The Influence of Educational Learning Paths in Academic Success of Mathematics in Engineering Undergraduate

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***Abstract*— Issues related to the failure of mathematics in the teaching of engineering and the negative impact that these difficulties have in various courses in engineering degrees is a problem to which we have devoted our attention and investigation. Most students when entering higher education have insufficient preparation in mathematics. It is further aggravated because of the different areas of knowledge from their background when entering degrees in Engineering. The Mathematics in Engineering Support Center (CeAMatE) is a space intended to monitor students who attend the course of "Differential and Integral Calculus". It allows the construction of an academic course that promotes the development of students' independent study skills, with the joint responsibility of building their own educational paths. It also facilitates the construction of learning and acquisition of new knowledge through the availability of various activities and resources aimed at overcoming students' difficulties. It also incorporates an e-learning component, adapting to the learning styles and cognitive levels of students. The understanding of the educational pathways made by students who attended CeAMatE and the corresponding academic achievement in "Differential and Integral Calculus" course is a goal of this study. This analysis will permit a better development of a set of suitable mathematical strategies/activities.**

Keywords*— *Learning paths; engineering; mathematics; blended learning

I. Introduction

The admission policies in higher education have a significant difference between educational supply and demand where there is a substantial decrease in the demand. Therefore, meseaures have been implemented to try to democratize the access. In Portugal, the Mathematics and Physics exams became mandatory for the access to most engineering courses in 2012. It was a measure that teachers had always certified as essential for the areas of Engineering. However, our perception is that most students complete their secondary school with a lack of knowledge in these topics. The reasons could be a future line of research because these topics are taught in secondary school and it is not a subject ignored by the teachers, but simply students couldn't master and apply these topics. Furthermore, it is difficult to entice the new generations in enjoying these types of subjects due to their previous difficulties, which have created a stereotype of adversion in our society to these areas. Consequently, there is a decrease in demand for engineering courses. To confront this problem, higher education institutions provide input mechanisms from a very diverse audience and from very different areas with different personal, motivational and cognitive characteristics. This heterogeneity demands that there be an increase in attention given to the inclusion of complementary means to the formation of some of the enrolled profiles.

In this context, it is a priority that the math teachers in undergraduate engineering, especially those who teach courses in the first year, look for changes in their teaching practices. This will allow the adequacy of educational strategies to cover such a huge diversity of students' backgrounds. This practice becomes a permanent challenge for teachers of Higher Education and launches a debate of some important issues, particularly with regard to the motivation, the student success and the design of the different learning paths.

II. The Diagnosis

A. Perception of the students dificulties

Due to the multiple concerns about the process of teaching and learning of mathematics at engineering degrees, in 2011 the Research Group in Teaching of Mathematics in

Engeneering (whose Portuguese acronym is GIDiMatE) was constituted. This group was interested in research work, which aims to understand how, where and why students may or may not learn math. The establishing of relationships between teaching and learning methods and the building of learning environments that give responsibility to all the people involved in the educational process was also a goal of this group.

The difficulties in teaching courses of Differential and Integral Calculus when students access undergraduate courses have been shown in many studies [1-5]. The difficulties experienced by students in basic content essential to their full integration in these courses is one of the main concerns expressed by teachers. This, inevitably, leads to an adaptation of curriculum organization and the definition of actions for changing the situation. In this regard, a major concern for teachers is how to present integrated concepts in Curricular Units of Differential and Integral Calculus (UC-CDI) in a way that allows students a better understanding of these topics. According to [6] the successful integration of students in theses subjects is verified by the need to reconcile the mathematical basis of knowledge acquired during the secondary education with the knowledge considered essential for the first year attendence in engineering. This consistency brings forth better student integration with the curricular units. Therefore urgent articulation between secondary and higher education is needed to reduce the degree of early withdrawal in classes with consequent implications for the academic failure.

