Supporting the Development of Complete Engineers

Juliana de Melo Bezerra[1], Neusa Maria Franco Oliveira[2], Cristiane Aparecida Martins[3], Raquel Caratti Piani[4], Lara Kühl Teles[5] and Maria Margareth da Silva[6]

[1]*Computer Engineering Department, ITA, Sao Jose dos Campos, Brazil*
[2]*Electronic Engineering Department, ITA, Sao Jose dos Campos, Brazil*
[3]*Aeronautical Engineering Department, ITA, Sao Jose dos Campos, Brazil*
[4]*Communication Department, ITA, Sao Jose dos Campos, Brazil*
[5]*Physics Department, ITA, Sao Jose dos Campos, Brazil*
[6]*Mechanical Engineering Department, ITA, Sao Jose dos Campos, Brazil*

Keywords: Engineering Education, Non-technical Competences, Project based Learning.

Abstract: Engineering technical competence is an indisputable need in an engineer professional life. However, to be a complete engineer, able to work in an ever changing globalized world, but sensible to cultural differences, it is necessary more than technical skills. It is then important for students acquiring non-technical competences, such as intercultural appreciation, leadership, self management, service and civic responsibility, teamwork, and understanding of engineering ethics. Here, we present the "Women in STEM2D" Program, developed with undergraduate engineering students, whose goal is to attract and keep female students in the technological and science areas. We provide a critical analysis about how the planning and execution of the program activities contribute to the development of non-technical skills in the engineering students.

1 INTRODUCTION

The continuous integration of technology in our infrastructure and lives requires an increasing involvement of engineers in the civic arena. So, it is in evidence the need to educate engineers who are broadly educated, who see themselves as global citizens, who can be leaders in business and public services, and who are ethically grounded (National Academy of Engineering, 2004).

On the other hand, looking back to the past, we see that many of the earliest engineering projects were the design and construction of public works for the general good of society. The Incan water canals, the Great Wall of China, the Greek public buildings, among others, were undertaken by the engineers in benefit of their societies. So, the work in the civic arena is not new for an engineer (Moore and Voltmer, 2004). However, nowadays there is an increasing interest in new non-technical qualities to an engineer.

Technical knowledge and skills are undoubtedly essential for engineers propose, develop and implement solutions for society. Even so, in order to provide comprehensive and sustainable engineering solutions, technical expertise must be paired with non-technical competencies. Woods at al. (2000) divide the skills required to address the challenge to future engineers in: independent, interdependent, and lifelong learning skills; problem solving, critical thinking, and creative thinking skills; interpersonal and teamwork skills; communication skills; self-assessment skills; integrative and global thinking skills; and change management skills.

More recently, National Academy of Engineering (2004) says "We aspire to engineers in 2020 who will remain well grounded in the basics of mathematics and science, and who will expand their vision of design through a solid grounding in the humanities, social sciences, and economics. Emphasis on the creative process will allow more effective leadership in the development and application of next-generation technologies to problems of the future."

Studying career success, Paul and Falls (2015) say that the most significant competencies related to an engineer's career success were career insight, proactive personality, openness to experience, and

Bezerra, J., Maria Franco Oliveira, N., Aparecida Martins, C., Caratti Piani, R., Kühl Teles, L. and Margareth da Silva, M.
Supporting the Development of Complete Engineers.
DOI: 10.5220/0006678002140221
In *Proceedings of the 10th International Conference on Computer Supported Education (CSEDU 2018)*, pages 214-221
ISBN: 978-989-758-291-2

lifelong learning. Being so, they propose that it should be worked on and improved the ability of engineering graduates to work on teams, to be effective communicators, to be socially adept, and to be prepared for leadership roles.

Addressing engineering educators, Woods et al. (2000) explain that our goals should include equipping our students with problem-solving, communication, teamwork, self assessment, change management and lifelong learning skills. The authors verified that these skills are consistent with ABET Engineering Criteria 2000 and critical to the engineer professional life nowadays.

With this overview about engineers and engineering desired qualities, their characteristics through time, and their expected responsibilities, we select six non-technical competencies as essential to engineers: intercultural appreciation, leadership, self-management, service and civic responsibility, teamwork, and understanding of engineering ethics.

