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Mathematics curriculum reforms in undergraduate engineering: An institutional analysis

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This paper analyses the curricular reforms that have been carried out in the engineering mathematics curricula in the context of the Universidad Técnica Particular de Loja (Ecuador). Starting from diverse documentation related to a specific curricular reform, we conduct an analysis using the levels of didactic codeterminacy. More concretely, we analyse the criteria used to develop the reform, the real and effective changes that are reflected in the new programmes as well as the level of questioning of the knowledge to be taught.

Keywords: Teaching and learning of mathematics for engineers, Curricular and institutional issues concerning the teaching of mathematics at university level.

INTRODUCTION

Research on mathematical education in engineering education is a flourishing field, especially within the framework of the anthropological theory of the didactic (ATD) (Chevallard, 1992). The previous CERME (see, for instance, González-Martín et al., 2019) and the INDRUM conferences have also gathered and discussed research papers on engineers' mathematics education. Moreover, addressing both, problems related to the teaching and learning of mathematics for undergraduate engineers and the advances in creating suitable conditions for innovative proposals in mathematics for engineers (González-Martín et al., 2021). The analysis of how mathematics teaching programmes have been defined and implemented are important aspects to progress on analysis of the ecological conditions, in the terminology of the ATD, under which mathematics is taught for undergraduate students. With this respect, Bosch et al. (2021) focus on analysing some didactic phenomena related to the definition of university mathematics programmes, when comparing how they have been established in mathematics university degrees in some European countries. The research presented in Kaspary (2020) presents some advances in the analysis of the interaction between the different actors and institutions involved in programmes' definition.

Another area of research is that of discontinuities, already announced by Felix Klein (2016). The *first discontinuity* refers to the students' difficulties encountered in the transition from secondary school to university. Several studies have addressed this phenomenon, including those by Gueudet (2008) and Fonseca (2004) about mathematics and didactic discontinuities in the transition from secondary school to university. The *second discontinuity*, announced by Klein, focus on the discontinuity that mathematics students experience when moving from university to become

secondary school teachers, when they are faced with the transposition of scholarly knowledge into knowledge that is to be taught.

In the case of mathematics education at engineering degrees, the recent work by Florensa et al. (2022) focuses on the characterisation of the *triple discontinuity* in mathematics education for engineers. Specifically, the first one is equivalent to Klein's first discontinuity (transition from secondary school to university), which according to Fonseca (2004) since in the tenth conjecture he states that:

School mathematics has a strong pre-algebraic character in secondary school and undergoes an abrupt algebraization at the beginning of university education, given that in secondary school, equations and formulas are used as calculation algorithms, while at university they are used as algebraic models. (Fonseca, 2004, pp. 147, our translation).

This conjecture is evidenced in the study carried out by Cuenca and Granda (2020) at the Universidad Técnica Particular de Loja (UTPL) in which they found that students face difficulties when solving problems in contextualized situations, being accustomed to solving them in an algorithmic and mechanic way.

The second discontinuity occurs between mathematical and engineering courses. In other words, this is a discontinuity that is internal to the school of engineering and is associated with the difference between the mathematics courses compared to the engineering courses. The third discontinuity refers to the passage from engineering school to professional practice.

In this context, our research focuses on the curricula reform as it has occurred in the Universidad Técnica Particular de Loja (UTPL), selecting the mathematics training of undergraduate engineers. Specifically, we address the following research questions:

- RQ1. How is the need for a curricula reform justified? In what terms do the intervening "noospherian" institutions describe and justify this need?
- RQ2. What are the criteria this reform is based on?
- RQ3. Which are the real and effective changes that crystallise in the resulting mathematics programmes?

CONTEXT AND CURRICULAR REFORM

The university institution we focus on is the Universidad Técnica Particular de Loja UTPL, placed in the city of Loja (Ecuador). This is an institution that offers ten university degrees in engineering: agricultural, food, civil, geological, computer, telecommunications, chemical, industrial, logistics, and transport. These ten engineering degrees have a 9-semester structure, which is developed in four and a half years and with an academic load of 15 credits (not ECTS) per semester (where 1 credit is equivalent to 26,67 hours of teaching). As it is usual in most of engineering programmes (Romo, 2009), during the first four semesters all degrees have common subjects of mathematics.

