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A place for arguing in engineering education: a study on students' assessments

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This paper focuses on the issue of how engineering programmes demand and/or promote argumentative reasoning, which is a subsequent aspect of curricular development. This was the main objective of the project on which this paper reports. This is to say that the focus is on assessment as a way to establish to what extent argumentative reasoning is demanded and mobilised in teaching and learning processes. This aim was achieved using a sample of assignments developed in courses in different Bologna undergraduate programmes at the Engineering School at the University of Porto, during the first semester of the academic year 2009/2010. Whereas problem solving in engineering constitutes a structural element in the curricular organisation of the engineering programmes and is strongly related to argumentative skills, it was possible to conclude that students demonstrate and explain extensively, but do not argue, possibly because their teachers do not invite them to do so in assessment situations.

Keywords: argumentative skills; curricular development in higher education

1. Introduction

The crucial changes that have occurred in the curricular and pedagogical structures in European higher education can be seen as a result of the dissemination of this education level. Furthermore, higher education dissemination is both a condition of success of the Lisbon agenda and a mandatory aim for the 'Europe 2020' agenda. The need to guarantee the success of higher education for all students, despite their economic conditions, refers to an ideal of social justice. The social justice at stake here is one that allows for intervention and citizenship capability, which cannot be guaranteed by access to basic education. On the other hand, it is also a condition for efficiency, quality and survival of the institutions of higher education (Bramming 2007).

The Bologna Treaty points out a training paradigm whose matrix is centred on learning, in the development of personal and professional skills and in the active participation of students, now considered as co-builders of their own learning.

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Together with the process initiated by the Bologna Treaty (1999) and with the criteria established by the European Qualifications Framework in 2000, a group of European universities started the Tuning Project (see http://europa.eu.int/comm/education/policies/educ/tuning/tuning_em.html), which drew higher education guidelines, in order to support the accomplishment of a desired convergence and the organisation of their syllabi.

While valuing a training system that goes beyond contents, the Tuning Project took as reference the paradigm underlying the Bologna discourse, bringing to the university's debate agenda the reflection about curricular organisation of the study programmes, the concrete activities in relation to the general skills to be developed by the students and the learning outcomes specific to each area of knowledge.

In addition to the traditional engineering technical skills (such as designing and engineering problem solving), there is a need to emphasise other skills, such as communication abilities, analysis, synthesis and decision making. These are the skills that stand on the development of argumentation, which are in focus in this paper. This group of skills is usually referred to as 'soft skills'.

It is clear in recent literature (Andrews 2010) that these soft skills are necessary to achieve success, but were generally missing in students, due to their families' lack of a cultural background that would stimulate argumentation skills. Therefore, it becomes urgent that higher education training projects do not lose track of this focus (Davies 2008, Andrews 2010).

Learning how to learn, being able to work in a team and to conceive adequate strategies to solve problems or being able to argue in order to confer credibility to a perspective are skills to be developed as priorities in terms of training objectives, whatever the area of study (Lea 2004).

However, it is a common understanding that soft skills are not dissociated from the approaches and concepts that, in the end, do justify and support them. No strategies or procedures can be accepted without the cultural framework that makes the acceptance process possible. This means that the added value of soft skills does not necessarily lead to devaluation of the contents that shape the curricular decisions. These contents merely become the object of a type of pedagogical management with more decisive cultural, intellectual, social, civic and formative impact on the subjects under training. Following this perspective, one can affirm that the soft skill concept, rather than being seen as incompatible with utilitarian information about the facts, points to recuperating the information from its less common use cases. Thus, it can be considered as a motor of a training project, which is congruent with the challenges and demands of life in democratic societies. Thus, knowledge – while an object of permanent enquiry – acquires a great importance that it never had before, as an instrument of daily enactment. As Andrews (2010) argues, political and technical actions depend more and more on democratic consensus, built upon argumentative reasoning.

Soft skills development is explicitly assumed as a training aim in engineering, namely, when the conceiving, designing, implementing, operating (CDIO) model is defined in European terms. The model has been successfully used in many universities to define curricular content and the skills required for engineers in a wide range of scientific domains (Bankel et al. 2003). The motivation for the development of this framework is clearly stated in the CDIO website (see <http://www.cdio.org/>): 'industry in recent years has found that graduating students, while technically adept, lack many abilities required in real-world engineering situations'. In order to overcome this problem, the CDIO syllabus defines a set of learning outcomes belonging to four main areas: (1) technical knowledge and reasoning; (2) personal and professional skills and attributes; (3) interpersonal skills: teamwork and communication; (4) CDIO systems in enterprise and societal contexts. In synthesis, one can state that CDIO considers that professional and technical skills require personal and interactive skills development. It must be noted that each of those areas is further subdivided into specific engineering education learning outcomes. The academic staff in charge of each course can then proceed to design the corresponding learning and assessment activities.