The work presented here is being developed in a program to both foster young girls to embrace STEM2D areas, and support those girls whom are already in STEM2D areas. STEM2D means Science, Technology, Engineering, Math, Manufacturing and Design. Programs to attract and keep students to these areas are expanding around the world (Bybee, 2010; Brown, 2011; Milgram, 2011). More than that, in the 21st century most jobs will need professionals with skill related to STEM2D education.

This paper is organized as follows. Section 2 presents each non-technical skill chosen to be worked here and related works and research which are being conducted around the world. Section 3 describes the general context of the "Women in STEM2D" Program, the situational characteristics and actions which characterize its development. Section 4 analyzes the non-technical skills related to the actions conducted in the program in 2016. Conclusions and future work are presented in Section 5.

2 CRITICAL COMPETENCES FOR COMPLETE ENGINEERS

Complete Engineer is understood in this paper as the non-technical competencies needed, beyond the technical knowledge, to solve the various societal challenges we face in the 21st century and beyond. As stated before, we selected six non technical competencies to be used as needed skills to a complete engineer professional. This section presents information about each skill chosen to be worked in this paper. Also, it is explained the importance of each one in engineering practice and professional career. Related works and research are indicated through the section.

2.1 Intercultural Appreciation

Engineering – at its core – is a service and helping profession. Since we are in a world increasingly globalized, the skills of engineering professionals must be such that they can understand, respect, propose solutions for and work with people from diverse cultural backgrounds.

For achieving intercultural skills, some research and activities are being developed. Deardorff and Deardorff (2016) verified that engineering companies are interested in graduates who have more than just content knowledge and technical skills. They are interested in hiring graduates able to be successful in diverse settings with peolple from a range of backgrounds.

Since the intercultural appreciation is established as a desirable skill in engineering professional, studies and activities are being made in order to promote these skills among the engineering students (Lehto, et al., 2014; Ciocci, 2005).

2.2 Leadership

Leadership can be stated as the ability of an individual or a group of individuals to influence and guide followers or other members of an organization. In recent years, Canada and USA urged the engineering educators to supplement technical coursework with multiple domains of professional skills development. One of such domains is engineering leadership (Rottmann, Sacks, and Reeve, 2014).

There has been a growth of engineering leadership education programs (Paul and Falls, 2015; Fernandez et al, 2015). However, it has not yet gained traction as a legitimate field of study and generally these skills are developed in extra-curricular activities.

2.3 Self Management

Modern engineers should present a continuous engagement in acquiring, applying and creating knowledge and skills. Engineers are increasingly involved with problems that demand to cohesively conceptualise engineering fundamentals to develop holistically acceptable solutions. In this way, Stewart (2007) studied competencies focusing in three factors, namely, self management, desire for learning and self control. Self-management factor was found to be an important predictor for college success, according to Huy (2005). In the model of desirable graduate attributes by Bridgstock (2009), self-management is indicated as important to lifelong career management and enhanced employability.

Procrastination, related to the difficulty in self-management, is a problem that affects a huge amount of people. Among students, their tendency to procrastinate significantly interferes with their academic standing, capacity to master classroom material, and the quality of their lives. Research examining the possible causes of both academic and chronic procrastination indicates that procrastination is related to low self-confidence and even health problems. Pychyl (2000) argue that procrastination is a self-regulation problem wherein the individual is over concerned with short-term affective improvement at the expense of long-term self management and goal attainment.

In order to manage and lead projects and teams, engineers must first lead and manage themselves. To be successful in these activities, it is appropriated to get used to reflect on one's behaviour and experience, managing one's time and establishing personal goals. Then, self-management, skill to be developed by the professional, helps him/her in taking responsibility, having initiative and assertiveness. These characteristics are necessary to a good 21st century professional, mainly to an engineer. Promoting activities to develop such skills among undergraduate students is a good strategy to educate them.

2.4 Service and Civic Responsibility

The Accreditation Board for Engineering & Technology (ABET) defines engineering as "the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind." (Moore and Voltmer, 2003). Looking back, the engineers of antiquity conducted themselves as a mean of raising the living standards of their societies. This focus – serving the needs of society – is the root of and, therefore, should remain the vision for all engineering education (Moore and Voltmer, 2003).