B. *The errors*

One way to analyze students' difficulties in learning mathematical content emerges from a careful investigation of the answers which students present to mathematical questions. The detection of errors contributes towards an understanding of how the students obtain certain knowledge [7-8]. In this context, the identification of errors and consequent comprehension of the mathematical thinking and cognitive style of students may arise as an important and needed pedagogical tool to be integrated into the design and implementation of teaching strategies, since it may potentiate a set of activities aimed at overcoming difficulties.

The observation of the mistakes made by the students, as well as the various versions in which they arise, will reveal the basic or elementary knowledge that is missing and is essential in the UC-CDI syllabus. This allows the construction of a basic framework and a set of strategies to include in the teaching practice. A study [9] carried out in the first half of 2011/2012 academic year and the review of the collected literature [3] identified a number of errors considered the most common and supposedly responsible for the incorrect answers to certain questions at UC-CDI.

A more specific analysis in the interpretation of these errors, as well as the various representations as they occur in the tests of student assessment, suggests the lack of basic knowledge in terms of understanding the difference between the properties of addition and multiplication. The study also shows that the incidence of these errors and their typology was directly related to the matter addressed in the evaluation. These findings infer the need to implement strategies in the classroom or outside, which can meet the real needs of students in overcoming their previously identified difficulties. These suggest the development of activities aimed at the acquisition of basic knowledge, which could run parallel to the development of the course.

For the proper functioning of the UC-CDI, this study also recommended the existence of a diagnostic test. It will enable an earlier detection of students' difficulties in order to make a timely intervention to avoid demotivation and consequent abandonment.

C. *The diagnostic test*

Following the recommendations proposed, the Diagnostic Test (DT) has become one of the visible faces of GIDiMatE. This DT was set in order to analyze the level of basic knowledge identified as fundamental to the full integration of the mathematics syllabus in UC-CDI.

Held for the first time in the academic year 2011/2012, the construction of the diagnostic test has had successive changes leading to a model that, in 2013/2014, was considered ideal for future comparisons. The amendments took into [10] through its working group (Mathematics Working Group) and further cooperation with the Dublin Institute of Tecnhology (DIT). Taking as reference the SEFI document and the Basic Education and Secondary Portuguese programs, the final version consists of twenty questions including topics of Algebra, Analysis, Calculus, Geometry and Trigonometry, nine of which are common to the diagnostic test (DT), which reinforces the transversality of this problem [11]. Therefore the students accessing to higher education should be submitted annually to an exam that diagnose their knowledge, at a basic and complementary level. This will allow individual support strategies and develop educational resources that can assist in overcoming the identified problematic gaps.

Independently of how the student was admitted to an engineering degree, results show that, in a sample of 853 students, 48.3% had a score below 10 right answers, 42.7% had a score above 10 right answers and 9% of the results were equal to 10 [12]. These unsatisfactory results are not, however, exclusive of ISEC (a portuguese acronym for Coimbra Institute of Engineering) students or even of the Portuguese students. In 1999 the European Society for Teaching Engineering – Mathematics Working Group [13] also witnessed a decline in results of students entering their undergraduate engineering degree.

III. THE CEAMATE – MATHEMATICS SUPPORT CENTER IN ENGINEERING

A. *The Center*

The natural perception of teachers on the reasons behind the failure of mathematics in Engineering degrees, supported by studies already done, conducted to a pedagogical intervention. Since 2013, an awareness of ISEC's educational community for the need to implement a Mathematics Support Center in Engineering (named CeAMatE) has begun. The

CeAMatE is therefore a structure to personalize support for students in learning mathematics in engineering, which includes two components: the CeAMatE-in and CeAMatE-on.

The CeAMatE-in is a physical space dedicated to support the learning of mathematics, located in DFM-ISEC (Department of Physics and Mathematics of ISEC). This space has resources enabling the development of activities, parallell to those developed in the classroom. It aims to provide a quality service and a wide range of learning resources in order to encourage students to overcome their mathemathical difficulties through self-study and with the help of teachers. Even though there is no mandatory attendance, it intends to establish itself as a strategy to fight against the dropout rate, reducing the number of students who choose not to renew their registration, often because they were overwhelmed with difficulties in their integration.

