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A 5-Step Pedagogical Design for Engineering Courses

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***Abstract*—This paper presents the design of a 5-step pedagogical framework based on student-centered approach prepared for engineering educators' mindset. This pedagogical framework has been applied and tested in various technical and engineering course units, been adapted for the new students of Generation Z. This framework can be a pedagogical toolbox in adapting the teaching and learning activities to the students' needs, also measuring qualitatively the students' dynamics and academic performance. So far, in the course units where this pedagogical method was applied there was a 20% increase of the success rate and a reduction of the drop-out rate between 5% to 15%.**

***Keywords*—pedagogical design, engineering thinking, engineering education, Generation Z**

I. Introduction

Nowadays, engineers play an important role in our technological society in constant evolution promoted by the industrial revolution 4.0. In this dynamic space of change, new applications, products, materials and solutions are sought in several scientific areas of engineering. The training, learning and experiences that students of an engineering course carry out in a school context shape the way future engineers from Generation Z will think and how they will face this dynamic of fast changes in the contemporary world, which also contribute to change them as a result of their human potential. Generation Z's ability to adapt and criticize the wealth of information available is recognized, as well as their ability to communicate, their pragmatism and critical sense, allied to the notion of social and environmental responsibility [1], can truly contribute to reversing the course of environmental disrespect produced by the industrialization of the last century. This Generation Z, due to its characteristics, justifies a teaching that tends to make better use of its potential, inducing them in a more technologically combinatorial training, integrating more scientific areas, encouraging transversal skills, improving the skills of technology users, further promoting their capacity of innovation and creativity. However, they have difficulty in dealing with the work routine and frustration, preferring an immediate lifestyle which makes them more vulnerable to emotional disorders [2]. It is a demanding challenge that is proposed to current engineering educators who have also been prepared in their technical-scientific training to apply the typical engineering mindset [3]. This means that they are ready and consequently prepare future engineers to define or detect a problem, to research and produce solutions, to define and choose a solution, to implement the solution, to evaluate the solution and disseminate the results obtained. This is called engineering thinking, characterizing the way engineers observe the world, how they interpret it and how they interact with it. It is recognized that there are different ways of thinking and engineering thinking is not the same as other professional segments that make up today's society [4]. This way of thinking is based on the mental habits developed along the academic path as well as in professional practice [5]. These mental habits are based on logic, pragmatism, innovation and visualization, resilience, analysis and communication skills, among others.

So, taking into account all that was previously pointed out, the traditional teacher-centered approach is not in line with the focus to enhance the positive characteristics that Generation Z carries, while constructively dealing with the emotional instability of these students. On the other hand, if the calls for changing attitudes or for applying a pedagogical methodology more appropriate to the characteristics of Generation Z are not understood as a real problem in the thinking matrix of engineering educators, everything remains unchanged, even when interesting training is provided to them, in the sense that the pedagogical training may not consider real aspects of the needs of an engineering educator, which is more affected by the demands of research activity and other non-teaching activities.

This paper aims to meet the thinking matrix of engineering educators and the urgent need of effectively implement the student-centered approach [6] on course units of engineering and technological courses through an innovative, systematic and pragmatic 5-step pedagogical design. This pedagogical design was developed, tested and implemented over several academic years in various course units of engineering and technological courses at Polytechnic Institute of Setúbal, an engineering Portuguese academic institution, on the context of the student-centered approach.

This paper has the following structure: in section II a critical reflexion about several scenarios and relevant issues that make it difficult the application of the student-centered approach in engineering course units is presented; in section III the 5-step pedagogical framework is described; in section IV the implementation of this engineering pedagogical method and its results are given and in section V some relevant conclusions are pointed out.

II. Context of Application

Young engineering educators who start teaching without pedagogical training have the tendency to use personal teaching methods that can result in no common teaching strategy of content presentation, no lesson plan, no clear objectives of the course unit, poor time management and no proper evaluation mechanisms for either the students' or the teachers' performance [7]. Effective teaching depends upon effective planning and design. Moreover, if the teacher-centered approach is applied, the teacher's intention to transmit knowledge to Generation Z students is boring, not challenging or motivating, and does not enhance the students' active attitude in the classroom. Therefore, Generation Z students are not encouraged to actively construct their own understanding, and the importance of interaction is not acknowledged [8]. In fact, teacher-centered approach is associated with the adoption of the surface or rote learning among students, while the student-centered approach encourages students to adopt a deep learning approach.