So, it can be said that Engineering is a service profession. To achieve this goal, it is required professional skills as vision, leadership, and a sense of responsibility to those you serve and those with whom you are serving. With such a professional, innovative solutions can raise the living standards of society and benefit mankind.

2.5 Teamwork

In Berteig (2009), there is a list of essential skills to teamwork, not only related to engineers, but to general public, since jobs requiring these skills are increasing among all professions and jobs (Expert Group Report, 2012).

Particularly for engineers, it is rare to serve without the benefit of a team. As teams are composed of people with diverse background, developing skills to improve the work development is desirable. However, most engineering programs provide little or no specific instruction in this area, even though the importance of teaching communication and teamwork skills is well understood. Also, the assessment of these skills is not trivial, so research about this theme is being conducted (Lingard, 2010).

Even with difficulties to assess teamwork skills, the importance of them is already established. Seat et al. (2001) describe a minor Engineering Communication and Performance, which is being designed to improve the ability of engineering graduates to work on teams, to be effective communicators, to be socially adept, and to be prepared for leadership roles.

2.6 Understanding of Engineering Ethics

Engineers must understand the importance of their professional conduct and how their actions can affect the safety, health, and welfare of the public (Harris et al., 2014). So Engineering Ethics is an established study area, with many ethical predicaments and decision-making dilemmas, including engineering confidentiality, corruption, conflict of interest, whistle-blowing and other related ethical impasses (Shuriye and Gombak, 2012).

Institutions around the world consider Engineering Ethics in courses or curricular and/or extra-curricular activities (Chung, 2015; Bekir et al., 2001).

3 THE “WOMEN IN STEM2D” PROGRAM

The program is held in a federal institute, whose mission is to provide teaching and education, and conduct research in the areas of interest to the sector of Aeronautics, Space, and Defense. In this paper, we focus on undergraduate education. There is no tuition. Students have low-cost dorms and free food. We have almost 600 engineering students from different regions of our country. Only 8% of students are girls. The institute aims to gather students from the entire country, using the strategy of applying the entrance exams in 23 cities scattered throughout the country.

There exists an honor code known by the acronym CD (Conscious Discipline) that was established by the undergraduate students in the early years of the institute. All undergraduate students of ITA adopt CD. Honesty, fairness, and transparency are then key values of the honor code. Such values help to create a pleasurable and harmonious environment where people trust in each other. CD implies in a proactive attitude by the person with respect to the maintenance of these values in the academic life of the group. Alumni carry these values, crafted during their academic lives, to their professional lives. Alumni have strong commitments to social and development efforts as professionals due to CD values.

In 2016, we have 18 undergrad girls participating in the “Women in STEM2D” program. Two professors are in charge of the program coordination, with the support of other three professors and one communication professional. All participants were women. In order to involve the institute in a broad way, the invited professors are from distinct areas: computer science, electronics, mechanics, aeronautics, and physics.

We provide a scholarship to each student, in order to meet her personal needs. We also give an extra financial support to allow girls to develop technical projects as they desired. Students are free to develop any project related to courses or other students’ initiatives. Projects are in general developed in heterogeneous groups with boys and girls.

In the beginning of the program, we had a meeting with all participants in order to discuss expectations, initiatives to promote, and groups to lead such initiatives. During the program, we had meetings to follow initiatives in terms of planning, execution and results. We identified three main initiatives: lectures, workshops, and events.

“Lecture” initiative involves the elaboration and identification of material (presentations and videos) related to STEM2D. Using such material, students then visit middle and high schools in our region and conduct a lecture itself. “Workshop” initiative aims to develop hands-on activities in STEM2D context, and also to offer such activities to a group of female students attending middle or high school. “Event” initiative involves the promotion of events to develop abilities and competencies of our students beyond those technical acquired in the engineering course.

4 CRITICAL COMPETENCIES IN THE “WOMEN IN STEM2D” PROGRAM

In this section, we discuss how the non-technical competences desired for engineers’ formation were addressed by the initiatives promoted by the “Women in STEM2D” program.

Table 1: Non-technical competencies in the program initiatives.

	context	lectures	workshops	events
intercultural appreciation	x			
leadership		x	x	x
self management		x	x	x
service and civic responsibility		x	x	
teamwork	x	x	x	x
understanding of engineering ethics	x			

In Table 1, we present the relation between competences and initiatives. Besides the program initiatives, the added program context, which has important data driven by institute characteristics, program team, and program structure. Details are discussed in the topics below.

