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Teaching as a fractal: from experience to model

La docencia como un fractal: de la experiencia al modelo

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Abstract

The aim of this work is to improve students' learning by designing a teaching model that seeks to increase student motivation to acquire new knowledge. To design the model, the methodology is based on the study of the students' opinion on several aspects we think importantly affect the quality of teaching (such as the overcrowded classrooms, time intended for the subject or type of classroom where classes are taught), and on our experience when performing several experimental activities in the classroom (for instance, peer reviews and oral presentations). Besides the feedback from the students, it is essential to rely on the experience and reflections of lecturers who have been teaching the subject several years. This way we could detect several key aspects that, in our opinion, must be considered when designing a teaching proposal: motivation, assessment, progressiveness and autonomy. As a result we have obtained a teaching model based on instructional design as well as on the principles of fractal geometry, in the sense that different levels of abstraction for the various training activities are presented and the activities are self-similar, that is, they are decomposed again and again. At each level, an activity decomposes into a lower level tasks and their corresponding evaluation. With this model the immediate feedback and the student motivation are encouraged. We are convinced that a greater motivation will suppose an increase in the student's working time and in their performance. Although the study has been done on a subject, the results are fully generalizable to other subjects.

Resumen

El objetivo de este trabajo es tratar de mejorar el aprendizaje de los estudiantes diseñando un modelo docente que intenta aumentar su motivación por adquirir nuevos conocimientos. Para poder diseñar el modelo, la metodología empleada se ha basado en el estudio de la opinión de los estudiantes sobre distintos aspectos que pensamos que afectan en gran medida a la calidad de la docencia (tales como la masificación de las aulas, el tiempo previsto para la asignatura, el tipo de aula en el que se imparten las clases), y en nuestra experiencia a lo hora de realizar distintas actividades de forma experimental en clase (por ejemplo, la corrección entre compañeros y las presentaciones orales en clase). Además de conocer la opinión de los alumnos, es fundamental basarse en la experiencia y reflexiones de los docentes que han estado impartiendo la materia varios años. De ahí hemos entresacado algunos aspectos clave, que en nuestra opinión, deben tenerse en cuenta al diseñar la propuesta docente: motivación, evaluación, progresividad y autonomía. Como resultado hemos obtenido un modelo docente basado en el diseño instruccional así como en los principios de la geometría fractal, en el sentido de que se plantean diferentes niveles de abstracción para las diversas actividades formativas y estas son auto similares, es decir, se descomponen una y otra vez. En cada nivel una actividad se descompone en tareas de un nivel inferior junto con su evaluación correspondiente. Con este modelo se fomenta la retroalimentación y la motivación del estudiante. Estamos convencidos de que una mayor motivación supondrá un aumento en el tiempo de trabajo de los estudiantes y en su rendimiento. Aunque el estudio se ha hecho sobre una asignatura, los resultados son totalmente generalizables a otras materias.

Keywords:
motivation; evaluation; active learning; instructional design; task-based learning; fractal.

Palabras Clave:
motivación; evaluación; aprendizaje activo; diseño instruccional; aprendizaje basado en tareas; fractal.

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1. Introducción

At the beginning of each academic year, university teachers face the task of getting their students to learn. Teachers must choose a training model to teach their subjects, hoping it to properly work. There are several problems, with no simple solutions, to be addressed. Among them, we could cite the lack of motivation of students. Another situation is that any attempt to apply new methodologies based on continuous assessment involves significant increase in the teacher workload.

At the end of the course, however, many questions and doubts about the process and the results arise. These hesitations may seem negative, but actually they are not, since they may cause further changes, developments and improvements in teaching the subject.

That is why we plan to design a new teaching-learning model to mitigate the difficulties that teachers meet and to increase learning success. To address this task, it seems necessary to analyze the opinion of students on some issues and also to do some reflections relying on other educational models, such as the instructional model, whose aim is to improve learning. The instructional model of Reigeluth (2012) (Instructional Theory) is student-centered. Student progress is based on the student's own learning. This model is built on the work of Merrill, who proposed a set of five instructional prescriptive principles that improve the quality of education (Merill, 2007, 2009). These principles have to do with the centrality of task, activation, demonstration, implementation and integration.

