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Challenges in a Physics Course: Introducing Student-Centred Activities for Increased Learning

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Abstract

This article identifies and analyses some of the challenges that arose in a development process of changing from a content-based teaching environment to a student-centred environment in an undergraduate physics course for medicine and biology students at Universidad de los Andes. Through the use of the Critical Research model proposed by Skovsmose and Borba, the development process was formed as a close co-operation between academics and researchers in both the construction of pedagogical changes and the responses to particular educational problems during the process. The analyses of the development process highlight a number of difficulties in relation to the introduction of specific student-centred approaches in relation to both the structure of the course and the conception of the content of the course.

Introduction

In recent years, higher education has been a field of interest for research because its study objects are the institutional bases of all academic disciplines, and because its systematic knowledge contributes to the future of society. As a consequence, the push for reform in this field is strong. However, Laurillard (2002) suggests that higher education cannot change easily: traditions, values and infrastructure have created an institutional inertia. In many cases, there is no professional training requirement for university academics in terms of their teaching competence, as there is for schoolteachers.

Academics define learning expectations ambitiously, in ways such as "critically assessing the arguments", "becoming aware of the limitations of theoretical knowledge in the transfer of theory to practice", or "compiling patterns to integrate their knowledge" (Laurillard 2002). However, course descriptions and syllabuses tend to focus in many cases only on the content that students will be learning. In this respect, certain questions arise: What are the dominant conceptions of learning at university level? What are some of the barriers to changing the curriculum?

In the last 20 years, there have been many studies relating to these questions, and several researchers distinguish between a teacher-or-content-centred and a student-centred approach to teaching (Biggs & Tang 2007; Lindblom-Ylänne, Trigwell, Nevgi & Ashwin 2006; Lueddeke 2003). Teachers whose approach to teaching can be categorised, in a certain context, as teacher-centred see teaching mainly as the transmission of knowledge, and they concentrate on the content being taught. Thus, the emphasis is on how to organise, structure and present the course content in a way that is easier for the students to understand. On the other hand, teachers whose approach to teaching is categorised as student-centred in a particular context see teaching as facilitating students' learning or students' knowledge-construction processes, or as supporting students' conceptual change. These teachers focus on what students do in terms of their efforts to activate the students' existing conceptions, or encouraging them to construct their own knowledge and understanding.

Lueddeke (2003) showed that teachers who teach "hard" disciplines – such as physical sciences, engineering and medicine – were more likely to apply a teacher-centred approach to teaching, whereas teachers from "soft" disciplines – such as social sciences and humanities – in general have a more student-centred approach. These studies suggest that there is much to be done in the design and implementation of physics courses that are student-centred.

In the spring of 2010, a Colombian university initiated a reform towards a more student-centred teaching approach. To assess some of the challenges that may arise from this change of perspective, a Centre for Research in Education (CRE) and a group of teachers from the Physics Department designed and implemented a student-centred approach for a physics course for biology and medicine students. This paper will focus on the implementation of the first semester of this course. The research objective is twofold. First, we wish to explore what changes in physical space, time distribution of the course and human-resources requirements were needed to allow for a student-centred teaching approach under the specific circumstances of the reform initiative. Second, we aim at analysing and reflecting upon the challenges that arose in the process of moving from a content-based teaching environment to a student-centred perspective.
We will analyse the challenges that emerged in the development process on two levels: course structure and content approach. Under course structure, we will examine issues such as time organisation, activities, classroom characteristics and human resources necessary to carry out the course. Under content approach, we will explore how the course participants understood science teaching and learning, and how this affected the implementation of a student-centred approach.

These two categories are of course not independent, but they are analytical constructs that will allow us to discuss the change process in more detail.

The paper is organised in five sections. The first section presents the research methodology and the team that participated in the development process. The second part describes the original course with a teacher-centred approach. In the third section, we explore the emergence of the student-centred course. In the fourth section, we analyse the processes that developed in the student-centred approach course and some of the challenges that emerged. Finally, we discuss these challenges and the implications of our findings for the development of future courses.

Methodology

In analysing the educational development process, we draw on the work of Skovsmose and Borba (2004) to frame the research process developed in connection with the reform initiative. They present "critical research" as participative research that focuses on the changes in the classroom, and that represents a form of cooperation between teachers and researchers as a response to particular educational problems. Critical research pays special attention to hypothetical situations – although still considering the actual situation – and investigates alternatives. In the following discussion, we introduce the central elements of this proposal.

To focus on investigating alternatives, we can introduce three analytical situations. First, a specific situation occurs before the educational experiment takes place; this situation, called by Skovsmose and Borba the *current situation*, contains problematic features. A second situation may solve the problem by highlighting a possible alternative; this is described as an *imagined situation*. This imagined situation is based on the relationship between two elements: the teacher's expectations and the support that the researchers can provide from their experience. Finally, the *arranged situation* is a practical alternative that emerges from a negotiation involving the researchers, teachers and possibly also administrators. The arranged situation may be limited by different kinds of structural and practical constraints, but it has been set with the imagined situation in mind.