4.1 Promoting Intercultural Appreciation

The program context itself contributed to develop intercultural appreciation, since we have students in the institute from different cities and in turn diverse cultures of our country. Other fact is that the participants in the program worked with professors with distinct formation and backgrounds.

The program also promoted in the participants a sense of belonging and strength. The main issue here is that girls are minority in our institute: only 8% of the 600 students. The program had the non-expected but grateful output of avoiding girls' isolation, and increasing their reputation. Figure 1 shows the students planning the initiatives at the begging of the program.

Figure 1: Students working on initiatives' definition.

4.2 Developing Leadership

By giving lectures and workshops, students develop leadership. They motivated, inspired and guided others during the presentation or the workshop execution. The definition and development of workshops were made in groups, where students faced coordination issues inherent to teamwork and then practiced leadership. In Figure 2, we show a lecture provided by undergrad students in a high-school.

Figure 2: Students giving a lecture.

The "event" initiative also contributed to leadership. In order to promote an event, students had to be protagonists to choose and invite lectures, to conciliate agendas, to invite the public, and to coordinate the day. In Figure 3, an example of event promoted by the program, specifically it was a lecture about leadership development.

Figure 3: Students participating in an event about organizational leadership.

4.3 Practicing Self Management

Since the first meeting of the program (as show in Figure 1), students had the opportunity to develop self management. In that occasion, they discussed how they would like to develop themselves and how they could contribute to incentive others in STEM2D. After that, we established the main initiatives in the program and started our activities always practicing the freedom of choice and the responsibility with deliverables.

A group of students provided the material to be used in lectures, including the preparation of presentations and the selection of videos. Students then develop self management in terms of taking responsibility and having initiative. The developed material presents STEM2D areas and applications, discusses women participation in STEM2D, and explains undergrad programs and students' life in our institute. Other students, when preparing themselves for the presentation, decided to adapt the material to cope with the selected public (chosen class in a school) and the available time to the lecture. It was an opportunity to practice assertiveness, time management and flexibility, which are key characteristics of self management. The lectures were conducted in 15 distinct medium and high schools, reaching a total of 1017 students.

The "workshop" initiative developed in students important skills related to self management, such as joint responsibility, interdependence, empowerment, and curiosity. Students had to decide the desired public to apply the workshops, so they focused on girls from 10 to 15 years old. Linking curiosity, empowerment and responsibility, students defined and produced six activities related to: tower of straws, LEGO constructions (shown in Figure 4), 3D printer, circuit, LEGO robotics, and logic gates (shown in Figure 5). The design of activities focused on children' motivation, incorporating aspects as games, competitions, and challenges. Students also practiced time and resource management, since they need to comply with the available time for the workshop and the available budget of the program. Students decided even how to promote the "workshop" initiative using events and social media, and how to accept online registrations. A group of 30 girls participated of all workshops in 2016.

Figure 4: Workshop about LEGO constructions.

Figure 5: Workshop about logic gates.

The practice of self management occurred in the "event" initiative as well. Students had the resolution and flexibility to choose the lecturers and to organize the day, including aspects as: room allocation, public definition and invitation, lecture briefing and reception, coffee-break organization, certification preparation, and event evaluation. Students promoted eight events for participants in the "Women in STEM2D" program. Three lectures were female professionals who talked about their trajectories and careers. Other events were: leadership and self development course; a course on self-consciousness and development focused on the professional environment; female identity and dreams applied to the professional area; self-knowledge applied on the professional area; communication and leadership applied on the professional area.

4.4 Developing Service and Civic Responsibility

Technological innovation evolves fast and the world becomes intensely interconnected. There is a need to prepare people to face technical issues in a multidisciplinary way, considering social, cultural, political, and economic forces. To prepare society to face these issues, it is desirable to spark an interest in pursuing STEM2D education in people. It would lead to more people chosen STEM2D carriers, so important to technological development. Meanwhile, our country faces critical social issues, including problems in quality and efficiency of public education system.