Some core ideas of this instructional paradigm of education are:

- Learner-centered vs. teacher-centered instruction.
- Learning by doing vs. teacher presenting.
- Customized vs. standardized instruction.

These ideas represent some characteristics of the instructional paradigm but the specific methods by which each principle is implemented vary considerably from one educational system to another. It is due to the different conditions of each situation. We propose a model that incorporates some of these ideas.

The use of the information technologies is nowadays more and more common in the teaching-learning process. As a consequence, the research on instructional design has been reactivated paying special attention to its adaptation to this new digital world. Task based instruction has proved to be effective for customized systems and student-centred learning. In these models, the assessment, the motivation and the active role of students are definitely the key. In fact, this is one of the main challenges in education and, in particular, in online education. Precisely, motivation, progressiveness and instant feedback are the pillars of gamification (Pastor, Satorre, Molina, Gallego & Llorens, 2015).

This paper is the result of these questions and hesitations, the inquisitiveness about new teaching-learning methods and the concern of improving.

The proposal presented in this paper is part of a course in introductory computer programming in the Degree in Multimedia Engineering, but the considerations and conclusions are not specific to this subject, so that they can be extrapolated to other areas in which a teaching-learning process is developed.

The paper is organized as follows. In section 2 the different perception of students and teachers facing the same situations is shown, along with different experiences that we have conducted over several academic years. Section 3 presents the cornerstones that we have identified and that are fundamental in the teaching process, from our point of view. Section 4 presents the fractal model of teaching, including the model definition and an example of application to the particular context of a specific course. Finally, the last section describes the findings from the whole reflection.

2. From experience

At any stage of everyday life, the actors have different appreciations depending on their role; just think in any situation that occurs between parent and child, boss and employee, or even friend and friend. The relationship between teachers and students is not immune to this reality and this fact is reflected in the various difficulties that the teacher founds in his professional life. Often, situations that teachers consider as problematic are irrelevant to the students, and vice versa. It is important, in our opinion, to try to find an explanation for these discrepancies. To compare the opinions of students and teachers in some key aspects of the development of classes, some questionnaires have been done. Also, during the different academic years, we have been making different actions with the intention of getting closer to the student and to his way of learning in order to obtain a greater involvement.

Although the study focuses on course Programming 1 of the Degree in Multimedia Engineering, questionnaires were carried out in all groups of this subject, and also in 3 groups of Programming 1 of the Degree in Computer Engineering, to compare heterogeneous groups. In the following sections the results are discussed and our conclusions are presented.

2.1. Quantification of student work

Teachers often feel that students do not spend enough time to work the subject outside the classroom. In our case, since it is a subject of 6 credits, considering the correspondence of the classroom and non-classroom hours of work, students should spend approximately 6 hours per week of non-classroom work. To measure non-classroom work, we asked two questions. The first one is of appreciative type, asking whether they devote enough time to the course; and the second one is of quantitative type, about the time spent, giving three possible responses: less than 3 hours, between 3 and 6 hours and 6 hours per week. Reviewing the results of the surveys it can be observed that they do not spend the determined time and they do not perceive that the time spent is clearly insufficient. Looking at Figure 1, virtually half of the students believe they devote the necessary time to the subject. However, in figure 2 it is found that most students spend fewer hours that the time considered by faculty as necessary to assimilate the material. Indeed, very few students have approached the recommended six hours of dedication as stated by the ECTS credits. These data corroborate the perception that teachers have on non-classroom student work, especially when considering the final marks. However, should we infer that the bad results come from the lack of dedication or are there other causes for low marks?, do the teachers know how to estimate the time required to perform the training activities?, do we really have a reliable method to know the time they spend? All these questions lead us to reflections and proposals that are presented in the next sections.