Among engineering educators there are still many supporters of the traditional teacher-centered approach or content-centered approach, arguing its applicability since they are the experts, or authority figure, on the scientific area of study for students. Students must rely on the expert and receive his knowledge to achieve positive grades in the final exam and/or assessment activities. Due to the engineering educator pragmatism and mindset, the pedagogy training courses, many times closed on themselves and with a high theoretical weight, are not fruitful. In fact, engineering teachers need an appropriate structure of logical reasoning pattern to accept new knowledge or new ways of acting, otherwise a pedagogical training can be seen as a reduce of their scientific-technical rigor on content lectures in classes, leading to an undervaluation of teaching.

One of the difficulties that is reflected in the teachers' interviews is the lack of practical knowledge on the student-centered approach, its techniques, good practices and implementation rules which makes the pedagogical transition process complex and difficult to apply without adequate training and support [9]. In fact, this pedagogical methodology requires from the engineer educators a significant knowledge of pedagogical engineering concepts and techniques and also an initial effort on planning a new pedagogical structure which has to be designed to interconnect the technical and scientific learning objectives of the course unit with the attitudes and skills of the students, along with suitable didactic resources, providing a fruitful learning environment which facilitates the student's learning [10]. The teacher must be open-minded and prepared to leave his comfort zone of traditional classes, with the ability to promote and apply more creative, integrative and rewarding solutions in case of different situations in the context of the student-centered approach.

In the student-centered approach, the typical passive attitude of the students in the classroom is reversed through learning activities in classroom context, whether theoretical, theoretical-practical or laboratory classes. These activities make it possible to achieve the learning objectives, as well as reinforce or develop the transversal skills of employment, such as autonomy, adaptability, cooperation, constructive criticism and time management [11]. This means that student-centered approach may vary between where the learning context is directed to the limit of a high degree of freedom that requires a balance between understanding the learning needs of students who are attending the course and the structure of the knowledge to be learned in the context of the course unit. This balance depends on the profile of the students, the subjects involved and the learning objectives to be achieved, requiring detailed and specific planning. This pedagogical approach allows the application of a wide range of active learning techniques depending on the aforementioned balance. This makes the student-centered approach very rich in terms of pedagogical resources but difficult to apply due to the variety of active learning techniques when one does not have the knowledge nor the necessary experience for its implementation. In addition, the application of some good pedagogical practices or an occasional active learning technique, may not produce the expected results due to lack of a pedagogical support structure. For a successful implementation of the student-centered approach, it is crucial to develop the entire pedagogical framework as the one described in the next section.

III. 5-Step Pedagogical Framework

This pedagogical framework based on 5 pedagogical steps, as shown in Fig. 1, was designed, tested and applied to course units of engineering and technological courses in order to optimize the students' academic workload, timeframe and learning process.

Outside classes students used virtual didactic resources provided by the teacher (texts, videos and other interactive resources in the Moodle learning platform) in order to give continuity to the learning process, contributing and consolidating the knowledge acquired in face-to-face classes, and to carry out some formative training tests, preparing them for summative assessment. In this context, the teacher assumes the role of facilitator of the entire learning process [12], guiding students´ training defined in the pedagogical framework, managing and analyzing the students' performance inside and outside the classes, using the support of an IT platform.

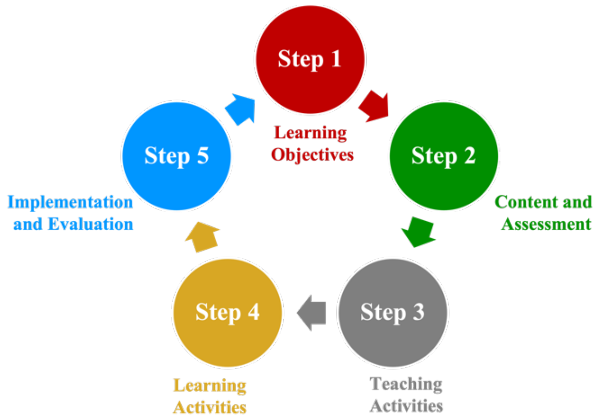

Fig. 1. 5-step pedagogical framework applied to a course unit

The 5 steps of this pedagogical framework are now described in detail.