In the context of the UTPL, the curricular reform was initiated from the request of the Higher Education Council to the higher education institutions to work on the reform of

university degree programmes under the third transitory provision of the Academic Regulations issued by the council (CES, 2015). Thus, the process of restructuring the mathematics courses was initiated considering some results obtained by Cuesta et al. (2016), stating that university students had difficulty understanding and addressing problems, which are often non-adapted to the university degree they have chosen. This is aligned with González-Martín and Hernandez-Gomes (2020) and González-Martín et al. (2021) who state that mathematics content is generally taught separately from professional courses, which implies that there is a disconnection between mathematics and its application to engineering in contexts. Cuesta et al. (2016) also mention that one of the possible causes that pronounce these problems is in the curriculum itself. In the UTPL curriculum, until 2016, mathematics subjects included a wide range of content that grouped together two or more domains (e.g. “Mathematics” course covered contents on the domains of Geometry, Linear Algebra, and Statistics). Furthermore, there is not a compulsory proposed sequencing of mathematics subjects. Sometimes students, joining one advanced course (e.g. Calculus), have not passed courses with more basic content (e.g. Basic Mathematics).

Implementing of the curricular reform

The team in charge of working on the reform consisted of two teachers: the first with a university background in pure mathematics and the other with a background in mathematics education. This team oversaw the project of restructuring the mathematics courses. They were also responsible of writing the final report of the reform project (Cuesta et al., 2015). This team of specialists was supported by 4 lecturers from the Physicochemical and Mathematics departments, who carried out an analysis of the mathematics courses taught in all the university's degree before the reform in 2016. This project resulted in a final report on the redesign of Mathematics and Physics subjects, which was submitted to the UTPL authorities.

Degree	Courses					
	<i>Pre-reform</i>	Credits	Year	<i>Post reform</i>	Credits	Year
Geology and mining engineering	Calculus	6	1	Geometry fundamentals	3	1
				Linear algebra	3	1
				Univariate mathematical analysis	3	2
	Statistics	4	2	Multivariate mathematical analysis	3	3
				Differential equations and numerical methods	3	4
Civil Engineering	Mathematics	7	1	Geometry fundamentals	3	1
				Linear algebra	3	1
	Calculus	7	2	Univariate mathematical analysis	3	1
				Multivariate mathematical analysis	3	2
	Advanced calculus	6	3	Differential equations	3	3
Numerical methods				3	4	
Computer and	Mathematical fundamentals	4	1	Mathematical fundamentals	3	1
	Calculus	6	2	Linear algebra	3	2
	Statistics	4	3	Univariate mathematical analysis	3	2

Information Systems engineering	Quantitative methods	4	4	Differential equations and numerical methods	3	3
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Table 1: Mathematics courses and workload pre and post-reform

Table 1 presents a summary of the different mathematics courses proposed in the pre- and post-reform curriculum, part of the three main engineering degrees in the UTPL. These curricular and programmes reforms are the result of, on the one hand, the specialist team who proposed the distribution of the courses and the prerequisites. On the other hand, the local teams who worked on the reform of the course programmes, selecting, and reorganising the contents.

DATA SELECTION AND METHODOLOGY

To analyse the reform process, the material to be analysed was selected by the authors of this paper. Firstly, three of the ten engineering degrees taught at the UTPL were selected: Geology and Mining Engineering, Civil Engineering, and Computer and Information Systems Engineering. The criteria for selecting them was that they are the engineering degrees with a higher load of mathematics courses in the post-reform. Then, the pre- and post-reform programmes of the mathematical subjects are used as empirical data for the analysis. Specifically, there have been analysed 3 pre-reform courses (Mathematics, Calculus, and Advanced Calculus) and 6 post-reform subjects (Univariate Mathematical Analysis, Multivariate Mathematical Analysis, Linear Algebra, Fundamentals of Geometry, Differential Equations, and Numerical Methods). We have decided not to include, in this first round of analysis, the courses on Statistics.

Secondly, the reports produced by the teams and commissions responsible for the reforms have been also important documents for the analysis. Finally, eight interviews have been carried out with the teachers in charge of these courses (five of them with experience in the pre-reformed courses) to complement the information about how the programmes are effectively implemented in the university classrooms. Due to space limitations, we do not include this last empirical data in this paper.