As previously mentioned, critical research is participatory. Hence, we should take into account the cooperation between the participants at different levels. Skovsmose and Borba (2004) describe three different processes related to this cooperation between teachers and researchers in critical research (Figure 1). First, the relationship between the current situation and the imagined situation is mediated by *pedagogical imagination* (PI). We can interpret this process as the type of actions and conceptualisation that help us create imagined situations. An imaginative construction of new alternatives has many resources; one of the resources is, naturally, the practical knowledge of the teacher. Other resources are the contributions that researchers can make in relation to the theoretical field of pedagogy and other research. As a consequence, negotiation and deliberation support pedagogical imagination.
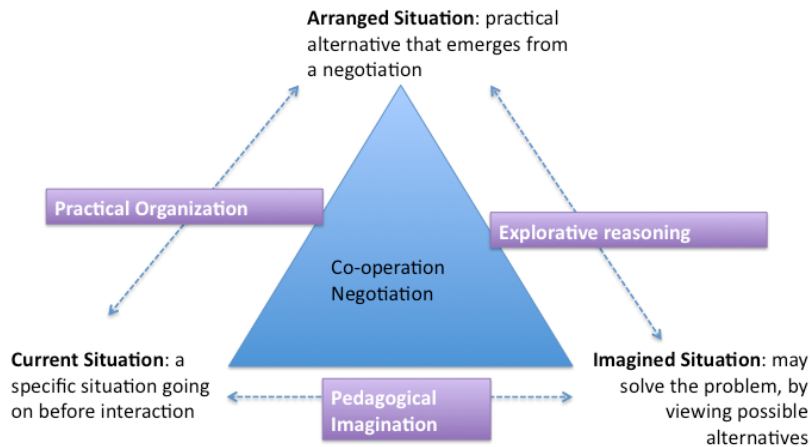
Figure 1: Model of critical research indicating the processes of cooperation involved (adapted from Skovsmose & Borba 2004, p. 216)**.**

Second, the relationship between the current situation and the arranged situation is established by *practical organisation* (PO): as much practical planning as necessary to establish a situation – an arranged situation – that shows some similarity to the imagined situation. To bring the imagined situation to reality, it may be necessary to negotiate new spaces, time distributions, activities, assessment forms etc. In many cases, these negotiations involve not only researchers and teachers but also administrators. The last procedure, *explorative reasoning* (ER), is the analytical process of reconsidering the imagined situation in the light of experiences relating to the arranged situation. It represents the critical interaction between pedagogical imagination and practical organisation and the necessity to reflect on the process.
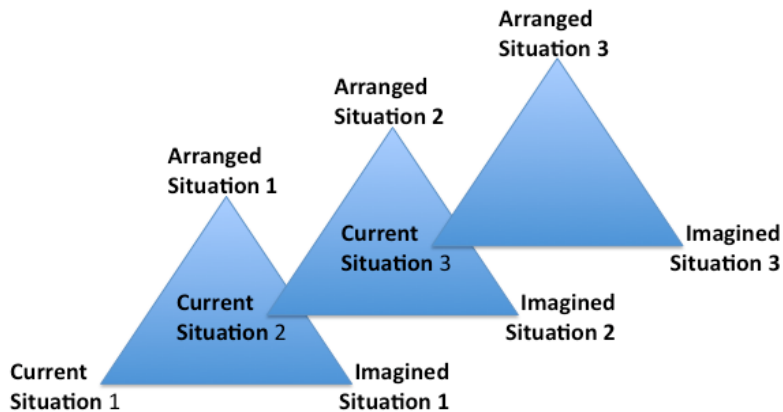
Figure 2: Model of critical research that shows that changes in the classroom are associated with changes in the three situations analysed (Skovsmose & Borba 2004, p. 221)**.**

Now, it is possible to think that the change process in classroom practices appears as a movement of these three situations through time: the current situation starts to be altered, and, in turn, the imagined situation and the arranged situations (Figure 2). As a consequence, such research includes changes as part of the research process. Thus the development of classroom practices can

be discussed in the same terms as the quality of critical research. Furthermore, it is also possible to discuss the qualities of critical research in terms of the qualities of the processes described above: pedagogical imagination, practical organisation and explorative reasoning. In our case, this paper discusses the first movement in the transition from a teacher-centred course to a student-centred course; that is, from the current situation through the stages of the model towards an explorative reasoning about the development process.

The makeup of the team that participated in the development project sheds light on the situation before the implementation of the new course. There were two physics teachers, each with a PhD in physics, whose field of research is biophysics. One teacher had been teaching the physics course for biology and medicine students for four years and the other for two years. In addition, three people from CRE participated in the development project: a PhD in education, a biologist who pursuing a master's degree in education and a physicist studying for a PhD in science education. During the first semester of 2010, the team designed protocols and questions to collect different kinds of data to conduct the explorative reasoning of the research project:

- The master's student from CRE made classroom observations every two weeks. Data, which was collected according to a prescribed format, described the actions, attitudes and interactions of the teacher, teacher assistants and students in the classroom.
- The PhD student conducted four semi-structured interviews: one with the teacher of the course and three with the teacher assistants. The questions were designed to identify the teachers' perceptions in relation to the development of the course, the activities, the students' activity and the interaction between teachers and students.
- The master's student from CRE carried out one focus group with nine students with high, medium and low achievement levels in the final exam of the course (three from each level). The interview was based on a fixed questionnaire that asked about their perceptions of the course in relation to the careers of medicine or biology, as well as the strengths and weaknesses of the course design. Additionally, questions were asked about the types of activities the students engaged in and about the teacher and the teacher assistants, and asked for suggestions for future courses.
- The PhD student carried out two interviews on the role of the CRE team: one with the master's student and one with the PhD in education from CRE. In these interviews questions were oriented to reflect upon the process of course design and implementation.
- The master's student and the PhD student took notes of the team meetings in a diary during the entire semester.