The CDIO framework is not the only engineering education model available. Particularly in Europe, the implementation of the Bologna process reinforced the development of the European Accreditation of Engineering Programs (EUR-ACE) standards (see <http://www.enaee.eu/>), defining a 'European quality label for engineering degree programs at Bachelor and Master level'. The EUR-ACE framework standards define six categories that may be seen as an alternative to the CDIO syllabus: (1) knowledge and understanding; (2) engineering analysis; (3) engineering design; (4) investigations; (5) engineering practice; (6) transferable skills. A comparison of these two quality assurance systems (CDIO, EUR-ACE) can be found in Malmqvist (2009).

Concerning this analysis, both models require the referred soft skills. Moreover, the Engineering School of the University of Porto is deeply interested in developing such skills, which are emphasised in several initiatives promoted by its faculty members and it can be considered an example of what the university is able to promote in terms of quality in higher education. In a broader perspective, teaching technical issues is not a question of manufacturing objects, but also a matter of justifying, arguing and communicating ideas (Emilsson 2008, Nair and Patil 2009). This means that the learning paradigms are changing in those technical areas and respective learning outcomes, namely, when connected with communication and argumentative skills (Lappalainen 2009, Andrews 2010).

Since many of the undergraduate and Master's degree programmes of the Engineering School are currently organised in accordance to the CDIO model, it began by building a list of all courses that included the 2.1 CDIO syllabus entry (personal and professional skills and attributes/engineering reasoning and problems).

This paper focuses on the issue of how engineering programmes demand and/or promote argumentative reasoning, which is a relevant feature of the curricular development processes. The structural conductors of this project are:

- (1) The true importance of argumentative practices in the training and assessment processes of the students.
- (2) The presence of structural argumentative elements in the assessment of student learning.
- (3) The forms of reasoning used by the students in the production of elements of proof in their learning.
- (4) The modes of communicating pragmatic procedures that are associated with the production of arguments.

2. Methodologies

The identification and characterisation of what could be argumentative skills and its textual evidence in the discourses constitute fundamental entrance points. These procedures enable everyone to understand the ways in which students apply these skills in their texts, especially in those that are the core outcomes in their learning processes, such as the assessment elements. The project analysed the assignments produced by the students in view of the use of argumentative skills. The respective sample was collected in the Engineering School, during the first semester of 2009/2010, and was composed of assignments developed in courses in different undergraduate engineering programmes.

The present authors chose for their study the courses that were listed in the syllabus of the respective degree programme, as these were the ones that might develop the CDIO skills that have been identified – such as problem solving – and concurrently the courses whose teachers found the challenge of the project interesting, i.e. to know whether and how their students used argumentative skills in their assessment tasks.

A *corpus* of materials made up of eight courses was collected for analysis. An optional course in the group was included, which is offered to the Engineering students. It substantiates a philosophical view of the technique and is entitled Philosophy of Science: central problems. Taking into account the reduced number of students and assignments produced from this course, as well as the transversal vocation, the analysis is presented separately from the group of the other courses analysed.

The assessment proposals from the teachers of the selected courses are not very diverse and include tests, research assignments and reports of simulated laboratory experiences. This choice of assignments resulted from the response given by the teachers as to whether assessment instruments proved to be more capable of generating argumentative skills in the students. At a second reflective decision, the most accessible materials that would facilitate the handling of the digital data were chosen. In spite of these decisions, and because the present authors were looking for the diversity and the saturation of the categories to be analysed (rather than their count), it was possible to add to the collection tasks completed by students in an evaluative situation that seemed to cover the previous list. Those tasks include digital texts and manuscripts, learning assignments developed out of lessons and in class tests, as well as group work and individual papers.