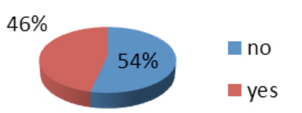

Fig. 1.Do you think you spend the necessary time to the subject?

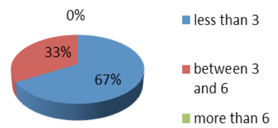

Fig. 2. How much time do you spend on the course outside the classroom?

2.2. The objective of learning

Another interesting question is to find out what are the perceptions of students about the learning objectives of the course. It may be surprising that the objectives that teachers set out and the ones that students perceive are often very different. In our case, we are interested in the idea that a first course student has about what programming is. In our experience, for a student programming is writing programs that perform the required tasks, regardless their appropriate design, simplicity, efficiency or whatever; that is, the programs must work no matter how. Given this perspective, it is well understood that they believe that the subject should be taught using computers. So we have asked if they consider that the subject must be taught in a computer laboratory. In Figure 3 we show the results: an overwhelming majority defend such type of classrooms as the most appropriate for the subject. This idea does not correspond exactly with the teacher's opinion. From our point of view, at the computer, students tend to focus on writing code without analysing beforehand the design of the solution as a whole. Predictably it will not work as expected and then they will patch it adding new instructions, copying and pasting code to finally join a program that may work but that it is completely incomprehensible. If they had spent some time thinking about the design, this would not happen, but the minutes they do not write code are wasted time for them. Clearly the use of a computer to implement the program is necessary, but the training activities should be designed so that this kind of "programs that work at any cost" is not rewarded.

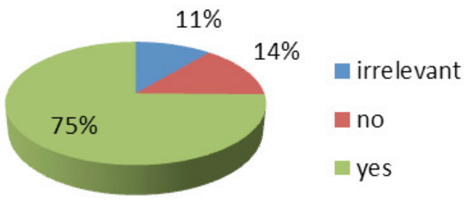

Fig.3. Do you think it would be better to teach the subject completely in a computer laboratory?

2.3. The class size and the teaching method

The high number of students in a lecture class is perceived by the teachers as a major setback. We consider extremely difficult to try to explain a very practical matter in a classroom with a hundred students. The only ones who pay attention are those in the front rows. Furthermore, when the group size is small, the teacher can closely interact with students. This way the evaluation might be less focused on exams and tests. Having fewer students means that the teacher knows the work and effort devoted by each student to the subject.

To obtain feedback from the students, we asked them if they thought the number of students in the lecture room is adequate. As we suspected, the students think that the size is greater than adequate in the vast majority, as shown in Figure 4. However, we found it interesting to know the opinion of the students belonging to groups of smaller size. Taking advantage of the fact that the teachers also give class in a subject of identical contents in the Degree in Computer Engineering where the group size is smaller, the same question was asked. The results are shown in Figure 5 for four different group sizes. It is observed that the number of students who feel that the group size is suitable decreases as the group size increases.

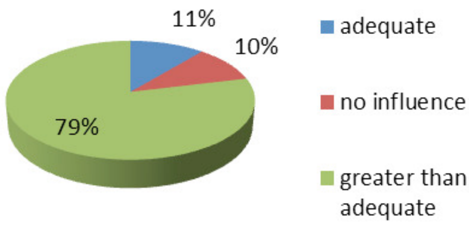

Fig.4. Do you think that the number of students in the lecture class is appropriate? (Reference group, size 125 students per classroom).

Although students corroborate our impressions, data are not as conclusive as expected. The problem of overcrowded classrooms has been partly alleviated because of the adaptation of the teacher to the group size: instead of promoting the active participation of students, the class is in lecture mode, the only possible way. Thus, the students do not suffer so much the crowded classrooms since massiveness does not affect them when attending the class. However, if during the lesson they played a more active role, they immediately would notice it is not possible in large groups.

