TEACHING TRANSVERSAL SKILLS IN THE ENGINEERING CURRICULUM: THE NEED TO RAISE THE TEMPERATURE

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Conference Key Areas: Interdisciplinary education, Future engineering skills
Keywords: transversal skills, mapping project, engineering curriculum, interdisciplinarity

ABSTRACT

Engineers and architects today are dealing with great social, technical and environmental complexities, and the demand for having broadly educated holistic engineers will only continue to grow in the future. Being able to manage and lead diverse teams, understand complex, interdisciplinary systems and solve open-ended problems across and beyond different subjects is expected from the next generation of graduates.

With the aim to understand how the future graduates are educated to cope with such complexities, we developed a tool to map out the course curricula and examined the extent to which transversal skills are taught at a leading technical university in

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Europe. Using MATLAB, we have conducted an exploratory analysis, and this concept paper offers the outcomes of analysing course descriptions of bachelor and master programmes throughout the academic year 2018-2019. By presenting the results in a visual form of a heatmap, we have examined at which moment throughout the curriculum and how frequently are transversal skills included in the teaching objectives.

The results indicate an overall gap between teaching transversal skills at both BA and MA level, but also a difference in teaching transversal skill in mandatory and optional courses. Furthermore, throughout the curriculum we observed a significant lack of some critical skills, such as those connected to ethical reasoning. This project opened valuable avenue to deepen the discussion regarding teaching and learning of transversal skills, as well as the structural changes that need to be considered in the education of the engineers and architects in future.
1 INTRODUCTION

1.1 Background

It has been evident for a while that future engineering graduates will face challenges that go beyond the borders of their discipline [1]–[3]. Global and local dilemmas [4] are demanding high levels of transversal skills. The worldwide pandemic at the beginning of 2020 that further aggravated social, health, and economic issues has proven it even more strongly. Thus, it is both from the perspective of emerging problems and from the perspective of labour market needs, that the 21st century will not be able to rely on the traditional educational directions within the engineering field, and therefore needs a better balance between technical and transversal skills [3], [5]–[7].

This concept paper reveals results of a projection analysis based on a mapping project which examined the teaching objectives of transversal skills at the École polytechnique fédérale de Lasuanne (EPFL). Contrasted and analysed against the evidence from literature, we examine the results by looking at different possibilities for change as well as by inciting new questions to the discussion tables.

1.2 Theoretical underpinnings

As world knowledge doubles every 10 years, the demand for better and more comprehensive educational strategies grows. In perspective of the future of engineering it has never been more necessary than today to have future graduates ready for managing, leading and understanding complex interdisciplinary systems [3], [8]. The next generation of engineers will need to be educated as “holistic engineers”, flexible and adaptive to bring solutions by combining engineering expertise within domains of technology, law, public policy, sustainability, arts, and so on [3]. While there is no lack of agreement that the appeals for high levels of transversal skills across the engineering curriculum are justified, the gap in achieving it still continues to linger [5], [6].

Brunhaver et al. [7] point out to the dangers of having a naïve presumption that all engineering careers go through a homogenous track and require a similar balance of technical and transversal skills. Through their research, they brought a better understanding of the vast array of different early career engineering profiles, emphasising the importance of problem solving and analytical skills, together with communication and business acumen as prevalent for those choosing managerial and consultant profiles. Furthermore, the issues in acquiring these skills are oftentimes seen in a very basic, technical way. For example, there is an assumption that communication skills in engineering are based on writing technical reports and providing oral presentations. Yet, in practice, engineers can spend up to 60% of their work-related communication in interaction with others, often from different backgrounds and cultures, for which they require good listening and collaborative skills [9]. In addition, effectiveness of transversal skills acquisition is rarely evaluated beyond student self-reporting [5], implying that it is less valued than the technical subject-related knowledge and skills.
Overcoming these gaps in the first several years of an engineer’s early career is time consuming, and, in most cases, avoidable [9]. Torres et al. [6] found that some of the general issues in pedagogical re-planning of the curriculum are indeed connected to excessive lecturing, lack of active learning, reduced engagement and poor motivation. Furthermore, some transversal skills, such as those related to ethics are frequently placed as optional courses rather than implemented as part of the core teaching. This is oftentimes connected to the fact that engineering teachers feel ill equipped and unprepared to deal with content related to ethics in engineering education [10]. Assessment, and more specifically lack of formative feedback, was identified as another large issue. Not being able to adequately address transversal skills from the pedagogical point and assessing them in a manner that brings out the value of the skills, has been a dilemma for many teachers and institutions.