Levels of didactic codeterminacy as methodological tool for the analysis

The analysis of the empirical material has been done through the theoretical and methodological tool of the levels of didactic codeterminacy (Chevallard, 2002). Our aim is, in part, to analyse the conditions, also the constraints, set up by the curriculum reforms developed at the UTPL. To develop this analysis, we use the levels of didactic codeterminacy (see Figure 1, adapted from Barquero et al., 2014) as a common framework to illustrate and distinguish between the different conditions and constraints affecting the teaching and learning processes of mathematics courses for the training of undergraduate engineers. These levels go from the most generic level, civilisations, to the most particular one, the specific questions considered in a particular course. The lower levels refer to the way a discipline, mathematics in our case, is organised (in domains, sectors, themes, and questions) in a given teaching and learning process. The upper levels refer to the more general constraints coming from the way our civilisations

and societies, through schools (universities, in particular) and their particular pedagogical conditions, organise the teaching and learning of the disciplines.

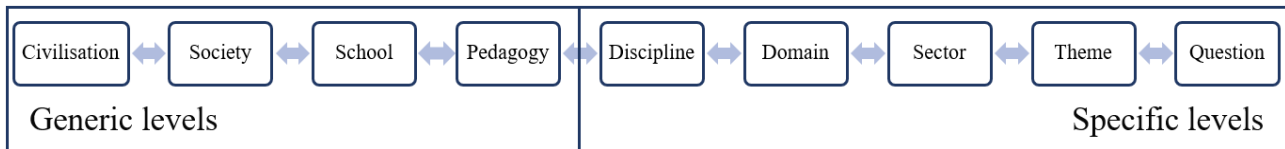


Figure 1: Scale of levels of didactic codeterminacy.

The second notion mobilised in the analysis is that of the “noosphere”. The noosphere is understood as the set of institutions and agents belonging to these institutions that decides and delimits the mathematics to be taught in school institutions, in particular, at university. The “noosphere” goes beyond the community of teachers, and includes, for instance, agents that legislate on curricular changes, teachers' associations, university quality agencies, among others. Thus, considering the levels of didactic codeterminacy and the notion of the “noosphere”, an analysis of the documents cited has been carried out and is presented in the following section.

RESULTS

Origin and need for the reform: proposals from the commissions

The reform arises in front of several needs that can be detected in the official documents considered and in the corresponding interviews with members of this commission in charge of the curriculum reform. Firstly, one of the stated aims is to close the gap between the Ecuadorian secondary education and the first years at university. Secondly, other aims are to homogenise the subjects, disaggregate them and ask about prerequisites before selecting the courses to be taken. The report drawn up by the commission of experts highlights that:

[...] The current curriculum at UTPL has a serious deficiency since there is no sequence of components. Under these conditions, students enrol in one course without having studied the necessary content taught in other course (Cuesta et al., 2015, p. 7, our translation).

Thirdly, and resulting from an interview with one of the two members of the commission, it is explained that the commission work consisted of analysing the content of the subjects: Mathematics, Basic Mathematics, Mathematics for the biological sciences, Pre-calculus, Calculus, Calculus I, Calculus for the biological sciences, Mathematics for the biological sciences II. It was then found that more than 80% of the content was similar in the different engineering specialties, leading them to work on unifying the content into common courses to then look for the specificities according to the engineering degree.

Last but not least, the other member of the commission highlights the importance of showing the usefulness of mathematics to thinking and solving problems in the engineering context. In one of the reports delivered, it is underlined that:

[...] After restructuring the subjects, it is expected to result in a course that: (i) enables the student to acquire the language of mathematics and the ability to use it to express and understand

mathematics and the science under study, and (ii) that enables the acquisition of the fundamental concepts in mathematics in a meaningful way. This is precisely the most important challenge of mathematics teaching, whose current formalistic approach leads to the fact that the knowledge acquired in class is not useful for students.

At the *society-school level*, the reports underline the need of characterising better and smoothing the abrupt change between the mathematics taught at the Ecuadorian secondary education and that of the first mathematics university courses.

