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# Assessment for Learning: A Case Study of an Online Course in Operating Systems

SONIA PAMPLONA
Science and Engineering Department, Universidad a Distancia de Madrid, Carretera de La Coruña, Km. 38,500, Vía de Servicio, no 15, 28400 Collado Villalba, Madrid, Spain. E-mail: sonia.pamplona@udima.es

NELSON MEDINILLA and PAMELA FLORES
Department of Information Systems and Languages and Software Engineering, Universidad Politécnica de Madrid, Campus de Montegancedo, 28660 Boadilla del Monte, Madrid, Spain. E-mail: {nelson, pamela.flores}@fi.upm.es

This study explores the effects of a formative assessment on operating systems, a subject that is part of the computer engineering degree at an online university. The formative assessment that we designed was based on the following goals: (a) to promote meaningful learning and (b) to make students aware of their learning processes. The research methodology used was the qualitative case study. The sample was composed of 9 students out of 13 who were enrolled in the class. The qualitative data analyzed were obtained from formative assessment tests taken by the students during the course. The empirical evidence shows that the assessment produced deep reflection on both the subject's main concepts and the student's learning style, which corroborates the results of other research in this area. This case study can help engineering teachers to create formative assessments for online courses.

**Keywords:** e-learning; online learning; formative assessment; assessment for learning; operating systems

## 1. Introduction

Formative assessment motivates and guides students towards their objectives and thus stimulates and facilitates learning. Consequently, this type of assessment is now considered to be a fundamental element of any educational experience [1].

In addition, assessment in online settings requires deep reconsideration because online learning is distinct from traditional face-to-face classes due to the asynchronous nature of the interaction between course participants [2]. Given this situation, the literature highlights the need to deeply investigate the formative assessment in online settings [3–7].

In addition, the subject of operating systems, which is a course taken by upper-level computer engineering students, is difficult according to teachers and students and the research literature [8–11]. Thus, the subject is ideal for implementing a formative assessment.

In spite of its importance, until now there have been few studies of formative assessment in online courses. Most of the research on online formative assessment has involved face-to-face settings in which the formative assessment has been conducted using computers [12–14].

Studies have presented various solutions for improving teaching the subject of operating systems [15–18]. In general, however, these studies lack a theoretical basis for their assessments and neither determine nor evaluate the learning objectives of the suggested experiences. Furthermore, there are no studies on the adoption of formative assessment in operating systems courses.

The objective of this study is to explore the effects of a formative assessment created for an operating systems course at an online university. The formative assessment has the following goals: (a) to promote meaningful learning and (b) to make students aware of their learning process.

The following research question guides this study: How does formative assessment influence the students' learning experiences?

## 2. Theoretical framework

The theoretical framework for this research is described below.

### 2.1 Formative assessment versus summative assessment

Michael Scriven was the first to use the terms 'formative assessment' and 'summative assessment' to explain the distinct roles played by the evaluation of a curriculum [19]. Later, Benjamin Bloom and his collaborators applied the same distinction to the evaluation of student learning, or what we today call assessment [20]. Bloom distinguishes formative from summative assessment in accordance with the purposes that each type of assessment pursues. That is, the terms formative and summative are not applied to the assessments *themselves*, but rather to their functions. Recently, the literature has referred to summative assessment as an assessment of learn-

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ing and to formative assessment as an assessment for learning [3].

Summative assessment is the type of assessment used at the end of a period, course, or program with the intention of qualifying, certifying, evaluating progress or investigating the effectiveness of a curriculum or educational plan. Formative assessment is the use of a systematic assessment with the intention of improving one of the following three processes: construction of the curriculum, instruction, or learning. Bloom states that the most important contribution of formative assessment is the assistance that it can provide to students in their learning processes.