The CeAMatE-on is an e-learning platform enabling the student learning according to their cognitive level and preferred learning style. In its implementation phase, it is a plug-in of the Moodle platform. It allows the construction of co-responsible educational itineraries, implementing various activities and using the resources available to students in order to overcome their difficulties. The lesson activity is chosen from the list of available activities in this platform. It is expected that the CeAMatE-on developes a personalized learning environment, making both teachers and students responsible for the educational process and responds individually to the differences of the students enrolled in ISEC degrees, both in terms of cognitive development and preferred learning style [14].

This project has implied some important characteristics, such as the association between higher education and civil society and also the association to the educational community in which it operates. From these intentions a partnership, with the private institution of social solidarity CASPAE (a Portuguese acronym of Social Suport Center for Parents and Friends of the School) for the implementation of CeAMatE-in in ISEC, was born.

Another substantial foundation of CeAMatE-in is the integration of successful students in UC-CDI within the existing volunteer program in the IPCSer (a Portuguese name for a volunteer project of the Coimbra Polytechnic - http://voluntariadoipc.wordpress.com/programas/). The work of these students will revert to the diploma supplement.

This project is in a pilot phase and is mainly directed to all students attending the courses of Differential and Integral Calculus in the 1st year of the ISEC engineering degrees. However other students; which may be indicated by teachers of other curricular units to access this monitoring or that self propose to do so, could attend the CeAMatE-in. In the first half of 2015/16, an analysis of data collected through the monitoring tools specifically defined for the project was done.

B. *The CeAMatE-in methodology*

The Center uses a composed methodology. It includes a diagnostic, recommendation and assessment methodology considered crucial, reflecting on the educational process of the student, their different roles, levels and contexts, and value the meaning assigned to it by the subject himself. The custom and responsible support offered intends to induce behaviors of self-efficacy, prevent demotivation and classes abandonment.

The basic instrument in the monitoring methodology applied in CeAMatE-in is the DT. The indication provided by DT referring to the base knowledge that the student has and needs to overcome, serves as a pretest or an alert signal at the end of the process. It also enables to draw conclusions on the progress of students with regards to their specific learning. This DT provides specific information about the mathematical content to be worked with the student at follow-up in CeAMatE-in and which will focus on a higher level of effort. For this purpose, a Working Individual Plan (PIT) is built. It is prepared according to [10] adapted to the Portuguese education. The minimum knowledge, advised for the entrance of Higher Education to an Engineering course, is detailed by areas and identified by topics in the Core Zero section of this reference on topics that were considered essential for integrating CDI and defined in accordance with Portuguese programs of secondary and primary education. This document, together with student data (personal and academic), includes a training plan, consisting of a selected set of flashcards and exercises taken from MathCenter (http://www.mathcenter.ac.uk/students/courses/) that is properly reformulated as the student porceeds and progresses while attending a defined study schedule.

A math teacher that will accompany the students by clarifying doubts and offering guidance throughout the independent study so that students can take advantage of the whole process of learning.

The evaluation of this work is performed on each of the student presence in CeAMatE-in through self-proposal tasks, promoting continuous monitoring in the definition of a sound and structured training. In addition, periodic realizations of adapted versions of DT, with consequent evaluation and redesign of the PIT are made until the student reaches the minimum required to be considered apt for integration in the syllabus of UC-CDI.

Still applied to the CeAMatE-in is a set of monitoring tools and actual monitoring of the evolution of learning that aim to analyze the preferences of students and understand how they feel about the whole process, which will show the degree of motivation to learn and personal investment in the proposed work.

IV. LEARNING ANALYTICS IN CEAMATE-IN

A. *First results*

Data collection was made at the beginning of the semester of the academic year of 2015/2016 with the completion of DT, and in the period since the official opening of CeAMatE-in made on October 14 until February 11, coinciding with the beginning of the 2nd semester.