Data were handled according to the three axes of analysis pertaining to the basic issues that had been identified: the characterisation of the argumentative structure (Muller Mirza and Perret-Clermont 2009), the identification of the main logic reasoning that sustains the production of arguments and the identification of the areas of communicative circumstance. The argumentative text is an author's production about a topic that has an audience that it intends to convince as an individual or collective target. Therefore, it makes sense to speak about the rhetoric modes of persuasion. Namely, it is interesting to study the modes in which argumentation and the spheres of communicative circumstance are promoted. The spheres of communicative circumstance are the topic that is discussed – logos, the subject that speaks – ethos and to whom he/she speaks – pathos. The arguments used also depend on that structure (Grácio 1998).

Data were analysed using two processes: statistical analysis of the occurrences of the different categories of discourse and reasoning that were identified in five courses of the engineering programmes. Some data could not be converted into text to be imported into the qualitative data analysis software program (NVIVO) so data content analysis of the remaining courses was not possible.

3. Results

The present authors analysed 226 assignments submitted by students from the Engineering School. These 226 assignments were provided by students from eight courses, enrolled in different years and different majors. The courses with the greatest number of assignments were Telecommunications and Operations Research, with 72 and 54 student assignments analysed respectively. On the other hand, Philosophy of Science and Control Systems were the courses with the least assignments analysed, with five and seven assignments.

Concerning the year in which the students are enrolled, 28 assignments were from first-year students, 19 from second-year students and 159 from third-year students.

The students came from two major engineering fields: 152 assignments were completed by students in the Integrated Master's Degree in Electronic Engineering and 54 by students in the Integrated Master's Degree in Civil Engineering.

3.1. Student reports and essays

This section now discusses only the student assignments from three of the eight courses – Microprocessors, Programming and Philosophy of Science – in which the students had to write a short

Table 1. Distribution of argumentative elements by course

	Philosophy of Science n = 5	Microprocessors n = 20	Programming n = 38	Totals
Arguments	3	19	1	23
Conclusions	2	8	1	11
Counter-arguments	0	9	0	9
Objections	1	11	0	12
Problem	3	1	0	4
Thesis	1	4	0	5

report or essay. Regular tests and other assignments from the remaining courses will be analysed below.

The analysis of the three courses in this group shows that Microprocessors is the course that generates more argumentative reasoning in terms of its diverse essential elements (Table 1).

In fact, 19 arguments in the Microprocessors assignments were found from the total of 23 in all the assignments. In addition, there is a larger set of argumentative elements found in the assignments of Microprocessors than in the assignments of the other two courses.

In the Programming course, the current authors selected for analysis a part of one exercise that asked the student to 'describe verbally a "calculate" mode function that would determine and return the value that appears more frequently in a group of values'. In the answer to that question, almost all of the students described the function but did not use argumentative skills, such as discussing other possible ways to achieve the same result.

Another result shown in Table 1 is that the argumentative elements more generally used by the students are arguments and objections. A deeper analysis of the basis of arguments and/or objections shows that these kinds of reasoning are supported by facts, derived from theory, experience or simulations.

Similar to what was referred to above in terms of the use of arguments, the use of objection appears to be focused on facts; in most cases, it is related to problems or limitations verified in practice, as demonstrated in the following example:

Through the circuit test we noticed that inversely there are failures that completely put at risk the correct functioning of the project. (Microprocessors)

The argumentative reasoning elements that were less evident in the students' assignments of this course group are identification of the problem, explanation of the thesis and counter arguments.

In terms of the reasoning structure used by the students (Table 2), it was found that the abductive and deductive types of reasoning are used more frequently. Again, Microprocessors was the course where the greater number of instances of that kind of reasoning were found (26 references from a total of 32). That kind of reasoning is illustrated by the following examples found in the assignments:

Example of abductive reasoning: If the computer program is sufficiently long and complex then no human agent (...) can say exactly what is the output generated, or that an aleatory generator associated to the program would be able to create original content, impossible to predict and explain by the creator of the machine.

Example of deductive reasoning: When this interruption occurs the program calls this routine, 'wave', which will send a voltage value to the DA converter. Therefore, a value for the DA converter is returned every time an overflow occurs in the timer0, as explained previously. This is the way to control the frequency of the wave and consequently the sound reproduced by the TH0 value.