To analyse this information, first, the interviews and focus group were transcribed. Second, all the information was classified according to the two levels under study: course structure and content approach. Third, each category was observed to identify patterns or tensions and generate the researchers' explanatory models. Finally, relevant fragments of the teacher's and students' interviews were translated from Spanish to produce an English narrative about the process. The narrative follows the three analytical situations and cooperative process proposed by Skovsmose and Borba on critical research.

The Current Situation

Our initial current situation involved a physics class for medicine and biology students. This course is offered by the Physics Department and its design can clearly be categorised as a teacher-centred approach. There are over 100 students per semester interested in joining the course, and usually the students are able to choose between two different schedules. For this reason, the course was designed for 60 to 80 people (a considerable number of people to teach). Usually, the teachers of this course are academics who do research in biophysics and work in the Physics Department.

A teacher assistant was assigned to each group of 20 or 25 students. Teacher assistants are students of the final year of physics or students of the master's or PhD degree in physics.

For a long time, the content of this teacher-centred approach course was organised and structured based on books by renowned physicists. From this perspective, the learning of physics is measured according to the student's ability to solve standardised problems similar to those the authors or the teacher have developed, since solving them requires recalling relevant information and applying it to the new problem (Ceberio, Guisasola & Almudí 2008). This is consistent with a statement of physics Nobel laureate R.P. Feynman that appears in the introduction of many physics books: "You do not know anything until you have practiced.", This idea is interpreted as suggesting that problem-solving ability is one of the main tests of knowledge of physics, and justifies the approach of trying to solve as many problems as possible (Selçuk, Çalışkan & Erol 2008). Hence, one activity teachers use is to select a group of key standardised problems to develop during a lecture, and another group to be assigned to students to solve on their own. Teachers expect students to understand the overall structure of the problems during the lectures and, subsequently, to solve several similar exercises by themselves.
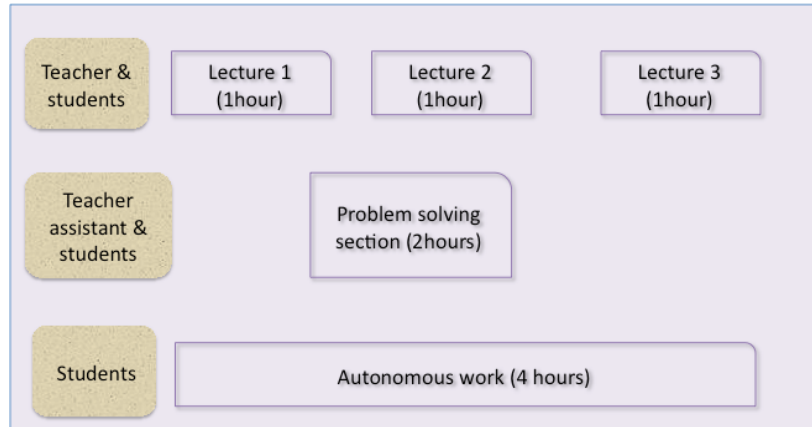

Figure 3: Time organisation and activities for one week in a teacher-centred course. This represents the original current situation in this study.

Class time, therefore, is organised in three activities per week (Figure 3): three lectures of one hour with the teacher, a two-hour session for problem-solving with the teaching assistant and four additional hours for autonomous work. During a lecture, the teacher presents the contents of the course: relevant concepts, some theoretical procedures and demonstrations and some exercises that show the structure of thinking in physics. Students observe, take notes and ask questions about the topic of the session. In a problem-solving session, the teacher assistant asks students to solve the assigned exercises on the board, gives tips to solve problems and answers specific questions. Active engagement by the students is expected during autonomous work in this order: start the week by reading sections assigned from the book on the same topics that will be covered in the lectures that week; after the lectures, try to solve the assigned exercises individually, or with the help of a problems clinic staffed by bachelor's students; finally, attend the session with the teacher assistant, where they are expected to solve the exercises on the board, getting help from the assistant where necessary to solve them.

Usually, the teacher uses two kinds of examples in the lecture: textbook exercises (only physics concepts) and exercises on medicine or biology that involve physics concepts. In this way, the

students can observe concrete examples of how to apply a physics structure to problems related to their degree (Example 1). Thus, physics teachers expect students to learn physics concepts, theoretical models and their implications; to apply these ideas in their professions; and to develop their scientific skills. Finally, this learning process is assessed through written exams in which the students solve similar exercises.

> An Escherichia coli bacterium located in the urethra of a patient experiences a drag force of 10 pN and it tries to adhere to the surface via pili. What is the distance travelled by the bacterium before it stops if its initial velocity is 10 cm/s?

Example 1: Usual exercise in the teacher-centred approach, which uses a medical context, but focuses mainly on numerical data, without an analysis of the concepts that can be used to understand and model the situation as a physics process.

However, the results of these exams have not been as expected, and in many cases physics teachers have observed that the students attempt to memorise the exercises instead of understanding them. During the second half of 2009, the two teachers of the class proposed including several active-learning components during class time. After reviewing the proposal, the physics department agreed to do a pilot for this change, with the condition that the professors seek support from CRE, among other requirements. Thus, the teachers sought pedagogical support for the first half of 2010 to propose a different model that could help students become more active in their own learning process.