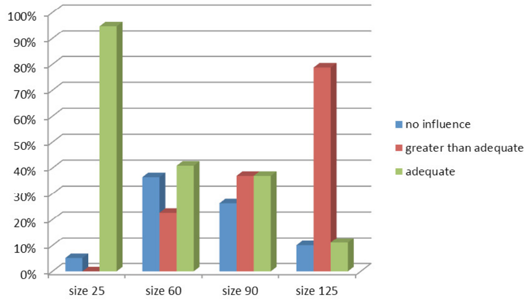

Fig.5. Do you think that the number of students in the lecture class is appropriate? Comparison between groups of different size.

2.4. Peer learning

Peer learning can be defined as the acquisition of knowledge and skills through active helping and supporting among status equals companions (Topping, 2005). There are several types of peer learning. We have decided to use peer assessment, that is, peer evaluation of the outcomes of learning of the other members of the group.

Peer review is useful in several contexts, such as academia and business. It has been featured in numerous conferences about education (Marqués, Badía & Martínez, 2013), (Oliver & Canivell, 2009), (Sánchez & Blanco, 2013). To perform a peer review of an exercise, students should not only use their existing knowledge of the subject but also they should know how to use them to analyse and assess the work of their classmates. A person is aware of what he knows when trying to explain someone a particular problem of the discipline. Applying this "common knowledge" to correcting colleagues' exercises, students test their level of knowledge and so doubts arise. It is a good opportunity to solve these doubts; for sure they will be more receptive. For the assessment process to achieve the pursued objective, avoiding confusion and overwhelm, our students are previously indicated what and how to evaluate. In addition, the correction should not only indicate the mistakes, but also their solution. After peer review, professor solves the problem by insisting on what is really important and what is not. Do not forget that this is a subject about Programming and there is no single solution. For example, they are warned that the essential aspect is the use of the appropriate structure, beyond the syntactic correctness. When correcting, the teacher's goal is the students to identify what is important and relevant to the design of a solution. Students consider this activity very useful and teachers do agree with them on this occasion. During peer review, students must test their knowledge to solve and review, while they must analyse other solutions, designed from a different point of view.

In some theory groups (no computers in the classroom), with a small number of students we could make another activity. In this case, students should prepare some topics of the subject to be explained to their classmates in the next session. Again, we have put into practice the idea that explaining a concept includes the knowledge acquisition and, therefore, it forces a deep preparation of the topic and a reinforcement of the learning process, as it is stated in (Biggs, 1999). Moreover, these exercises allow the development of the transverse oral presentation skills.

Both students and teachers believe that this activity is useful not only for the student who makes the presentation, but also for those receiving the explanation, because they all speak the same language. With this activity, the teacher can correct errors or interpretations that otherwise would not know.

3. Through cornerstones

In addition to the issues discussed in the previous section, there are other questions that underlie the common thinking of teachers but are not easily measured.

3.1. Motivation

All human activity is performed according to the reward you get to carry it out. This reward can be varied. To give some examples, the work provides, among other, financial rewards but can also provide satisfactions of more personal nature; altruistic help provides emotional rewards; leisure satisfy us for fun, etc. This can be brought to education and in this sense, students work to achieve their own reward: in many cases the reward they seek is to pass the subject, but in others, satisfaction is provided by the pleasure of learning itself. This is what is usually called extrinsic motivation (achieved through external rewards) and intrinsic motivation (which depends on ourselves and which is given by the interests of each person) (Rinaudo, Chiecher & Donolo, 2003), (Tapia, 1995). It is essential that there is some intrinsic motivation for a good result in the learning process. Just as Jenkins argues (2001), if the students are not motivated, they will not learn.

The intrinsically motivated students select and perform activities for their interest, curiosity and challenge, and they are more willing to implement a significant mental effort while performing the task, to engage in more rich and elaborate processing and in the use of deeper and more effective learning strategies. For example, students who have a real interest in learning to program try to do other than expected exercises, ask questions concerning "how this would be done", ask for issues that are not in the syllabus, or are interested in aspects that belong to more advanced subjects.