Considering the three rhetoric modes of persuasion, it was observed that the majority was centred on the logos mode, with 42 occurrences, from the total of 86 persuasion occurrences registered (Table 3). However, many students also used the pathos mode, centring on the person to whom the communication is directed; in this case, the teacher. From the total of 86 persuasion

Table 2. Distribution by type of reasoning structure used

	Philosophy of Science n = 5	Microprocessors n = 20	Programming n = 38	Totals
Abductive	2	16	1	19
Analogical	2	0	0	2
Deductive	2	10	1	13
Inductive	0	1	0	1

Table 3. Distribution by rhetoric modes of persuasion

	Philosophy of Science n = 5	Microprocessors n = 20	Programming n = 38	Totals
Ethos	0	10	1	11
Logos	2	14	26	42
Pathos	0	33	0	33

instances, 33 correspond to the pathos mode. Thus, the arguments are selected in accordance and depending on the recipient. The case of the Microprocessors course is different from the global results, because in that course the persuasion mode used more frequently was pathos, as in the following example, where a student justifies the limitations of his assignment:

I was only able to achieve a few objectives within those stipulated. Not because I did not understand but due to lack of time, and application and motivation, partly. (Microprocessors)

The total number of instances of the ethos mode in all three courses was only 11, indicating that students give less importance to the matters of argument legitimacy than to the message content.

Not all three modes of persuasion will appear when the students' tests are analysed in the next section. They have all been found in this section, because students' reports and essays have been analysed. As has been seen, those modes of persuasion have been used mainly when the students try to justify the limitations and problems encountered.

3.2. Results of the tests data

Data handled quantitatively are in conformity with most of the qualitative data, presented in Tables 1 to 3, even though they do differ in some aspects.

As can be observed in Table 4, most of the elements of argumentative reasoning used by the students are based in theories (111 in a total of 313) and in facts (100 in 313). Arguments structured on a theoretical base have their foundation in theories supported by different authors or entities, from which one structures and formulates the arguments and extracts results, and are considered objections. On the other hand, arguments structured on facts rely on students' experimental practice, through the use of empirical verifications and simulations. An example of this type of argument is the following:

Even though it works, because it has to test the parameters several times, it becomes slower and less effective.

Conclusions are extensively used by students, displaying a significant representation in the sample of the tests, in opposition to what was observed relatively to the data coming from assignments and reports. This type of conclusion can be illustrated with the following example:

By comparing the theory and the practice, it is possible to conclude that the sound waves are identical even though we do not visualize the light wave in the condenser's current (and secondary of the transformer) when this one descends from its peak until it becomes null.

Table 4. Distribution of the elements of argumentative structure by the courses analysed

	Computation n = 13	Electronics n = 26	Operations Research n = 55	Control Systems n = 7	Telecommunications n = 37	Totals
Thesis		1	21			22
Theory arguments	3	20	17	6	65	111
Facts arguments	13	14	48		25	100
Example arguments			5			5
Theory objections				1	2	3
Facts objections	5	10		1		16
Counter-arguments	1	7			1	9
Conclusion	7	6	30	2	2	47

Table 5. Distribution by reasoning structures

	Computation n = 13	Electronics n = 26	Operations Research n = 55	Control Systems n = 7	Telecommunications n = 37	Totals
Inductive		2			1	3
Deductive	3	12	47		31	93
Abductive	8	25	7	5	24	69
Analogical		3	7			10

Relatively to the reasoning structure, results confirm what was verified in relation to the qualitatively analysed texts – assignments and reports: the abductive and deductive structures are often jointly used by these students, respectively 93 and 69 cases in a total of 175, as displayed in Table 5.

Regarding the rhetoric modes of persuasion, there is a convergence between data coming from tests and handled in quantitative terms and those studied in a qualitative way, in assignments and reports. As one can verify in data from tests, the most frequently used mode is logos (171 in a total of 183) (Table 6). This means that the texts written by the students are focused on the topic that is being handled. The communicative dimension less present is the ethos, just as it was also verified in the analysis of texts. The exception to this rule appeared in the text of a student who organised his argumentative structure around the validation of the technique and the simulator constructed in the course of his experimental work. In terms of reasoning, it was classified as abduction; in communicative pragmatic terms, it relates to validating the process followed as a form of confirming the conclusion. The communicative dimension focused on the recipient (pathos) is (relatively) less important here than it was in the texts analysed qualitatively. Nevertheless, it was possible to find some arguments that raised the pathos dimension to a universal communicator (Muller Mirza and Perret-Clermont 2009). In other words, they stopped writing to

Table 6. Distribution by rhetoric modes of persuasion

	Computation n = 13	Electronics n = 26	Operation Research n = 55	Control Systems n = 7	Telecommunications n = 37	Totals
Logos	13	23	55	7	73	171
Ethos		2				2
Pathos		10				10

the teacher and began to address the social collective to make their point to the goodness of the proposal.