Imagined Situation and Pedagogical Imagination

In CRE's pedagogical understanding, there are two central elements concerning what learning means. On the one hand, learning is a complex process and a product of the activity, context and culture where it is developed and used (Vygotsky 1978, 1986). It requires the activity of the learner in authentic practices. This means undertaking the same types of activities developed by the experts in the field of knowledge that people need to learn (Díaz-Barriga 2003; Roth 1995; Roth & Roychoudhury 1993). In this sense, learning will not occur as expected unless the teacher provides specific support for the students through participation in intentional, planned and systematic actions that generate this process.

On the other hand, learning is stimulated and activated in a variety of mental processes that arise during interaction with others in different contexts, and it is always mediated by language (Carrera & Mazzarella 2001; Radford 2008; Roth 1995; Vygotsky 1986). For this reason, the classroom is only a special context in which the students can interact with the teacher and other students to increase learning opportunities.

The main objective in pedagogical design, according to the conception guiding CRE, is to follow a process that starts by identifying the course learning objectives, then proposing coherent activities to help students achieve those goals, and finally designing an assessment to determine whether the objectives were achieved. Such a procedure is consistent with critical research (Skovsmose & Borba 2004) that involves cooperation between researchers and teachers. This cooperation implies negotiation about and deliberation with an existing educational setup. Thus, the development process started with several meetings to present, discuss and analyse the objectives of the course,

its development, achievements and weaknesses, to suggest some changes and create our first imagined situation. These meetings include both the study team and the course teachers. The teachers had proposed a course that included different types of activities, whose purpose was to engage students with different learning styles. Additionally, the proposal envisaged the inclusion of problematic situations – open problems – oriented towards biological and medical sciences, rather than standardised problems; this was in order to make the course more interesting for the students and develop different competencies. The teachers also explained that they knew what was happening in a lecture, but they did not know what was happening in the problem sessions or during students' autonomous study time. There was no clarity as to how the assistants were running the sessions, and there were large disparities between the grades of the sections run by different assistants. There was also no clear understanding of how the students used their autonomous time. The team concluded that it was important to promote greater activity for students in the classroom, not just outside class. This was difficult in a big group of students with only one teacher, but possible if smaller groups of students were created and helped by the teacher assistants.
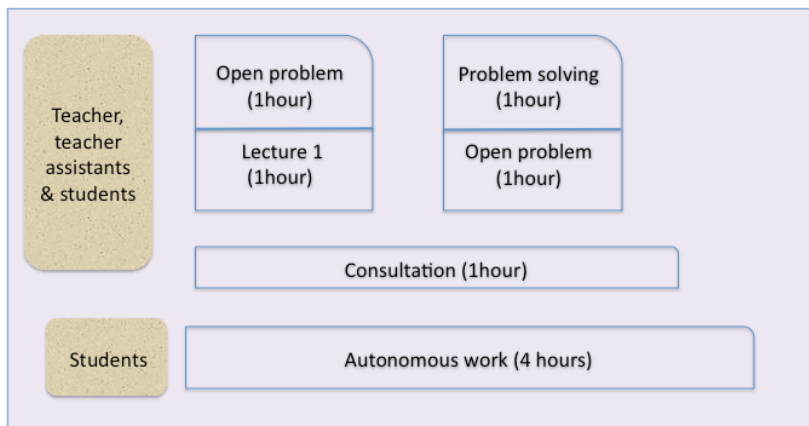

Figure 4: Time organisation and activities for one week in a student-centred course. This represents the study's first imagined situation.

This new proposal, which clearly had a more student-centred approach, included distributing the course time in a different way: two sessions of two hours each with the teacher and teacher assistants at the same time, one hour of consultation during the office hours of the teacher or the assistant (a total of three or four hours per week are available for students to questions) and, as in the original situation, four hours for autonomous study. This change removed the division between the lecture and the problem-solving sessions, and defined new activities and roles in the class (Figure 4).

The students were imagined as organised in small groups of three students, including at least one student from a different degree, and each teacher assistant would be in charge of six or seven groups. With the help of the teachers, in the first session of the week, the groups would work for one hour on an open problem related to the topic under study; in the second hour, the teacher would assume a role similar to that of the lecturer to present the concepts, answer questions and establish conceptual relations. In the second session, the students would again work in their small groups in workshops similar to their former problem-solving session, but with several standardised problems related to their field of study, and the teacher and teacher assistant would help them to develop strategies to think about these problems in a scientific way.

As part of pedagogical imagination another issue had to be solved. It was not clear to the pedagogical team what "thinking about the problems in a scientific way" meant. To solve this issue, the team had more meetings, and finally the teachers wrote in the course syllabus that learning physics helps to develop skills such as identifying relevant information in a problem, being able to interpret physical situations, justifying decisions based on physics concepts and having an organised approach to solve the exercises. This was in contrast to the former syllabus where the main objective was to introduce students to the fundamental concepts of mechanics.

An Escherichia coli bacterium resides in the urethra of a patient. It is believed that a body's defense mechanism is the expulsion of fluids at high speed to sweep. Unfortunately, the bacterium also has defense mechanisms and adheres to the surface via pili. We want to determine the distance that the bacteria would travel before stopping and analyze whether this result makes sense in the biological world. Assume that the bacterium is a cube of side 1 micrometer, the initial velocity of the bacteria is 10 cm/s and the force component in the opposite direction to the flow is 10pN. The results should be expressed in the following terms:

v_i: Initial velocity of the bacterium
m: mass of the bacterium
F: Force in the opposite direction

a) Do you have information about the three parameters that we will use? How do you know the bacterium's mass? (Suggestion: use the volume of the bacterium to estimate its mass)
b) Write the equation that describes the final velocity of the bacterium in terms of F, m, v_i and t.
c) Derive the time it takes to stop, according to the above parameters.
d) Calculate the numerical result of this time.
e) What distance does the bacterium run before stopping as a function of v_i, m, F?
f) Calculate the distance in numbers. Which are the units of this distance?
g) Does this value make sense in relation to the size of the bacterium or the length of the human urethra?