Instead, extrinsically motivated students engage in certain activities only when they are

offered the possibility of obtaining external rewards; moreover, such students may choose easier tasks whose solution assures them the reward. In education, these rewards are usually getting good grades, achieving recognition by others, avoiding failure, etc.
Generally, extrinsic motivation is easier to induce than intrinsic motivation. So teachers work mainly extrinsic motivation, so they repeat very often sentences as: “you should work harder to succeed”, “if you do this exercise, you will get a higher final grade” … All in all, we emphasize the reward to get a purpose. Of course, the teacher’s ability to convey his enthusiasm for the subject causes in many cases that the intrinsic motivation of students wake up, but measuring the intrinsic interest in a subject is extremely complex.

3.2. Evaluation

Another difficult situation that the teacher faces is how to track the work of the student as closely as possible. Driven by this goal, eventually we work very hard but we do not always get the proposed goal.
These inquisitiveness about motivation and how to awaken it, has been detected by all teachers in our daily work, possibly in a more informal way: we are convinced that our students do not show much interest in the matter, do not work hard enough, study just enough to pass the exams, and they do not do an activity if they do not get something tangible from it (an increase in the mark). We strive to repeat that they must work and bring up the matter, commonly with few results. What is wrong in our work? Probably we make many mistakes, but perhaps one of the key issues is the evaluation. We want them to work every day, to have their own initiative and to show interest in going a bit beyond the levels set in the syllabus, but we only evaluate them using an exam, or in the best of cases, using several tests and works along the course. Many of the activities we propose them or even we would like them to undertake on their own initiative are not evaluated, that is, they do not carry any reward. In short, we are leaving much of their learning (perhaps the more interesting part) to its own intrinsic motivation. The question is: can we get all these tasks associated with their own reward? Maybe so, the external reward will lead them to internalize the interest in this matter.
As a starting point of our teaching model, we propose the following core idea: “there should be no activity without evaluation”, that is, every activity that the student performs in the course (all, including attending classes, participation, any exercise and even home study) should be evaluated. The challenge is therefore to identify which activities are necessary for the student to acquire the skills and knowledge that we have proposed, and how we evaluate them.
Evaluating does not mean making an exam, of course. The evaluation can be an activity

itself as a test or a class presentation, but it can also be any faint element within an activity: for instance, validate whether certain content is searched, check the time spent performing an activity, answer a question in a forum or simply check whether the student has read it, see if the materials have been downloaded from their Learning Management System, etc. In short, we should design the subjects from activities, each defined to achieve one or more skills, and each with its own assessment.

3.3. Progressiveness

Another activity in this course has been to force delivery of a particular exercise of each practice to allow the progress in solving the following practices. The statement of the practice problems contains some solved exercise as examples and some proposed exercises to solve. To unblock the access to the following practice, the students are forced to deliver at least one of the proposed exercises. The idea is to apply something similar to the strategies used in gamification, but at a very basic level. It is similar to overcoming the various levels of a game, so they value their progress. The aim of this exercise was to motivate them to finish to advance. Moreover, the teacher's review provides feedback, allows redelivery and review what was presented. The students appreciate this type of exercises but teachers consider that they have not met the objectives and, besides, they have significantly increased the teachers' workload. We are disappointed because the students have focused on solving the proposed exercise just for delivery, even copying other classmates' solution. It is true that it has been useful for some students, but it is also true that those students would have progressed similarly if there were no obligation to deliver any exercise.

3.4. Independent learning

An interesting activity that we have implemented at the beginning of the course is the students to prepare a given topic, and them to make a test about this topic with no teacher's explanation. After completing the questionnaire, the teacher explains each issues and solves the doubts. Again students and teachers agree on the usefulness of this activity. The goal of the test is not to get a mark to add to the final evaluation, but the students to anticipate the teacher's explanation. Thus when the teacher explains the subject, students have some prior knowledge that make them more perceptive and allow them to perfectly follow the class.

4. To model

4.1. Teaching as a fractal

Considering the arguments described above and relying on theories of other authors as the Instructional Theory of Reigeluth (2012), fractal design model is proposed (Compañ, Molina, Satorre & Llorens, 2014).