A. *Step 1 – Learning Objectives*

The learning objectives connect what students must be able to do, how will they get there and when will they be evaluated about it. The setting of a course unit's learning objectives must be a compass for teachers and a learning guide map for students, previously known by both. In order for the learning objectives to be clear and understood both by teachers and by students, it is essential to use the SMART criteria. This mean that each learning objective must be Specific, Measurable, Achievable, Realistic and Time-bound. The application of the SMART criteria to all learning objectives contributes to the evolution and improvement of the development of this planning process for achieving a good specification.

In this first pedagogical step, it is also important to set the level of depth or complexity of the cognitive domain that must be reached by students for each learning objective. This can be addressed by applying the Bloom's taxonomy [13], characterized by action verbs associated with the 6 levels of the cognitive domain.

However, the setting of the learning objectives of a course unit may not be an easy task to carry out for a teacher who has no previous experience as they incur some of the following risks:

- possibility or existence of oversizing the course's learning objectives, due to excessive specification or improper setting of the knowledge levels of complexity in each part of the content.
- unrealistic learning objectives concerning the timetable to implement them, inside and outside the classroom.
- pedagogical constructive alignment hard to hold on due to the lack of suitable didactic resources.
- difficulty in levelling the assessment with the learning objectives.

To minimize these risks, continuous review on the application of the learning objectives established must be carried out, re-evaluating them if necessary.

B. Step 2 – Content and Assessment

In this second pedagogical step, the course material is properly organized. This means that structured content, established with a logical sequence of learning milestones for supporting the learning objectives, must be prepared. The need to produce documents or digital content depending on learning needs is recurrent. The content must be aligned with the learning objectives, supporting them.

In this step, the method of evaluation should also be defined, along with the instruments to be used and the grading of all the assessment activities, duly aligned with the course's learning objectives [14]. The assessment activities should be based on training tests, self-assessment and summative tests. Assessment should also be aligned with the available timeframe for each learning objective, extending the relationship of dependence between learning objectives, content and assessment, as shown in Fig. 2.

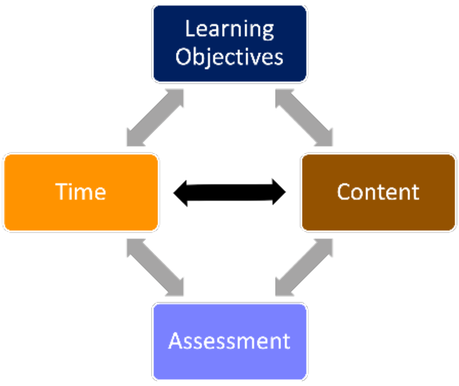

Fig. 2. Alignment between learning objectives, content, assessment and time

C. Step 3 – Teaching Activities

In this step the teaching activities, carried out by the teacher during classes to foster the students' learning, are established. In order create significant impact on students, the teaching activities must be intentional, meaningful and useful. Each teaching activity should use diverse means of application, such as short-term exposure, demonstration with questions, content video analysis, case studies, discussion or debate on real situations, task-oriented or knowledge structure with other related areas, among other means.

This pedagogical step can be complex since it cannot simply depend on the teaching style of the teacher. In fact, creativity, specific learning techniques and suitable motivation must be considered for each learning objective to produce real impact on the students' learning.

D. Step 4 – Learning Activities

In this step the learning activities, developed by the teacher to be carried out by students, are established. But the relevant question is: how to create learning activities with significant impact on students? How to design powerful learning experiences? Each learning activity in the course unit should be aligned with the learning objectives. This means that every learning activity in the course unit should be intentional, meaningful and useful. This step of the pedagogical framework can be the most complex of all steps since it depends on the practices of the teacher on active learning techniques. Moreover, it depends on the soft skills to be worked in the context of synchronous and asynchronous classes. The teaching style of the teacher, the creativity, the particular active learning techniques to be applied and the proper motivation have to be considered for each learning objective in order to produce an effective impact on the students' learning. This can be done through the combination of attractive technical-scientific real questions or problems with an attractive learning activity, contributing for a significant learning and enhancing the student's participation and engagement.