Example 2: Exercise developed in the student-centred approach, which uses a medical context and focuses on identifying relevant physics information in a problem, interpreting physical situations and justifying some decisions based on physics concepts**.**

As a consequence of this new course structure and the list of crucial skills in the syllabus, the team concluded that it would be necessary to develop specific material for the course. The material design involved choosing the exercises and activities that would help students explicitly develop the skills proposed earlier. In this sense, many of the examples used by the teacher in past courses were good exercises, but they were focused on calculations and gave few opportunities to discuss the meaning of these procedures or the model used in the exercises. To learn the skills, the students needed alternative ways to think and proceed. Consequently, the new exercises had questions that required the students to think in relation to these other levels, and not only in terms of calculations (Example 2).

At this point, one of the teachers assumed responsibility for the course during the first half of 2010; the other would teach the following course in the second half of the same year. It was also agreed that the design of the material for the course would be done progressively throughout the semester in weekly meetings, and it would be discussed before the class with the teacher assistants.

Finally, to gain an idea about how students would perform in the new course, the teacher decided to use the same kind of evaluation as in the original course: individual written tests. The team members negotiated other types of assessment, but in the end these were not fully implemented.

Practical Organisation, Arranged Situation and Results

In the first weeks of January, the team had new meetings to develop the material for the first weeks of the course. Other important activities were a formal presentation of this new design to the teacher assistants and the discussion of their new role in this process: rather than answering the students' questions, their work would be to help them to identify and analyse the information, concepts and procedures in the more open-ended and explicitly skill-oriented problems – that is, the expected role of the teacher in a student-centred approach. They accepted their job without any objections, and followed the tasks provided by the teacher.

The course had 54 students: 34 women and 20 men. There were 19 biology students and 35 medicine students; 48 of the students were second, third and fourth semester of biology and medicine, and the remaining six were in the last part of their degree (they had completed more than seven semesters at the university and were all biology students). In mid-January the course started with a presentation by the teacher explaining to the students the purpose, methodology and evaluation of the course. Next, the students took an individual written test that was used as a baseline to inform the final results. At this point, none of the course's participants perceived it as being significantly different from any other.

The differences appeared in the second session: the teacher started to arrange smaller groups. He proposed to organise groups freely, with the condition that there had to be students from different programmes in each group. The students did not accept the change well, and they organised their groups with friends from their own degree. Thus, the teacher intervened to redistribute the biology students, and finally each group had a biology student. At this point, we started to see the arranged situation in action and the challenges in relation to the inclusion of the students in decision-making.

Next, the groups were given a problem to solve (the type of open-ended problem presented in Example 2) and they started to work on it. Many groups did not understand the problem, and they tried to find a formula in the book to solve it. One hour later, the groups had not finished their discussions. Still, the teacher tried to end this work so he could start the lecture as planned. However, the students remained focused on the problem, constantly asked about it, and did not pay much attention to the concepts of the lecture if these were not related to the problem. As a result, the problems were not solved and the teacher was not able to give his lecture in a structured way. The class ended in a disorderly fashion.

The next session started with the students working on the open problem of the previous class in their groups. In many cases the groups of students achieved good proposals, but they took longer than expected by the teacher. Next, the students had to use all the remaining session time to work on a set of similar problems in workshops. To ensure the progress of work in the class, checkpoints were established in the problems, and each group was assigned a specific teacher assistant who reviewed the problems and collected this information. The first workshop was designed with five problems about movement and its representations. In many groups, the students only solved two or three problems, and they began to show dissatisfaction with the time given to do the exercises. The teacher and the teacher assistants had difficulties with how to divide their time between groups. For the second time, the class ended in disorder. By the end of the first week, the teacher was seriously concerned about the differences between his experiences with this

new type of course and with previous courses, and he was very aware of the developing challenges related to the implementation of the new learning strategies.

The second week did not improve in class and several groups complained that the wording of the problems was unclear; they did not understand what they were being asked and did not what to do, especially in the qualitative questions that did not require numerical calculations. At this moment, a certain level of tension in the meetings for the design of materials for class was evident among the whole team. The CRE team observed that the number of exercises proposed was excessive, and that the students could not finish them in the session; they suggested giving fewer problems but with more detail. The teacher expressed for the first time a recurring theme that *"he could not cover the entire course, if he had less time for lectures and students solved fewer problems"*.

Another difficulty arose in relation to the distribution of the classroom space. In the imagined situation, the classroom has movable tables and chairs that allow groups to form and teachers to move freely around the room. In contrast, the current-situation classroom had static chairs and tables because students were always facing forward and there was no need to move. The teacher and the group in CRE tried to negotiate with the central administration of the university to provide a new classroom, but it was only possible to change it for the second session in the week. As a consequence, the first session classroom was small and static, and the second session classroom was bigger, but the tables were still static and only had movable chairs. The teacher's and teacher assistant's movement between tables and groups was difficult, meaning that some of the groups were not paid as much attention as others. Also, some students used this difficulty to distance themselves from teachers and avoid interacting with them.