A fractal is a geometric object whose basic structure is repeated at different scales. The mathematical concepts related to fractals can inspire us in proposing a teaching model. We propose to define a primitive element that is repeated at different scales, so self-similar, the style of fractals. Therefore each primitive element is formed in turn by elements of a lower level but with the same scheme, giving the proposal a fractal character.

The primitive elements of the teaching model are training activities. Thus, each level consists of a series of training activities, all with a common structure: learning objectives, a set of activities of a lower level which it divides into, and assessment, based on the lower levels (Figure 6).

Note that each activity, regardless of its characteristics (complex or simple, instant and long lasting, abstract or concrete, theoretical or applied), entails some evaluation.

To follow the fractal scheme, training activities are integrated in turn by lower level activities with the same structure. The minimum level is marked by the nature of the activity and the type of subject, allowing the teacher to design his course according to his own criteria.

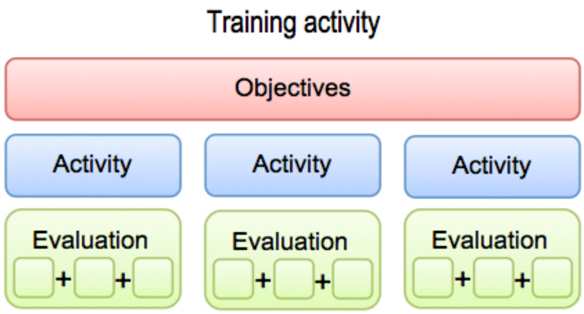

Fig.6. Elements of a training activity..

As a result of applying this model, learning emerges naturally from the design itself: the sum of activities of different type and different level prepares students to face problems of different nature and facilitates the processes of analysis, synthesis and generalization; evaluating each activity helps the student to be aware of the importance of the activity and its ultimate impact on learning outcomes.

In the proposed model, the last level, or atomic level, must be simple enough for the evaluation actions to be easily automated. To do so, it is necessary to incorporate technological tools to facilitate this task and provide the student immediate feedback on their progress.

The analogy between the proposed model and fractals is not merely anecdotal. Some characteristics of fractals can be related to the model resulting in a new formalization and conclusions. Here are some of the interesting features.

- Fractal objects are too complex and irregular to be described through traditional geometrical concepts. The teaching process is, of course, very complex and irregular. Every subject, every activity, every teacher and even each student may require a different training design.
- Fractals are self-similar objects, that is, its shape is defined from smaller copies of the same figure. Thus, copies are similar to the whole, with the same shape but different size. This concept is key to our teaching design: despite the irregularity of the process, we can find a common pattern and it can be repeated at different scales: degree, grade, subject, topic, activity...
- Fractal objects need new dimensions to be defined: for example, we find fractal curves (whose topological dimension is 1) that fill the entire plane. New dimension formulations arise (for example, fractal dimension or Hausdorff-Besicovitch dimension) that informs in a better way how the fractal occupies the space. Somehow this concept can be extended to the learning process: instead of a linear teaching of dimension 1 (one concept after another, which will hardly cover all the teaching space) a fractal teaching with a dimension higher than 1 is proposed (this allows to go down to lower levels and fill the entire space through training activities).
- Fractals allow not just the representation of geometric objects, but have also been used to model the evolutionary dynamics of complex systems. This dynamic consists of cycles (in which starting from a established simple reality a new complex reality is created) which in turn are part of more complex cycles belonging to the development of another major cycle dynamics. The teaching process can be seen as a complex system under an evolutionary dynamics.

4.2. An example

To complete the proposed model, we present a concrete proposal of a fractal design of the subject that we have mentioned above. Since the full design of the course is too long, here we present just some levels and activities that we consider significant and provide an overview of the complete model.