Bloom's recommendations for the creation of formative assessment have been broadened and enriched by the recent research on learning. In 2007, William and Thompson [21] distinguished three fundamental processes of teaching and learning to provide a firmer theoretical framework for formative assessment:

- Establish where the students are in the learning process
- Establish where they should go
- Establish what needs to be done to direct them to that point

Based on the processes set out above, the authors conceptualize formative assessment using five strategies:

1. Clarifying and sharing learning objectives
2. Obtaining evidence of student comprehension
3. Providing students with feedback to help them achieve their learning objectives
4. Encouraging student collaboration
5. Making students responsible for their own learning

These strategies provide the theoretical framework for the formative assessment carried out in this study.

### *2.2 Bloom's revised taxonomy*

The goals of the formative assessment designed for our course are as follows: (a) to promote significant learning and (b) to make students aware of their learning processes. To achieve these goals, we used Bloom's revised taxonomy [22], which allows for the creation of goals and assessment tests aligned with the purpose of the assessment.

Meaningful learning is based on transference, which is the ability to use what is learned to solve new problems, respond to new questions, or facilitate the learning of new subjects. In contrast, rote learning is based on retention, which is the ability to remember material in a way similar to the way in which it was presented [23].

The concept of meaningful learning appears frequently in studies of formative assessment [12–14]. This concept may be known by different names, such as deep learning, learning with understanding or problem solving, depending on the study's theoretical framework.

Bloom's revised taxonomy has two dimensions: cognitive processes and knowledge type. The dimension of cognitive processes is made up of six categories: remember, understand, apply, analyze, create, and evaluate. Each of these categories is associated with two or more specific cognitive processes. For example, the category 'remember' is associated with the cognitive processes of recognizing and recalling. Rote learning is related to the remember category, and meaningful learning is related to the five remaining categories. The categories of cognitive processes are very important to our study because they allow us to differentiate meaningful learning from rote learning.

The first category, remembering, consists of recovering knowledge from long-term memory. The category of understanding consists of constructing meaning from instructional messages communicated in oral, written, or graphic form. One of the most important cognitive processes included in this category is inference, which means relating knowledge to extract conclusions that were not made explicit during instruction. The category of applying consists of carrying out or using a procedure in a particular situation. The category of analyzing consists of dividing a subject into its constituent parts and determining how these parts are related to each other and to the general structure. The evaluating category consists of making judgments based on criteria and standards. Finally, the creating category reorganizes elements into a new pattern or structure.

The dimension of knowledge includes four categories: factual, conceptual, procedural and metacognitive. Factual knowledge consists principally of the terminology used in a particular discipline. Furthermore, knowledge of persons, dates, and sources of information is considered factual. Conceptual knowledge refers to knowledge of extended and organized bodies of content, such as concepts, principles, models, and theories. Procedural knowledge is knowledge of how to do something. Metacognitive knowledge is knowledge about cognition in general, along with awareness of and knowledge about one's own cognition.

Metacognitive knowledge has a very important presence both in our study and in other research regarding formative assessment [14, 24]. Existing studies have studied metacognitive knowledge in various ways, such as conducting online discussions [24] or measuring the reliability of students' responses [14]. In this study, there were questions asked for the sole purpose of assessing metacognitive knowledge.

### 2.3 E-learning and online learning

There is no agreement in the literature regarding the meaning of the terms ‘e-learning’ and ‘online learning’ [25, 26]. Below, we provide the definitions that we use as references in this study.

E-learning is a modality of teaching and learning that can represent all or part of the educational model to which it is applied and which makes use of electronic media and devices to facilitate access to, the evolution of, and improvement in quality in education and training [26].

Online learning is teacher-led education that takes place over the Internet with the teacher and student separated geographically, using a web-based educational delivery system that includes software to provide a structured learning environment. It may be synchronous (i.e., the participants interact in real time, e.g., by using online video) or asynchronous (i.e., the participants’ communication is separated by time, e.g., when using e-mail or online discussion forums) [27].

In this study, e-learning is considered to be any learning that takes place through electronic media, and online learning is a specific modality of e-learning in which communication takes place through the Internet with the student and teacher geographically separated.

Most of the studies that include the keywords ‘online formative assessment’ involve assessments that use computers in in-person settings [12–14]. Our study describes a completely different situation: the development of a formative assessment in a course that has been developed entirely online, in which teachers and students are geographically separated. In online learning, formative assessment may be more important than in an in-person course because it may constitute a guide for the student, which allows students to assess their learning at any moment.