It can be argued that skill and knowledge gaps exist because of the “necessarily generic nature of university education and the specific requirements of individual job roles” [11, p. 297]. Furthermore, the majority of engineering courses are embedded in a single discipline while trying to prepare graduates for an interdisciplinary engineering practice [11]. In addition, transversal skills are rarely taught in a way to glue the different disciplines together. This goes along and notwithstanding the fact that learning transversal skills is a joint venture of teachers’ instructions and students’ engagement, in which educational institutions have an important role to provide the impetus and raise the profile of transversal skills so that they are as significant as the technical ones [5]. Leaning on this, it is necessary to adequately and continuously examine how engineering curricula is prepared and delivered, as well as how institutions encourage the value of transversal skills through different aspects of student journeys.

1.3 Context

This concept paper focuses on the analysis of intentions to teach transversal skills in bachelor and master courses at EPFL. The mapping of the intentions was done by using the official course descriptions and combining the information to understand which skills are represented with what frequency and intensity, at which particular time across the entire curriculum and across all of the EPFL faculties. The aim of this mapping project was to understand the prevalence of the skills and potential gaps, as well as to identify examples of good practice.

At EPFL, each course description has several parts including a description of the content, exam type, semester of delivery, and learning objectives. The learning objectives are divided into two parts, (1) the subject related knowledge and skills and (2) the transversal skills course objectives. When designing their courses, teachers can select from a list of 32 different transversal skills that can be integrated into their subjects. Each teacher can “drag and drop” as many skills as they plan to teach in their courses. This means that a course could have between 0 and 32 skills included in their learning objectives.

The list of the 32 transversal skills is divided into 5 skill-families: (1) Communicate, process, manage, and generate information, (2) Personal effectiveness, (3) Project
management, (4) Working in the society, and (5) Working in groups and organisations. The list was created in 2012-2013 through a process of institutional consultation led by the experts in EPFL’s Centre for Teaching Support, and taking into consideration the main theoretical and empirical trends at the time.

2 METHODOLOGY

2.1 Data

Analysis involved a total of 929 course descriptions found within 13 bachelor and 25 master programmes during the academic 2018-2019 year. This included 351 bachelor courses, 475 master courses, 75 minor courses, 22 master project courses and 6 other courses. From the available data imported from the course descriptions, we used the information on transversal skills, independent of whether a course is obligatory or optional, the level at which it is taught (in semesters from BA1 to MA4), the number of students per course and to which faculty the course belongs.

2.2 Procedures

To analyse the data, we used Microsoft Excel and MATLAB. The two were used simultaneously in order to validate the imported information and support the development of categories. Furthermore, we used MATLAB to generate heatmaps in order to visually present the large amount of data. The analysis consisted of measuring and visualising by displaying heatmaps of two main distributions:

1. The distribution of the number of courses proposed to EPFL students, across the curriculum and for the 32 transversal skills that can be selected in the course descriptions,
2. The distribution of the number of students participating at each of these courses, across the curriculum and for the 32 transversal skills that can be selected in the course descriptions.

It was necessary to prepare both distributions because bachelor level courses include more students, while at the master level there are overall a greater variety of specialised courses taught. Therefore, looking only at the number of courses and neglecting the number of students, would give an incorrect representation of the situation.

Using MATLAB, a graphical user interface (GUI) has been developed in order to facilitate the selection of data to visualize in the heatmaps. This GUI allowed for selecting sections of interest, for instance specific tracks of students, for example mathematics or chemical engineering. This means that by selecting specific sections only the data related to courses proposed to students of the selected sections are displayed in the heatmap.
MATLAB software has a specific feature that allows for categorical data to be used, which was one of the main reasons for selecting it as a tool for displaying results. This helped in reducing the maximum computational resources required to update and visualise the data when the selected section is modified, as well as to successfully compute accurate heatmaps.