First we present the top level design of the subject as a whole. The defined activity is the whole course and its objectives are broad and cover all the subject (Figure 7). Each activity of the lower level is a large thematic block of the subject, and in turn they will be divided into other activities (not described here due to space restrictions). Importantly, each activity of the second level includes an

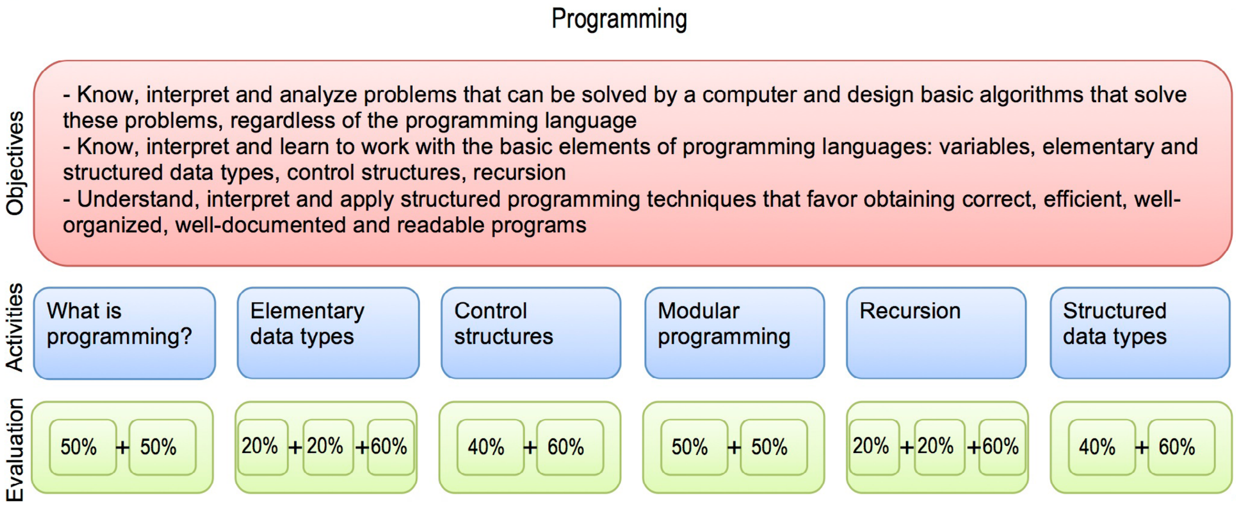

Fig.7. Training activity of first level. It corresponds to the entire course.

assessment described here as percentages, but the teacher can define it at his discretion. In Figure 8 we present an activity of penultimate level that is broken down into two atomic activities, that is, they belong to the last level. These activities allow us to realize how the assessment is made. As it can be seen, the actions of evaluation are at this level very specific and simple. Many of them can easily be automated (they are indicated with *) while in other cases the active participation of the teacher will be required. As already noted, the key aspect of this model is evaluation. For example, referring again to the activities of Figure 8, if we want students to understand the idea of iterative solution and the concept of loop, it is important for them to understand that the