### 2.4 Operating systems

Operating systems is a subject that is included in most upper-level computing courses worldwide. Its importance is recognized in the curriculum that has been published for more than 40 years by the two principal professional computing societies: the Association for Computing Machinery (ACM) and the Institute of Electric and Electronic Engineers (IEEE) [28].

## 3. Methodology

The purpose of this study is to examine the effects of formative assessment on students’ learning processes. Given the exploratory character of the research, our methodology is the quality case study [29]. Below, we describe the context of the course, the processes of analysis and collection of data, the design of the formative assessment carried out, and the study’s limitations.

### 3.1 Setup

The study was conducted in an operating systems class taken by second-year computer engineering students at an online university. The class lasted for 14 weeks, running between October 2012 and February 2013.

Below we describe the course’s online learning setting:

- The students had at their disposal a virtual classroom setup using Moodle, a learning management system that contained all course materials and activities.
- The virtual class provided forums for interacting with the professor and the other students.
- The course was taught exclusively online.
- Students were expected to learn by reading a manual and participating in formative assessment activities.

### 3.2 Data collection

#### 3.2.1 Sample

The sample is composed of 9 students out of the 13 who were enrolled in the class. The sample included every student who performed the activities required; that is, every student who had not dropped out of the class during its first weeks.

#### 3.2.2 Documents

To answer the research question, all of the formative assessment tests given during the course were analyzed. They included the following:

- Three multiple-choice questionnaires
- Two activities focusing on solving operating system problems
- One activity focusing on the use of an operating systems simulator [30]

### 3.3 Data analysis

The data analysis proceeded in two phases [31] with the help of ATLAS.ti, a qualitative analysis program [32].

The object of the first phase of the analysis was to familiarize ourselves with the case study data and patterns. To do this, we coded the text that identified students’ phrases related to our research question. Once the primary analysis of all of the documents for the case study was completed, we studied all of the codes created to identify patterns in the students' responses.

In the second phase of the analysis, we again analyzed all of the data for more information about each pattern. The objective of this phase was to obtain a deeper knowledge of the studied phenomenon and to triangulate the data to verify the results.

### *3.4 Design of the formative assessment*

Below, we describe how the study's formative assessment was designed. Our intent is that the assessment should serve as a reference for other online teachers. This is one contribution of our study because most empirical studies of formative assessment do not provide a detailed description of the design and implementation of the studied assessment.

The design process for the formative assessment consisted of two phases:

1. Establishing the objectives of the course
2. Designing the assessment tests

The sections that follow describe the steps followed in each of the phases.

#### *3.4.1 Establishing the objectives of the course*

Establishing the learning objectives of a particular subject is fundamental because the assessment process should check whether these objectives have been met. However, no studies of operating systems education have explicitly described the objectives of the studied courses.

To establish the objectives of our online operating systems course, we started with the learning objectives recommended by the ACM/IEEE Computer Science Curriculum [28]. In particular, objectives that constitute the nucleus of the subject of operating systems were selected: an overview of operating systems, operating system principles, concurrency, scheduling and dispatch, memory management, and security and protection.

The first step was to classify the selected objectives in accordance with Bloom's revised taxonomy [22]. This classification presented two difficulties, which are described below.

The first difficulty was that classifying learning objectives is not as automatic a task as it might seem. It requires a deep knowledge of the cognitive processes collected in Bloom's revised taxonomy. For example, on many occasions the verb used to present a learning objective does not coincide with the cognitive process. For the objective, 'Explain the benefits of building abstract layers in hierarchical fashion', the cognitive process involves *interpreting*, not *explaining*, as one might expect, because this taxonomy defines *explaining* as 'Constructing a cause-and-effect model of a system'.

The second difficulty that occurs in classifying educational objectives is the need to know or assume the nature of the students' educational experiences during the course. Thus, for example, a problem presented in a test will require complex cognitive processes if the situation presented to the student is new, whereas the problem requires no more than simple recalling if the student has already experienced a learning experience involving analysis and discussion of a problem of the same type.