At the end of the fourth week, the tension in the class reached a peak and students complained directly to the teacher: they demanded more time for explanations and clear problems. The team had an extraordinary meeting. Everyone at the meeting agreed that the students were overloaded with activities and that it was necessary to sacrifice some of the activities to keep the students from getting lost. The teacher expressed his decision to change the use of time in the course in the following way: the first session would be only a lecture, without open problems (Figure 5). The teacher argued: "*In this way, the problem with the classroom would be minimised, the students' demands satisfied and I would have enough time to explain the important concepts and give examples.*" Also, the teacher saw a need for simpler exercises, arguing that since the students had not prepared properly for the class (they had neither read the book nor done the assigned exercises), they needed some practice with the physics-only exercises before going to more conceptually challenging biological or medical problems.

At that time, our arranged situation became the second current situation, and the course ended with this time-activities distribution. After the change in the course activities, it was difficult to have a periodic meeting for the design of the material. In addition, the workshops changed: they started with physics problems to understand basic concepts and ended with calculation-oriented biological applications (the kind of exercises described in Example 1).

This resolved the problems of the first session. However, in the second session there were always difficulties. On the one hand, the number of exercises was greater than what the groups would have been able to solve if they had discussed among themselves. The teacher did not fully accept this difficulty: "*I did not understand why a problem that I can explain in detail in five minutes took 40 minutes for a group of three students with the help of a teacher assistant.*" He continued, therefore, to design workshops with (usually) two exercises and a standardised problem. Many groups decided to distribute the problems so that each person solved one or two; thus, they

completed the tasks but they stopped working in groups. During the interviews some students stated, *"It was important to get to checkpoints in the workshop, show them to the teacher assistant and get the points of the day."*

On the other hand, the teacher was disappointed because some students were engaged in other activities, such as talking about other topics, playing with their telephones or checking their e-mail. However, the students argued, *"We do not feel the same passion for physics as the teacher…he wants us to be a biophysicist like him, and this is impossible."*
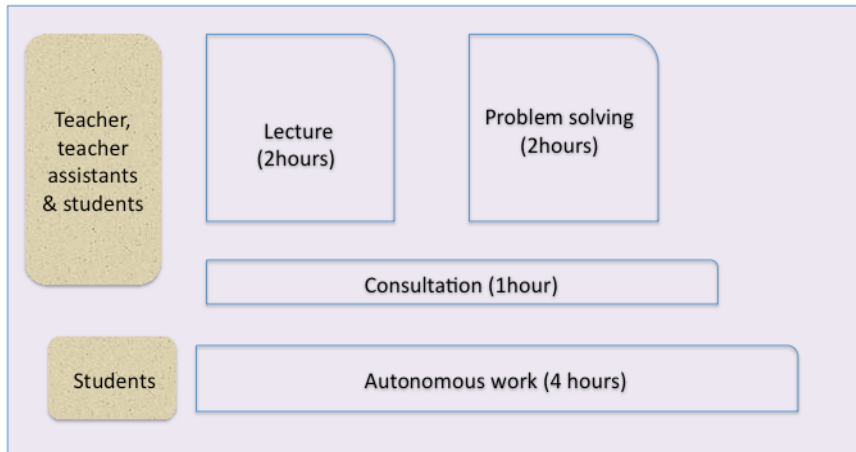

Figure 5: Final distributions of the course times and activities. This represents the second current situation.

Another important element in the problem-solving session was the teacher assistants' performance. There were three teacher assistants in this course: two students from the programme whom the teacher knew and trusted, and a new student of the physics master's programme from another university, whom he did not yet know. During the first part of the semester, they did not attend the team meetings to discuss the workshop activities; consequently, they were sure about neither their role, nor how to answer students' questions. The teacher was unhappy with this behaviour, and the three first observations showed that the effort of the three teacher assistants was similar: they reviewed checkpoints and answered students' questions directly without having a dialogue with them.

The team decided to have a meeting with the teacher assistants to reflect on their role in the course, and the type of interaction with the students that was expected from them. The subsequent observations showed an important change in their performance: on many occasions they tried to help the students answer the questions by themselves. However, in the interview, the students expressed that this interaction was very different among the different teacher assistants: they preferred the new teacher assistant who had just started working on the course because *"every time we speak to him we know what to do and how we can solve the exercise"*. On the other hand, the other teacher assistants were considered *"not clear and they didn't explain much"*.

In the teacher assistants' interviews it was possible to observe different attitudes towards teaching. The new teacher assistant expressed surprise that there was a course like this for biology and medicine students but, nevertheless, he had concern for them and their learning needs. In comparison, the other two teacher assistants assumed the course as a way to help the teacher, but they were less concerned about the students.

The final two elements in the allocation of course time was the consultancy hour with the teacher and the independent study time. Very few students used the consultancy hour, and they only did so towards the end of the course. In the interview, one student expressed, "*I never went to the professor's office because I was afraid; moreover, it is difficult to say I do not understand right after the class...it is like accepting that I am stupid.*" In contrast, a large group of students reported that they attended additional meetings organised by the new teacher assistant, close to the dates of the assessments.