E. Step 5 – Implementation and Evaluation

Throughout the previous steps, the pedagogical framework has been built based on the learning objectives. The implementation of all elements of the framework should be part of the teaching planning that is used to disseminate the course unit to students. This means that the course unit's learning objectives, content, teaching activities, learning activities and assessment should be available on a communication or learning IT platform, complemented with a collaborative whiteboard platform, depending on the type of active learning techniques to be applied.

After the implementation of the pedagogical framework, the activity of reflection and evaluation of the entire training process, and its design based on the course unit's learning objectives, is essential to be carried out. All the necessary adjustments must be implemented at this stage, regarding any inaccuracy in the pedagogical elements developed or any learning difficulty traced on students in achieving the intended learning objectives. It is also necessary to check if the learning objectives satisfy the training needs, if the pedagogical techniques applied were adequate and if the evaluation and training results are satisfactory.

Finally, another important aspect to be defined, even before the beginning of the implementation of the pedagogical framework, is the evaluation criteria, instruments and indicators that are intended to be used to quantify the effectiveness of the training.

IV. IMPLEMENTATION

From 2014, the 5-step pedagogical framework design previously outlined was applied, tested and adjusted in some pilot trainings at Polytechnic Institute of Setúbal. Since the academic year 2017/18, this 5-step pedagogical design has been fully applied to the engineering and technological course units of electrical machines and fundamentals of mathematics. In the academic year 2018/19, this pedagogical method was applied to the course unit of mathematical methods. More recently, since the academic year 2020/21, boosted by the post-pandemic period, the course units of industrial electronics machinery, home automation and electromechanical energy conversion have also been taught applying this pedagogical method.

The receptiveness of new students on the application of the 5-step pedagogical framework has been positive so far. Students have relationships with teachers and peers who care about, believe in, and support each other. Students are fully embraced for who they are and develop a sense of positive identity and belonging. Initially, there was passive resistance from some students, only during the first week of term time, because they were not used to being active in the classroom, which eventually was their standard attitude in the other course units.

The success rate of the electrical machines' course unit was around 82% in the academic years of 2017/18, 2018/19, 2019/20 and 2020/21, which corresponds to an increase of more than 20% when compared to the three previous academic years, where the 5-step pedagogical framework design was not implemented, from 2014/15 to 2016/17, and the success rate never reached 60%. In the mathematical methods' course unit, this pedagogical method was implemented from the academic year 2018/19 to 2020/21 with a success rate around 46%, which corresponds to an increase of more than 20% when compared to the two previous academic years, 2016/17 and 2017/18, where the success rate was around 25% using the teacher-centered approach. In the course unit of fundamentals of mathematics the 5-step pedagogical framework design was implemented since the first edition, in academic year 2017-18, until nowadays, always reaching a success rate higher than 81%. In addition, the drop-out rate of all these course units also experienced a reduction: 5% in electrical machines, 15% in mathematical methods and less than 5% in fundamentals of mathematics.

Overall, the outcomes of the application of this pedagogical framework resulted in a reduction of the drop-out rate and an increase in these course unit's success rate, compared with similar course units where the teacher-centered approach was used.

V. Conclusions

The success rate improvement occurred on the engineering and technological course units where the 5-step pedagogical framework was implemented, encourages applied research and deepening of knowledge about the diversification of techniques and strategies in the preparation and use of teaching and learning activities. This pedagogical structure also makes it possible to qualitatively measure the dynamics and performance of new students on the course unit, acting just in time to amend the learning trajectories, if necessary. In fact, the change in the teacher's focus to analyze the learning students' quality during its performance on the learning activities, provides the teacher with a richer pedagogical toolbox to deal with various anomalous and/or unforeseen situations.

Current and future research about this 5-step pedagogical framework design is linked to its dissemination, teaching and application carried out by specific training with a strong practical nature on the 5-steps' implementation. Due to its pragmatic and flexible features, this pedagogical method can embrace (i) the new didactic technologies, whether in teaching, learning or assessment, (ii) the diverse active learning techniques, depending on the transversal skills to be worked out, that can be added to the new pedagogical models that are emerging, such as challenge-based learning, research-based learning and design-based research, and also (iii) specific skills and competences outside professional environment, such as responsible citizenship and ethics, that we foresee as relevant skills in the next decades for engineering trainings.

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