A total of 384 students performed the DT. They were distributed by degrees in the following engineering degrees in the subsequent way: Computer Science (212), Electromechanical (2), Mechanics (67), Electronics (9) Biological (22), Industrial Management (20), Civil (11) and Biomedical (41). At this early stage and prior to the focus on the most complex research issues of the Project, we found that 69.6% of the students (282 students) carrying out the DT had a score below 60% and were therefore advised to proceed to registration in CeAMatE-in. The definition of this 60% level of correct answers is not equivalent to the students having the basic knowledge to a full integration into UC-CDI. It only means the acceptance of a minimum alert threshold calling the attention for an eventual need for additional support in order to undertake the standardization of knowledge needed to entry into higher education.

Regarding the results of DT, 62 students completed the registration form needed for the attendance of CeAMaTE-in. 38 of these students really attended the Center and 12 more students without previous adherence attended, which made a total of 50 students who joined the program, registering a total of 302 visits in the mentioned period. The distribution per course showed a greater participation of Computer Science students. This result was expected since this is the ISEC degree with more students. There was also a predominance participation of 71 students repeating the year 2014-15 and 13 freshmen.

The follow-up time was adjusted as the students were requested adhesions and was divided evenly by 5 days a week, with a total of 17 hours per week. Wednesday was the busiest day of the week, evidence that meets what would be the choice of support time in CeAMatE-in, since students at ISEC in daytime, have this afternoon off.

Regarding the daily permanency time in the room, it varied between 5 minutes and 4h36m, with an average of 1h55m and a median of 1h45m. Regarding the distribution per student, the total stay registered over the semester lied in the range of 1h05m and 45h33m with an average of 11h46m and a median of 7h10m. It should be noted that participation in CeAMatE-in is voluntary, without any return in the classification in the course units of the degree, and the set times was made according to the students availability. Registered values were highly variable, as shown by the standard deviation obtained either in the daily stay (55m) or in stay of each student (11h52m). This induces the need to define motivation strategies for the students engagement in their autonomous learning processes, with the possible introduction of a B-learning component, with presence monitoring to measure the acquired knowledge.

As regards to the assessment that students make about the support given by the CeAMatE-in structure is clearly positive, averaging a very good evaluation, considered on a Likert scale of 5 points (1-very poor to 5-very good).

B. Educational Pathways

The understanding of the educational paths made by students who participated in the CeAMatE-in simultaneously with the contribution of the corresponding academic performance at UC-CDI is very relevant to this investigation. It is also a boost for the future of this project that offers an individual plan overcoming difficulties with mathematics; which are hindering the progress of students and encouraging withdrawal. This study will allow to draw conclusions that may prove significant in understanding the problems associated with learning and teaching of mathematics, demystifying it and making it more accessible to all. In addition, it will allow a better development of a set of mathematical strategies/activities for teachers that allow the compatibility of the topics to teach with the diversity of learning styles [15]. These approaches can be included in comprehensive learning environments in order to address the basic and fundamental needs of students, to fully appreciate the mathematical basis of issues.

In this context it was decided to make a detailed analysis with students of Computer Science, since the collection of data would be simplified by the fact that one of the researchers teaches UC-CDI in that degree course.

202 students of Computer Engineering performed the DT, and 115 achieved a result below 60%, which is defined as the lower acceptable limit of basic and elementary attainment for inclusion in UC-CDI and subsequent counseling for participation in CeAMatE; however, only 30 students completed their own PIT.

An analysis of students' educational paths took into account the characteristics of the student (type of access in higher education, type of mathematics in secondary school, grade obtained in DT), performance in participation in CeAMatE-in (attendance, participation, completion of the PIT and academic performance of each student at UC-CDI (attendance at practical classes, including the continuous component in the evaluation of UC-CDI, participation in assessment tests and results).

Regarding characterization of students, it was found that the results obtained in DT are quite low with 26 students (87%) obtaining a score of 40% or less. These are mainly students who are in higher education for the 1st time (67%) and students who have completed secondary education having passed Mathematics B (93%). This type of mathematics is directed at Scientific-Humanistic courses in Visual Arts and at Technology Courses, and its syllabus covers how to handle the calculation tools at the level of ideas for solving problems and applications, without directly tackling the content of the Core Zero Reference work [10] as adapted to Portuguese education.