In relation to how the teaching of the different disciplines is organised, that is, placing at the *university-pedagogical level*, several aspects are emphasised. The first is related to the fact that, as the pre-reform subjects are arranged, there is a great deal of intersection in their contents. This leads to the proposal to unify them insofar as they are common and to integrate a specificity by promoting the use of contexts and situations specific to the studies being undertaken. As described above, it is proposed that in addition to the mathematics subjects providing a “mathematical language and the ability to grasp and use it in mathematics and other disciplines”, the ability to use this knowledge in the specific contexts of application in the professional field of engineers must be assessed.

At the *disciplinary-pedagogical level*, another agreement is when proposing a better sequencing of the subjects and to propose subject itineraries, which cannot be started without the prior approval of those taken. Consequently, the mathematics courses are proposed with less teaching load (from 6-7 credits in the pre-reform to 4 credits in the post-reform).

Effective changes in the resulting programmes

As already mentioned, we base our analysis of the mathematics courses’ programmes in the pre-reform (3 courses) and in the post-reform (6 subjects). The main tool here used are the specific or lower levels of didactic codeterminacy, which are used to analyse how a particular discipline is organised into domain, sector, theme, topics, and type of tasks. Figure 2 shows the results using the levels of didactic codeterminacy for the course of “Mathematics” (pre-reform course). Figure 2 and Table 2 show how the contents were redistributed, changed or reorganised in the post-reform courses proposed. Due to the space limitation, we are not able to include the analysis developed for the rest of the courses, but the results are available at https://bit.ly/INDRUM2022_RM.

Concerning Figure 2 (and the ones the reader can find in the repository), it is important to explain that different colours are used to indicate how the content of a pre-reform course is distributed in different subjects (indicated between them with different colours) in the post-reform. In the case of the analysis of the “Mathematics” course’s programme (pre-reform vs post-reform), the summary is illustrated in Figure 2. Based on the contents structure of the “Mathematics” course, the orange boxes indicate the contents that were assigned to the domain “Linear Algebra” that are transferred to the course of Linear Algebra in the post-reform, the dark green the ones assigned to the

domain “Analytical Geometry” that are transferred in the post-reform as a course of Geometry fundamentals and, in light green colour, the new learning outcomes declared for each of the courses (“Linear Algebra” or “Geometry fundamentals”), and associated to specific themes.

Pro-reform course	Post-reform course	Comments about the changes in the post-reform programmes
Mathematics	Linear algebra	One new sector, ten topics, 35 types of tasks, and one type of task from the geometry domain is maintained.
	Geometry fundamentals	Two new domains, seven sectors, twelve themes and 45 types of tasks are added.
Calculus	Univariate analysis	14 new types of tasks.
	Multivariate analysis	One new domain, two sectors, seven topics, and 37 new task types.
Advanced Calculus	Differential equations	Two new sectors, three new themes and one new task types.
	Numerical methods	Not derived from any (pre-reform) course

Table 2: Changes identified in the courses in the post-reform

In the initial analysis of the course of “Mathematics”, two domains are identified “Linear algebra” and “Analytical geometry”. They are, in fact, delimited as two courses in the post-reform. Regardless of this change, the distribution of the sectors, topics and types of tasks remain almost the same plus some additions. Most of these “additions” are located at the specific levels of the type of tasks associated with each topic. In other words, the new additions do not introduce big changes to the rigid structure of the two post-reform courses.

A similar situation occurs with the calculus and advanced calculus courses. The changes observed are oriented to redistribute the contents in the new courses in the post-reform, as well as to add new types of tasks. Additionally, the inclusion of the numerical methods course, which does not derive from any course from pre-reform, includes a new domain and three new sectors "errors, roots, curve fitting", that helps to distribute better the contents.