3.3. Discussion of the results

Concerning the elements of the argumentative structure, results express the preference of the students for argumentation rather than for the use of objections and conclusions. In terms of the structure of argumentative reasoning, the students frequently use deductive and abductive types. The pragmatic discourse focused on the *logos* dimension as a construction of the assessment assignments to be transversal to all texts.

This paper next compares the analysis results of the data derived from assignments and reports and data derived from tests, taking into account that the first correspond to assignments/theoretical reflections (in the case of the course of Philosophy of Science: Central Problems), reports of experimental activities and open questions in tests, whereas the second pertain to tests. It can then be concluded that:

- (1) In relation to argumentative reasoning, it is evident that data handled in a qualitative form (assignments, reports of activities) reveal less heterogeneity in the usage of the different elements. In data from tests there seems to be a more balanced exploitation of the diverse types of elements that constitute argumentative reasoning.
- (2) More objections are developed in the longer texts (assignments, reports of activities) when compared to data from tests.

These results seem to bring into evidence that the assessment assignments demanding from the students the development of a theme, while taking into account theoretical and empirical references, lead them to construct more complete and complex argumentative reasoning. This is shown by the use of the different elements as well as by the frequent mobilisation of objections, revealing a questioning attitude of the work they completed, in terms of the resolution of the posed problems. Conversely, data concerning tests show that the students' argumentative discourses focus on the arguments and the conclusions. Objections or counter arguments are rarely used, pointing out the linearity of the relation between the argument and the conclusion that emerges from it.

In relation to the reasoning used in the production of arguments, there is a similarity between data of the different courses as well as among the type of texts analysed. Therefore, generally, the students use abductive and deductive reasoning. On the other hand, inductive and analogical reasoning are less frequently used. These results seem to be linked to a strong explanatory component, which is present in the texts written by the engineering students.

4. Conclusions

The preference of the Engineering School students for abduction and deduction, when needing to explain their options, may be related to the fact that the dimension of proof of knowledge is traditionally associated with learning as identical to the production of truthful knowledge. This is supported in theoretical and/or experimental foundations relating development of reasoning with the justification for a predetermined assertion.

The analysis of rhetoric modes of persuasion also showed some differences, when data from distinct texts were analysed. In this way, and despite the *logos* dimension appearing very noticeable and transversal to all types of texts, all of them focused on the topics, the *pathos* dimension is far more frequent in the assignments and reports (handled qualitatively). This seems to indicate that the more open assignments, such as reports, theoretical essays and questions requiring open answers,

lead more frequently to discourse focused on the reader. Therefore, as mentioned previously, this dimension is often associated with justifications to the teacher about the limits that may have occurred in the execution of the assignments. On the other hand, the characteristics of the tests did not permit these types of explanations by the students, focusing even more on the issue to be handled.

The reduced argumentative exercise found in the students from the Engineering School can also be explained by the fact that the courses analysed belonged to the first years. In these cases, it is a sufficiently ambitious task to expect that the students are able to communicate in a structured way and that they gather some 'soft skills' that will help them to understand and adopt a social responsibility intrinsic to being a university student. It is also concluded that the assessment methods influence the way that students develop and structure their argumentative reasoning and it can also be claimed that the argumentative characteristics are dependent on the proposed assessment methods.

Therefore, it is understood that the ability to argue is at a higher stage of maturity not yet reached by the majority of the students. Furthermore, it is also claimed that they only develop these reasoning skills, which are different from the deductive and abductive types (didactic objects of some courses at the Engineering School), when they exercise more non-established knowledge ('open knowledge') and become a potential target for the counter argument of their peers. Since it is not possible to gather any of these conditions in a traditional assessment paper, conditioned by a time frame and having the teacher as recipient, it is recommended that the reports are administered to students with practical assignments that last a few weeks.

The full completion of students' argumentative ability only occurs in individual dissertation papers, specifically at the end of the graduate and postgraduate programmes. It is in these final stages that communication should be seen as curricular object, as suggested by Lappalainen (2009, p.128): 'the university has to rise to the challenge and integrate communication into subject curricula. This is the first step towards self-actualized and self-leading engineers (. . .)'.

It can also be concluded that the acquisition of specific ability for argumentative skills should be the object of a progressive learning process, which should be promoted intentionally and be included in the courses' synopsis.

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