When the students were asked about the independent study time, the common response was, "*I spent much time, about eight or nine hours in two or three days, close to the assessments, but this was not enough…finally I had the same poor results*". None of the students reported using the four allocated hours of autonomous work during the week when there was no assessment coming. Many in the focus group believed that the time spent in the physics course was part of the obligations of their curriculum but not really relevant for their profession. In addition, they thought that "*using a bacterium that stops instead of a block is just a trick to try to make assessments more difficult, but really in our degree we don't use physics*".

Finally, the quantitative results in the written examination of the course (the in-class problem solving, checkpoints in group sessions and other non-written activities did not form part of this final course grading) did not show a significant difference with previous semesters. The teacher stated: *"Well, [the] grades are not the best but I learned a lot about the students and their difficulties…. I am surprised with the lack of reflection of the students about their own knowledge: they could not define what they know and what they do not know…so it is difficult to learn more."*

Explorative Reasoning

This section analyses and reflects on the challenges that arose in relation to implementing the student-centred approach in the physics course for medicine and biology students. As Skovsmose and Borba (2004) state, critical research pays special attention to investigating alternatives. This implies a deep reflection on the arranged situation in relation to the imagined situation, with the purpose of identifying the next step in the process of changing this particular physics course. We begin by examining the two proposed categories separately – course structure and content approach – and discuss some relationships between them.

Course structure

As mentioned above, "course structure" is used here as an analytical category in relation to time organisation, activities, classroom characteristics and human resources implemented to carry out the course. In our case, the new structure was the product of negotiation between the CRE team and the physics teachers. At first, it involved a visible change in the course: reorganisation of time and human resources and design of new activities to increase learning opportunities for the students. Once the course began, the course-structure category was hardly discussed in the team meetings. After four weeks, there was an important change in time organisation as a product of the teacher's decision; later, we will discuss how this variation is a consequence of the understanding of the approach to the content of the course.

However, we can highlight three interesting points within this category. First, in our experience, it was difficult to find a classroom suitable for a course with a student-centred approach: in the university, most large classrooms are designed for lectures, and they do not have movable chairs or tables. One element of the imagined situation that we could in fact achieve was to work with a large group of students in activities such as group work, discussions and workshops, in addition to

the lecture. For the teacher and the teacher assistants, the classroom characteristics made it difficult for them and the students to switch to the new proposal, because the spatial distribution did not help the interaction between the teacher and teacher assistants, on the one hand, and the students' groups on the other. In this sense, we found our first challenge: to promote student-centred teaching with big groups of students, the university needs large flexible classrooms with movable tables and chairs for different and varied types of activities.

Second, in relation to the human resources available, the fact that the teacher, teacher assistants and students could be in the same place at the same time opened a new perspective for the teacher in relation to the teaching and learning processes. An important gain was that the teacher could observe the teacher assistants' and students' performance during the workshops. In this regard, the teacher became aware of two situations: first, he could see the teacher assistants' difficulties as new actors in this student-centred approach; second, he could experience the different kinds of processes that the students went through while developing the exercises. As a result, the team could start to discuss the strengths and difficulties of the students' learning process and the complexity of the interaction with them to promote learning.

Third, in the distribution of time, we found that a weekly reduction of one hour in the time allocated for lectures was hardly noticed by the students, and it did not have an impact on their grades. However, the teacher felt constrained in the first scheme, specifically with regard to the clarity of explanations in the limited time taken to cover the content. In relation to autonomous work, we know from the interviews that the students spent much of the time close to the exams of the course and not much during the usual weeks of the course. It is clearly necessary for future courses to highlight and clarify what is expected from the students during these time gaps, and also to build a course structure that connects the lectures and workshops with the autonomous time.

Content approach

This category focuses on how course participants understand the learning of science, and the consequences of this understanding in the implementation of a student-centred approach. For this reason, we will start by describing the teachers' understanding of science learning in the course. We found two teachers' ideas on this aspect. First, during the initial meetings between CRE and the teachers, there was an important difference in the conception of learning as regards to the *authentic practices* (one of the CRE's central ideas about learning). The teachers agreed that solving the standardised problems in the textbook is not part of their activities as physicists, but they argued that learning physics starts by developing a strong structure involving concepts and theories. In their view, the lecture and problem-solving provide that analytical base. Second, the teachers believed that the course was the only opportunity for the students to learn physics; they felt it was their responsibility to show them a relevant range of topics of this discipline. In this respect, it was important to cover most of the content normally covered in the physics courses for engineers. These two ideas are consistent with the rationale of the teacher-centred approach in the original course, as described above, and we will call it the institutional arrangement as it originates in the culture, traditions and learning environments of the physics department of this Colombian university.

The teacher shared and expressed the institutional arrangement throughout his performance, but during the process he did not always refer to it as the reason for his actions in relation to the course. For example, according to the teacher's perception, the change in the time structure and activities that he performed in the course in the fifth week was a consequence of the difficulties with the classroom characteristics, the difficulty of covering the material in only one hour per week and the students' overload of activities, as well as their demands for more traditional lecture

time. Another example relates to the new kind of exercises introducing skills such as identifying relevant physics information in a problem, or justifying decisions based on physics concepts; these were new for the students, and they needed time to think and internalise them. For the teacher, this time was too long, and he felt that increasing the lecture time could reduce it. At the end of the course, however, the teacher stated that he had learnt much about the students and their difficulties in learning physics.