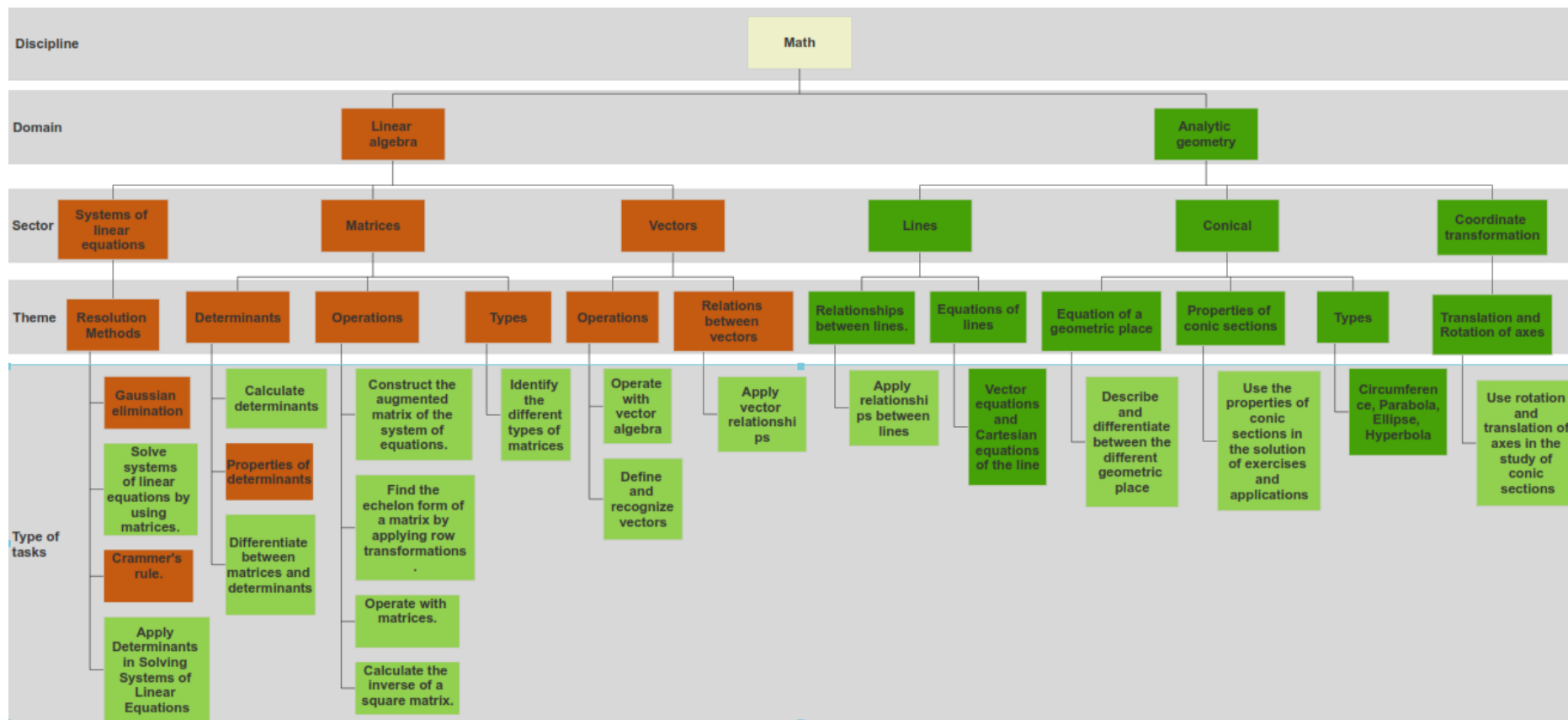


Figure 2: Analysis of the subject of Mathematics (7 ECTS, pre-reform) in relation to the levels of didactic codeterminacy

CONCLUSIONS AND OPEN ISSUES

This work can be considered as a first step of a broader analysis that is being conducted, and which will be enriched by the results of interviews with different teachers involved in the mathematical courses at UTPL. Nonetheless, the data analysed show that the noospherian institutions, in our case the Higher Education Agency and the commission in charge of the reform, play a crucial role as the initiator of the reform process. In addition, this agency establishes the main criteria to be followed, focused on softening the transition from upper secondary mathematics education to undergraduate programmes for engineers. Additionally, the analysis of the pre- and post-reform curricula and programmes reveal that the main changes have been introduced at the *pedagogical level*. That is, the changes have consisted of proposing a redistribution of contents into the different courses (disciplines-domains), a shortening of the courses (by a reduction of the number of credits) and the organisation of a pre-requisite system between courses. Most of the changes, besides this reorganisation of the already existing content, is the introduction of new content, most of the time at the very specific levels of the “type of tasks” or some new “topics”. Another relevant change is the introduction of a new subject related to “Numerical Methods”. In this case, the definition of the contents introduces more novelties than in the rest of the cases.

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