2.3 Limitations

While analysing the data, we noticed several potential limitations. First of all, we need to emphasise that the course descriptions highlight only the intentions and not necessarily what is actually being taught by the teacher nor what is being learnt by the student. Hence, the analysis addresses merely the intended learning objectives and not the learning outcomes. Secondly, the analysis points out the intended learning objectives at a fixed moment in time. This goes to say that the course descriptions highlight the intentions before the semester starts, and it is important to take into account that this may change in practice by the end of the semester. Another limitation is that we did not survey teaching staff to question how they interpret the inclusion of certain skills in their course description. In other words, we do not know whether they actively teach these skills or whether they assume students will learn these skills implicitly during their courses. In addition to this, we must assume that there are skills which might not be included in the course descriptions but are taught by teachers even unconsciously. And, finally, some courses are mentioned as being part of a minor (“plan mineur”) but might not be displayed in the heatmaps because of missing information. This means that the total number of courses displayed in our analysis at the master level might be slightly lower than the actual numbers. Being aware of these limitations supports a better
interpretation of the results and leads to more adequate recommendations for further actions.

3 RESULTS

3.1 Transversal skills throughout the curriculum

Across all courses and levels, we have registered a total of 5182 transversal skills in the course descriptions. Table 1 provides information of the total number of transversal skills at different levels and between obligatory and optional courses.

<table>
<thead>
<tr>
<th></th>
<th>BA1-BA6</th>
<th>MA1-MA4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obligatory courses</td>
<td>835 (48%)</td>
<td>575 (16.5%)</td>
</tr>
<tr>
<td>Optional courses</td>
<td>872 (52%)</td>
<td>2853 (82%)</td>
</tr>
<tr>
<td>Uncategorised</td>
<td>0</td>
<td>47² (1.4%)</td>
</tr>
<tr>
<td>Total</td>
<td>1707 (100%)</td>
<td>3475 (100%)</td>
</tr>
</tbody>
</table>

Looking at the total numbers, there is a noticeable discrepancy between bachelor and master courses, especially for the optional courses. However, it is good to keep in mind that while the number of courses is higher at the master level, the number of students per course is higher in the BA courses, especially in the first year. At the master level the course-student ratio becomes smaller yet more specialised and optional. This explains some of the reasons behind having higher numbers in optional MA courses.

Computed as a heatmap, Figure 2 presents the prevalence of the 32 transversal skills at each level, starting from BA1 to MA4.

² At master level there were 47 entries which were not categorised as either obligatory or optional
As we can see in Figure 2, there is a clear horizontal gap between the bachelor and master level. The second evident observation is vertical “cold” area around the “Working within society” family which indicates the lowest number of taught skills. Even though it is already possible to draw conclusions regarding the distribution of the transversal skills in general, the representation of this heatmap reflects the number of courses taught, and not the number of students following these courses. This is relevant to take into account, since some BA courses have up to 200-300 students while some MA courses can have as low as 1 student. Hence, a heatmap of the total numbers of students attending the courses has been computed in order to complement Figure 2.
What we can additionally learn from looking at Figure 3 is that since there are greater numbers of students at bachelor level, the overall curriculum of transversal skills does reach more students than represented solely by courses. We can observe that most represented skills are “Use of a work methodology appropriate to the task”, “Access and evaluate appropriate sources of information” and “Write a specific technical report”. This comes in contrast with the least represented skills which relate to already mentioned “Working in the society” family, including “Chair a meeting to achieve a particular agenda, maximising participation”, “Take responsibility for health and safety of self and others in a working context”, “Take account of the social and human dimension of the engineering profession”, as well as those in other skill-families such as “Resolve conflicts in ways that are productive for the task and the people concerned”, and “Design and present a poster”. At the bachelor level “Respect the rules of the institution in which you are working” and “Write a literature review which assesses the state of art” are additionally noted as low.