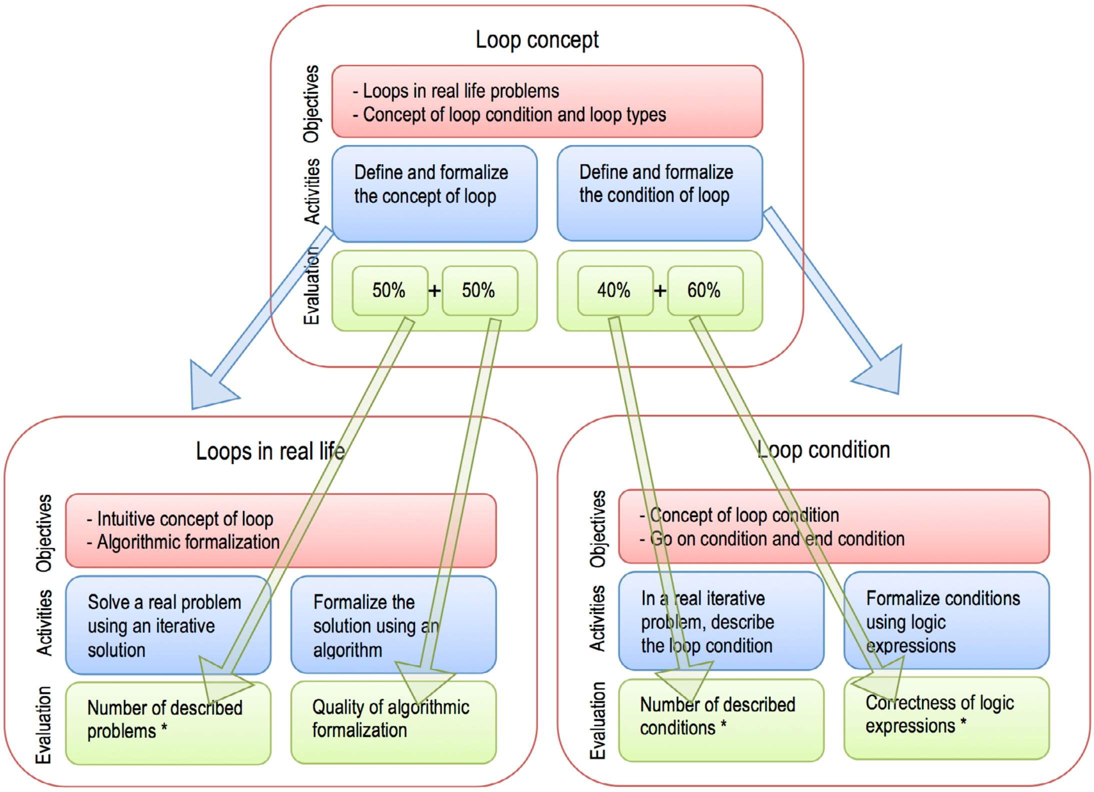

Fig.8. Training activities belonging to the penultimate and last level

iterative solutions to a problem are present in real life. Therefore a possible activity is to describe a real problem whose solution is iterative. Since every activity must include some kind of evaluation, it is necessary to find a way to assess this activity. We simply propose to quantify the number of described problems. Of course this measure is not itself very indicative of the level of the student understanding, but it estimates the effort made by the student, and we must consider that it is just an atomic value in a very large set of indicators, all of which together shall be much more valuable. Furthermore, the activity "Formalizing the solution as an algorithm" allows the assessment of higher cognitive level skills.

This is just a simple example, but it illustrates what has been described in the previous paragraph: if you go down to the adequate level, practically every action of the students can be evaluated, allowing a very powerful feedback of the process. For the model to be implementable, most evaluation actions should be automatic. This way, we will free teacher from repetitive tasks and get the student to have an immediate feedback, motivating him and stressing the value of that activity in the final result of learning.

5. Conclusions

In this paper we have presented a teaching model based on fractal design. This model is the result of analysing the different perspectives of students and teachers before the circumstances that occur in the classroom and trying to solve some of the shortfalls in order to increase learning success.

The proposed model incorporates some ideas of instructional theory. Each training activity is integrated by lower level activities and so on. Therefore it is a model focused on the task. Learning is student-centered, who performs multiple activities that make up the different levels of the fractal model. Students learn by doing rather than listening to the teacher´s explanations.

The model focuses on the evaluation of all activities undertaken by the students with two objectives: firstly to provide feedback to students to enhance their motivation and report on their progress and secondly to facilitate the teacher's evidence that will make the evaluation more objective. If further automation elements are introduced, the work of teachers is facilitated and immediacy of feedback is provided. Therefore, the support of technological tools is essential in a proposal like this.

As for the dedication of the student we are convinced that a greater motivation will suppose an increase in working time. Besides, technological tools will allow us to better monitor the working time and bring the student-centred learning to larger groups.

Atomic activities function as building blocks so their reuse elsewhere in the subject and their incorporation into any other is facilitated.

It happens that teachers have many interesting ideas, but they must adapt to the reality in their daily work, that is, crowded groups and few resources. Meanwhile, they will be able to apply only some of these ideas and leave the less automatable activities to groups where their size and characteristics make it possible.

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