The investigators considered that in a 13 weeks period of the program frequency, the working and study time in the CeAMatE-in should correspond to at least 2 hours per week, which would make up at least 26 hours. Of the 50 students who attended the CeAMatE-in, only 9 students of Computer Science fulfilled that goal. Therefore, the appropriation by the students of this service now provided by ISEC, is certainly a process that also requires the direct involvement of teachers of the courses and indirectly the whole community.

It should also be noted that only 5 students maintained their presence in the center in the examination period, although less frequently, with only one student maintaining his record of participation. It is also noted that the number of visits to the center is very low (50% of students of Computer Science made fewer than 6 visits), so that in the future motivation strategies for involving students in obtaining the knowledge considered essential for integration in the UC-CDIs will have to be devised.

No less important is the number of average daily hours, by participation, that these students dedicated to self-study to overcome their difficulties with mathematics, detected at their entry into higher education, and arising from the reduced preparation in mathematics. Analyzing the data we can see through observing the high standard deviation values (apart from those corresponding to students with a very small number of visits, who cumulatively do not spend much time in the center), that the participation of students is very irregular, and that no model of individual participation was observed during the semester. Compliance with the PIT was only achieved by two students, who went on to complete the second DT. Although there has been an improvement in the results they still fell short of desirable.

With regard to academic performance at UC-CDI, 20 students had an attendance frequency higher than 60% in the course. In order to encourage students in their continuous preparation, the teacher responsible for the UC-CDI introduced weekly systematization tasks on the matter taught, as a complementary component in the learning process. This strategy involved a commitment to (85%) attendance in theoretical-practical classes and delivery of work within a set deadline; 7 students adhered to this continuous component but only 4 completed the evaluation process. Of the five students, who presented evidence to the interim and final evaluation, only one student achieved success.

V. CONCLUSIONS AND RECOMMENDATIONS

We stress that the results obtained refer to the first phase, design implementation – considered, as needs, diagnosis data. Indeed, since it was not possible to build a behavioural profile able to produce success in UC-CDI the data not only clearly demonstrate that students require additional support to overcome their difficulties in basic knowledge essential to integration in Higher Education, but also evidence an emerging intervention to influence the motivation to learn, to combat early abandonment of the course and avoid failure.

Concerning participation in the CeAMatE, the results suggest the importance of dissemination strategies, so that all students know the existence and functioning of the Center and can take advantage of this service that ISEC offers its students, to build a sound base of mathematical knowledge, recognized as essential for successful integration into the Differential and Integral Calculus Course Units.

The results for the participation in the CeAMatE are very variable, which points out a need to define motivation strategies for involvement in students' autonomous learning processes, with the possible introduction of a distance component, and monitoring attendance to so as to measure knowledge acquisition. The adaptation of resources to the learning style is certainly one of the keys that could facilitate the teaching/learning of these students on their path to Engineering, as the diversity of resources available in CeAMatE-in is a concern of the team involved in the project. Translation of MathCenter files into Portuguese, although deemed a non-essential task, may be a strategy to pursue to promote reversal of the behavior adopted by students in the learning process.

Given the personal and economic investment that students and/or families make to get the degree that will enable them to improve their work prospects, it seems appropriate to present a set of strategies that improve the way that the ISEC receive and welcome new students especially those who do not follow the general regime. Our experience as teachers leads us to believe that the sooner students tackle the mathematics course units, the greater the probability of success in engineering courses. This view is reinforced by descriptions provided by the students themselves, whose expectations are directly proportional to their level of knowledge [9]. We therefore consider it important that our Institution should continue to invest in the operation of UC-CDI in alternate semesters (also in the 2nd semester), as a measure aimed at academic success, allowing adequate and timely preparation of students with regard to knowledge considered essential in the 1st semester.

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REFERENCES

[1] M. A. Barbosa, "O insucesso no ensino e aprendizagem na disciplina de cálculo diferencial e integral [The failure in teaching and learning in differential and integral calculus course, *in english*]," Dissertação de Mestrado [Master's thesis], PUCPR, Brasil, 2004.