The institutional arrangement implies that the content approach in the course is focused on the discipline area, and this has traditionally not included many considerations of the learning needs of those who are learning. In the imagined situation the teacher was closer to the students, but in the arranged situation they did not feel confident enough to express their difficulties to the teacher. This was evident in two respects: first, the classroom observations revealed that some groups systematically avoided interaction with the teacher or the teacher assistants. Second, during the interviews, the students gave a number of reasons for not using the consultation hours. The serious consequence was that the students did not feel involved in the course, and strongly believed that the physics course was not relevant for their degrees, as shown above, particularly in the focus-group interview.

In conclusion, the most important difficulty in developing and implementing the student-centred approach of the imagined situation was the institutional arrangement concerning the proper approach to the learning of physics. Many of the activities and open problems proposed in the first part of the course were not developed fully because the teacher felt constrained with regard to the number of topics and activities it was possible to cover.

Final Reflections

By using the critical-research method and the close connection between ideas proposed by teachers as well as researchers in the development process, we have experienced several challenges in the implementation of a student-centred course. In relation to the structure of the course, a number of conditions must be met to have a successful implementation within the physical space available, in the broadest sense. However, as tedious as this may sound, it is absolutely vital that these spatial considerations be taken into account in the planning of new initiatives. The backing of the project from the organisational leadership proved to be essential in this study. If these conditions are not met, many unnecessary problems can arise, especially during a process of renewal where all uncertainties and tensions are highlighted more than usual.

The significant and enduring challenge, however, is related to the dominant conception of knowledge and learning in a given department or university culture. In most projects under development this conception will, to some extent, be present through the teacher's and students' expectations about what a "proper" course looks like. In our study, the teacher, teacher assistants and especially the students struggled in different ways with the new structure and content of the course and, thereby, became engaged in the hard work of change towards a student-centred approach to teaching and learning. The need to develop a more complete study in relation to students' perception of the new course and their resistance to change is evident.

In retrospect, it is clear that the process of discussing different conceptions of learning and knowledge, as well as their connection to the imagined situation and arranged situation, should have been further examined. There was sincere dialogue and the will to succeed among the participants in the development team, but much of the time was used, for example, on the construction of new types of assignments, adapting tools to assess how students worked in groups and trying to make sense of the data acquired during the course. In practice, the ongoing debate in the development team and among teachers, teacher assistants and students on issues such as the

rationale behind a student-centred approach, the way students are expected to interact with each other and their teachers and the teacher's role in different educational setups appeared to be extremely important. To obtain a successful process of change, this debate must take primacy over many of the other issues that were in fact discussed in detail during this particular change process. Without this deeper understanding of the fundamental ideas behind the process of change among all the participants of the course, the implementation process will be very vulnerable.

References

Biggs, J & Tang, C 2007. *Teaching for quality learning at University* (3rd ed.), McGrawHill, New York.

Carrera, B & Mazzarella, C 2001. Vygotsky: enfoque sociocultural. *Educere*, vol. 5, no. 13, pp. 41-44.

Ceberio, M, Guisasola, J & Almudí, JM 2008. ¿Cúales son las innovaciones didácticas que propone la investigación en resolución de problemas de física y qué resultados alcanzan? (What are the teaching innovations proposed by research to solve problems in physics and what results have been achieved?). *Enseñanza de las ciencias*, vol. 26, no. 3, pp. 419-430.

Díaz-Barriga, F 2003. Cognición situada y estrategias para el aprendizaje significativo (Situated Cognition and Strategies for Meaningful Learning). *Revista Electrónica de Investigación Educativa*, vol. 5, no. 2.

Laurillard, D 2002. *Rethinking university teaching, a conversational framework for the effective use of learning technologies* (2nd ed.), Routledge Falmer, London.

Lindblom-Ylänne, S, Trigwell, K, Nevgi, A & Ashwin, P 2006. How approaches to teaching are affected by discipline and teaching context. *Studies in Higher Education*, vol. 31, no. 3, pp. 285-298.

Lueddeke, GR 2003. Professionalising teaching practice in higher education: A study of disciplinary variation and "teaching-scholarship." *Studies in Higher Education*, vol. 28, no. 2, pp. 213-228.

Radford, L 2008. The ethics of being and knowing: towards a cultural theory of learning. In Radford, L, chubring, G & Seeger, F (eds.), *Semiotics in Mathematics Education: Epistemology, History, Classroom, and Culture* (pp. 215-234). Sense Publishers, Rotterdam.

Roth, W-M 1995. *Authentic School Science, Knowing and Learning in Open-Inquiry Science Laboratories*. (Tobin, K, ed.) *Science and Technology Education Library* (vol. 1, p. 296).Kluwer Academic Publishers, Dordrecht, The Netherlands.

Roth, W-M & Roychoudhury, A 1993. The development of science process skills in authentic contexts. *Journal of Research in Science Teaching*, vol. 30, no. 2, pp. 127-152.

Selçuk, GS, Çalışkan, S & Erol, M 2008. The Effects of Problem Solving Instruction on Physics Achievement, Problem Solving Performance and Strategy Use. *Latin American Journal of Physics Education*, vol. 2, no. 3, pp. 151-166.

Skovsmose, O & Borba, M 2004. Research Methodology and Critical Mathematics Education. In Valero, P & Zevenbergen, R (eds.), *Researching the Socio-Political Dimensions of Mathematics Education* (vol. 35, pp. 207-226), Kluwer Academic Publishers, Boston (doi:10.1007/1-4020-7914-1_17).

Vygotsky, LS 1978. *Mind in society*, Harvard University Press, Cambridge, MA.

Vygotsky, LS 1986. *Thought and Language*, MIT Press, Cambridge, MA.