To complete the overall analysis, we computed a heatmap according to whether the courses are obligatory or optional. This allowed us to see the extent at which students receive obligatory courses that include transversal skills, and how much of it is left as an option.
As we have observed in Table 1, optional courses are numerous, especially at master level. Looking now at Figure 4, we can see that this occurrence significantly influences the overall trend of teaching transversal skills. As much as skills in families of “Personal effectiveness” and “Project management” are relatively well covered in obligatory curriculum at bachelor, we can clearly note a gap in several of the skills in the family of “Working in groups and organisations” and, the already mentioned, “Working in the society”.

Finally, we have noticed a large discrepancy when analysing data from specific sections and, most importantly when looking at the Social and Human Science (SHS) programme. The SHS is an integral cross-curricular programme offered at Bachelor and Master level, and while courses of SHS are often provided as optional courses, they are required for students at certain levels. When analysis the data we noticed that SHS courses have the highest level of transversal skills, compared to any other courses taught by individual sections. Hence, since the SHS are cross-curricular, we computed two heatmaps to understand the difference between courses taught within a section with and without SHS.
In the two figures, Figure 5 and Figure 6, we present an example of a randomly selected section at EPFL and how the heatmaps look when SHS courses are included and when not. What we wanted to illustrate with this comparison is the mere fact that the main curriculum of the section (Figure 6) significantly lacks in teaching transversal skills. Furthermore, we also wanted to state that having SHS
programme (Figure 5) to supplement this gap helps in improving the picture and offering students chance to learn transversal skills.

3.2 Discussion

One of the first points that this analysis brings forward is the existence of a wall between teaching transversal skills at bachelor and master level. This might be problematic, for several reasons. One could be that not all bachelor graduates continue their studies at master’s level, hence their transition to their early career might feel difficult due to the need to compensate for the lack of the skills [9]. It is also quite common that bachelor graduates are more likely to engage in a wider variety of career paths, hence the necessity of having stronger transversal skills is even higher. Many of the transversal skills are deemed as a basis for any workplace, and consequently they should serve as the foundation for the more domain specific skills [5], [6], [12].

On the other hand, the analysis surely corroborates that most of the subjects embedded in the engineering curriculum are oriented towards technical skills, they are monodisciplinary and they follow quite a generic approach, especially at the bachelor level [11]. Considering this, we do question the meaning of a specific transversal skill within the engineering curriculum and profession [7], [9]. By this, we both refer to the necessity to understand for example what is the scope of communication skills for an array of engineering professions today and tomorrow, as well as what can be the gradual acquisition of these skills and how can it be taught in a steadily progressive way. This said, a specific skill, such as problem solving or leadership, needs to be taught at all levels with a different intensity and depth. Furthermore, the idea of teaching transversal skills as part of SHS programme is a helpful addition to provide skills to more students, however it is a patchy solution. Teaching transversal skills outside of the main engineering curriculum might offer an idea that these skills are second-grade in comparison to the more technical ones taught in the compulsory courses. Additionally, if the transversal skills are not reflected in the content, issues and problems posed by technical courses, their applicative value might be lost too. While battling this problem might involve a huge amount of efforts in equipping engineering teachers with necessary skills [6], [10], lack of motivation and reduced engagement can no longer stand in the way of bettering engineering education.

Finally, the analysis did bring up the question of institutional challenges when attempting to teach transversal skills [6], in which the question of planning the curriculum, training teaching staff as well as assessment skill mastery play a significant role. It is worthwhile considering what sort of curricular model is most likely to provide a stronger coverage of transversal skills and how institutions can support raising the profile of these skills [5]. In addition, the analysis does indicate the need for further exploration both in terms of understanding which are the most important transversal skills and how they should be taught in order to holistically prepare engineering graduates for complexities of their future jobs.
4 SUMMARY

The lessons learnt through this projection analysis are truly multifaceted and can be extended to a number of discussions related to the present and the future of engineering education. While we point some of them in this concept paper, our project continues to go deeper by examining the examples of good practice and showcasing different models of teaching transversal skills across the curriculum. Understanding pedagogical cases that bring the temperature up in the heatmap, as well as exploring what makes the curriculum cold, will help in dissecting how engineering education can be re-shaped to better prepare the holistic engineers for tomorrow.

REFERENCES