[2] W. M. Resende, "O ensino de Cálculo: Dificuldades de Natureza Epistemológica [Teaching Calculation: difficulties of epistemological nature, *in english*]," Tese de Doutorado em Educação [Ph.D. thesis], Faculdade de Educação, Universidade de São Paulo, USP, Brasil, 2003.

[3] O. Gill and J. O'Donoghue, "The mathematical deficiencies of students entering third level: An item by item analysis of student diagnostic tests," in *Proc. of Second National Conference on Research in Mathematics Education*, Dublin, UK, 2007, pp. 228–239.

[4] M. Cardella, "Which mathematics should we teach engineering students? An empirically grounded case for a broad notion of mathematical thinking," *Teaching Mathematics and its Applications*, vol. 27, no 3, pp. 150-159, 2008.

[5] O. S. Rosa, "Aspectos Motivacionais do Cálculo Diferencial e Integral [Motivational aspects of Differential and Integral Calculus, *in english*]," Programa de Pós-Graduação Stricto Sensu, Mestrado Profissional em Educação Matemática, Universidade de Severino Sombra, Brasil, 2011.

[6] M. E. Bigotte, C. Fidalgo, J. R. Branco and V. Santos, "ACAM – Competency Assessment/Improvement Actions: Diagnose to guide," in *Proc. of the 17th SEFI MWG Seminar Mathematical Education of Engineers*, 2014.

[7] H. N. Cury, C. R. J. Azambuja, F.A. R. Silveira, N. S. Gonçalves, B. Konzen (December, 2011) Análise de Erros em disciplinas Matemáticas: um estudo com alunos de engenharia e ciências da computação [Error Analysis in Mathematics subjects: a study done with engineering and computer science students, *in english*]. [Online]. Available: http://www.eee2005.uerj.br/artigos/artigo04.prn.pdf

[8] H. Cury, "Análise de erros em disciplinas matemáticas de cursos superiores, [Error analysis in mathematical courses of higher degrees, *in english*]" relatório Técnico-Faculdade de Matemática PUCRS, Brasil, 2007.

[9] M. E. Bigotte and A. M. Coelho, "Mathematics in Engineering: The Perspectives of Students," *in Proc. of the 22nd Annual Conference of the European Teacher Education Network, 2012.*

[10] SEFI (2013) A framework for Mathematics Curricula in Engineer Education. Mathematics Working Group.

[11] M. Carr, C. Fidalgo, M. E. Bigotte, J. Branco, V. Santos, E. Murphy, and E. Ni Fhloinn, "Mathematics diagnostic test in engineering: An international comparison between Ireland and Portugal," *European Journal of Engineering Education*, 2014.

[12] M. E. Bigotte and C. Fidalgo, "O ensino da Matemática nas licenciaturas de Engenharia: ACAM-Avaliação de Competências/acções de melhoria [The teaching of mathematics in undergraduate Engineering: ACAM-Assessment Skills/Improvement actions, *in english*]," in *Proc of the 1st International Conference of the Portuguese Society for Engineering Education*, 2014.

[13] M. E., Bigotte, D. Martins, and E. Silveira, "CeAMatE-Um Programa de Promoção de Conhecimentos Matemáticos para Alunos de Engenharia, [CeAMatE – Promoting a Mathematical Knowledge Program for Engineering Students, *in english*]" *Revista de estudos en Psicologia Y Educaión*, vol. Extr., no 1, pp. 119-122, 2015.

[14] SEFI (1999) The Newsletter of the SEFI Working Group on Mathematics in Engineering Education. Spring Edition.

[15] M. E. Bigotte and A. Gomes, "The CeAMatE-on project: an online Mathematical Support Center in Engineering," in *Proc of XVII Simpósio Internacional de Informática Educativa*, 2015, pp. 169-175.

[16] R. M. Felder, and B. A. Soloman, (s.d.) Learning styles and strategies. Richard Felder's Education-Related Publications. [Online]. Available: http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/styles.html