conducted by the engineering departments. This statement is supported by interviews that were made with a sample of students and with the project advisors. The students had to divide tasks, solve conflicts, coordinate activities and aggregate the work of several individuals in both activities, to achieve the final result.

Qualitative evaluation of oral and written skills

In traditional lecture-classes, students have few chances to express their knowledge. However, IEP was completely conceived to be active-learning-based courses. It is very important to emphasize that the students were warned and motivated about the importance and opportunity that they would have to develop oral and written skills. In the end, it was possible to perceive their evolution.

During the problem-based learning sessions, that happened in IEP I, the teaching team could know the students and discover who is shy and who is not, who wants to participate naturally and who does not want. Because of the infrastructure provided, intrinsic motivation and the pressure for obtaining the grades it is possible to perceive that, at the end of IEP II, even the shy students improved their oral skills. It is easily assessed during the intermediate and final oral assessment (mentioned in Figure 1), where the students follow a rubric guideline to reach a good presentation performance.

CONCLUSIONS

The change promotion in engineering education is a current challenge that many HEI have handled in order to prepare the 21st-century engineer. In this context, there are two main outcomes of this work: to report the contribution of the design-implement course to the ongoing change process at IME and to provide a start-kit to groups that want to implement similar changes at their institutions.

The transformation process has been managed using John P. Kotter's 8-step model (Kotter, 1995). In this context, IME has adapted the curriculum of the Department of Basic Sciences. The first change was the substitution of science-focused course, called Scientific Theme (ST), by new design-implement courses (IEP I & II). A relevant result was the high level of motivation of students and teachers, bringing impacts to all engineering programs.

Based on the results of three different surveys involving students (3rd and 4th semesters) and teachers, it is clear that the new course connected theory to practice brought to IME an additional active-learning experience and promoted multidisciplinarity. Additionally, the students improved their oral and written skills, practiced team working and enhanced their motivation as described in the result sections above. This perception was shared not only by students but also by the teachers involved.

Finally, we consider that other groups could benefit themselves from the start-kit available at http://www.iep.ime.eb.br. Although it is a work in progress, it includes the PBL workbook, the competition of popsicle-stick bridges description and video, besides the courses specifications.

ACKNOWLEDGMENTS

Beyond the authors of this article, the teaching team also included: Paulo Cesar Salgado Vidal and Leila das Neves Gouvea. Despite they did not participate in this text, their work was crucial for the course success. Additionally, the authors wish to recognize the leadership of Jorge Luis Rodrigues Pedreira de Cerqueira that brought important knowledge from Sweden and worked hard along with IME's teaching advisory board to make these courses happen.

REFERENCES

Crawley, E. F., Malmqvist, J., Brodeur, D. R., Östlund, S., & Edström, K. (2014). Rethinking engineering education: the CDIO approach.

Dougherty, D. (2012). The maker movement. *Innovations, 7*(3), 11-14.

Guerrero, D., Palma, M., & La Rosa, G. (2014). Developing competences in engineering students. The case of project management course. Procedia-Social and Behavioral Sciences, 112, 832-841.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review*, *84*(4), 495-504.

Kotter, J. P. (1995). Leading change: why transformation efforts fail. *Harvard Business Review*, *73*(2), 59-67.

Likert, R. (1932). A technique for the measurement of attitudes. Archives of psychology.

Määttä, S; Roslöf, J; and Säisä, M. (2017) DEVELOPMENT OF THE LEARNING PROCESS IN A PROJECT-BASED LEARNING ENVIRONMENT. *Proceedings of the 13th International CDIO Conference.*

McMasters, J. H. (2006). Thoughts on the Engineer of 2020. *The Future of Engineering, Science and Mathematics: Who Will Lead*.

Nguyen-Xuan, H., Sato, K., Dam-Duy, L., & Xuan-Hoang, V. N. (2018). THE EDUCATIONAL INFLUENCES OF PROJECT DESIGN EDUCATION ON STUDENTS' LEARNING ABILITIES. *Proceedings of the 14th International CDIO Conference.*

Passos, A.C., Kondo, E.K., Magno Neto, W.B., Soares, C. D. M. (2018). PEDAGOGICAL RESULTS: JOINT ENTREPRENEURSHIP COURSE IN ENGINEERING AND BUSINESS SCHOOL. *Proceedings of the 14th International CDIO Conference.*

Passos, A.C.; Magno Neto, W.B.; Dias, M.H.C. (2017). O processo de transformação do Instituto Militar de Engenharia no contexto do Sistema Defesa, Indústria e Academia. *Revista Militar de Ciência e Tecnologia*, 34(1), 20-27.

BIOGRAPHICAL INFORMATION

Aderson Campos Passos is D. Eng. in Electrical Engineering, belongs to IME since 2005 and teaches courses in the interface between business and engineering: entrepreneurship, project management and innovation management. He is part of the team responsible for the implementation of pedagogical good practices at IME. His current research interests include innovation systems, university management and engineering education.

Humberto Henriques de Arruda is M. Sc. in Operational Research, belongs to IME since 2014 and teaches the courses entrepreneurship, project management and computer programming. He belongs to the team responsible for the implementation of pedagogical good practices at IME. His current research interests is engineering education.

Marcelo F. Vasconcelos is D. Eng. in Defense Engineering, belongs to IME since 2017 and teaches the courses computer networks, project management and computer programming. He belongs to the team responsible for the implementation of pedagogical good practices at IME. His current research interests are computer networks and engineering education.

Felipe Ferrari is M. Sc. in Defense Engineering, belongs to IME since 2016 and teaches entrepreneurship, project management and computer programming. His current research interests include engineering education and artificial intelligence.

Corresponding author

Dr. Aderson Campos Passos
Military Institute of Engineering
Praça General Tibúrcio 80, Praia Vermelha
Rio de Janeiro, RJ, Brazil, 22290 270
55-21-2546-7085
aderson@ime.eb.br