In the "Women in STEM2D" program, mainly the "lecture" and "workshop" initiatives contributed to develop service and civic responsibility in our undergrad students, since they actively participated in the community in a committed and constructive manner. Students recognized the human dignity and understood the concept of the common good. The positive impact of the program is confirmed by the results of the "lecture" initiative. A total of 1017 students of middle and high school informed if the lecture improved their interest in STEM2D. Results showed that 45% strongly agree, 41.5% agree, 9.3% disagree, and 4.2% strongly disagree.

Two testimonies below also confirm that the program participants engaged in an active process that goes beyond passive citizenship.

"The best of everything was to make the difference in the children lives. Maybe we did not define a career, but certainly we spark their interests."

"At the beginning of the program, my only concern was to receive a financial support to my technical project. Now, I would make all again but with a different reason: the satisfaction of the students during the workshops."

4.5 Practicing Teamwork

As all initiatives in the program were made in groups, students had the opportunity to practice teamwork skills, including: communication, reliability, and conflict management. Communication is the central part, since students had to communicate to define and organize the initiatives. Students trained active listening, when they gather ideas and concerns of their peers in a respectful manner. Reliability was developed as each student had to cope to specific deliverables and to follow a joint scheduler, always according to the initiative goal. Conflicts are intrinsic to teamwork due to distinct views and perceptions, so students also had to manage conflicts. It is important to mention that professors were supporting groups, in order to coach them during challenges and conflicts.

At the end of the program, the 18 students evaluate their experience with teamwork. Nine students agree and nine students strongly agree with both sentences: “My team worked together” and “My team kept a positive attitude”. Seven students agree and eleven students strongly agree with both sentences: “My team discussed and solved its problems” and “My team completed the assigned task”. Thirteen students strongly agree, four students agree, and one disagrees with the sentence: “Members cooperated in my team”. The data shows students’ feedback, mainly regarding collaboration and coordination that they experienced in teams.

Problems in teams were also reported, for instance: the need to establish feasible deadlines; some teams were overloaded; the desire to participate in activities promoted by other teams; communication issues; the difficulty to conciliate program demands and academic activities.

4.6 Promoting Understanding of Engineering Ethics

The context where students belong already brings ethics to their formation, mainly due to the honor code CD. CD includes moral principles to guide life in campus, rights and responsibilities, conduct, and moral decisions. Honesty and integrity, the basis of CD, are essential to engineers’ conduct due to the impact of engineering activities on society.

In the “Women in STEM2D” program, students were always remembered about moral principles for a good relationship in groups, and also about their responsibilities in the program including the quality and deadline agreed for deliverables.

Regarding the overall evaluation of the program by the 18 students, twelve students believed that “the program surpassed my expectation”, six students agreed that “the program met my expectation”, and two students were neutral. A final remark regarding the relevance of the program was stated in a testimony:

> *“I believe in the transformation potential of this program in our society. The program should be disseminated in other universities and reach girls in the whole country.”*

5 CONCLUSIONS

Non-technical skills in the engineer professional lives are increasingly needed and in evidence. Here we chose some of these skills and verified their development in extra-curricular activities. The activities were developed in a program called Women in STEM2D, with engineering undergraduate students. This project aims to attract and keep female students in the technological and science areas. We described the main initiatives in the project and explained how they cope to the development of non-technical skills of our undergraduate students.

The program conducted in 2016 was successful. It reached hundreds of students in medium and high school students, through the initiatives of lectures and workshops. Parallel to these reached goals, the non-technical skills worked on the undergraduate students participating in the program are very important to their professional lives, as it was presented here.

As future work, we aim to quantify how program participants perceived the development of each non-technical competence. Increasing data related to the improvement of the competences during the development of the activities, statistics analysis could be generated and presented. We intend to encourage the participation of students in organization and execution of distinct initiatives, in order to broad their experiences. Other goal is to organize our effort to increase the number of children reached in lectures and workshops, as well as to expand our events in terms of themes and public.

The program is focused on women due to the characteristic of the received grant. However, program initiatives are generic enough to be applied for other students in the institute. In this trend, we intend to provide a detailed explanation about the program structure, in order to easy its implantation and adaptation in other universities.

ACKNOWLEDGEMENT

A special thanks to Johnson&Johnson company for funding the program.

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