This difficulty was resolved by assuming that students' educational experiences during the course were limited to participating in the formative assessment and studying the manual. The manual was created expressly for teaching of this subject online and is consistent with the curriculum recommended by ACM/IEEE. For example, the objective 'Describe the need for concurrency within the framework of an operating system' is related to the cognitive process of *inferring* because the information to be described is not explicitly stated in the manual, but rather must be inferred by the students.

Below, we show the results of the classification of the learning objectives for the two dimensions of cognitive process (Table 1) and knowledge (Table 2).

The results show that 88% of the objectives are related to cognitive processes for the category *understanding* and 90% of the objectives refer to conceptual knowledge. Thus, one could state that the principal objective of our operating systems course was to understand concepts. In accordance with Bloom's revised taxonomy, the understand category is composed of the cognitive processes of interpreting, exemplifying, classifying, summariz-

**Table 1.** Number and percentage of objectives by category of cognitive processes

| | Number of objectives | Percentage |
|---|---|---|
| Remember | 2 | 5% |
| Understand | 37 | 88% |
| Apply | 3 | 7% |
| Analyze | 0 | 0% |
| Evaluate | 0 | 0% |
| Create | 0 | 0% |
| Total | 42 | 100% |

**Table 2.** Number and percentage of objectives by type of knowledge

| | Number of objectives | Percentage |
|---|---|---|
| Factual | 2 | 5% |
| Conceptual | 38 | 90% |
| Procedural | 2 | 5% |
| Metacognitive | 0 | 0% |
| Total | 42 | 100% |

ing, inferring, comparing, and explaining. These processes imply a relationship among concepts and suppose meaningful learning.

Table 2 shows that the ACM/IEEE document contains no learning objective related to metacognitive knowledge. However, students' knowledge of their own cognition plays a very important role in learning [7]. Thus, in addition to the learning objectives suggested by ACM/IEEE, we included as a course objective that students should reflect on their learning.

#### *3.4.2 Designing the assessment tests*

The tests were as follows:

- Three multiple-choice questionnaires
- Two activities with a focus on solving operating systems problems
- One activity that focused on the use of an operating systems simulator [30]

The test design took place in two phases: selecting the tests for the principal operating systems texts and modifying those tests.

##### *3.4.2.1 Selecting tests for the principal operating systems texts*

The objective of this phase was to select tests that promote meaningful learning. The assessment tests for the course were constructed based on questions and problems included in the principal operating systems texts [33–38]. The process of selecting the tests consisted of the following phases:

- Making the learning objectives for the textbooks' assessment tests explicit
- Classifying those learning objectives in accordance with Bloom's revised taxonomy
- Deciding whether the test should become part of the formative assessment. The deciding criterion was that the question's learning objectives should both correspond to the course's learning objectives and produce meaningful learning

To carry out the first phase, one must remember that there are various types of learning objectives. The objectives recommended by ACM/IEEE are called educational objectives, the time needed to achieve them is weeks or months, and their principal function is to design the curriculum for a particular subject. On the other hand, the learning objectives for each of the assessment tests are called instructional objectives, the time needed to achieve them is hours or days, and they serve to prepare classes and assessment tests [39, 40].

Below is an example of one of the problems selected. Table 3 includes its instructional objectives and the educational objective of ACM/IEEE to which it is related.

*Problem 1.* A CPU executes, on average, 50 machine instructions per μs. Suppose a program processes a file of records where reading and writing a record from the file takes 11 μs each. If the program needs to execute 150 machine instructions between each reading and writing, what is the CPU utilization? Source: Exercise 2.3, page 124 [38].

##### *3.4.2.2 Modification of the tests selected*

Modification of the tests selected was performed with two distinct purposes in mind:

1. Obtaining evidence of student learning
2. Promoting metacognitive knowledge

Below, we describe the steps taken in relation to each of those purposes.

##### *3.4.2.3 Obtaining evidence of student learning*

Formative assessment requires confirming that students have achieved established learning objectives [21]. This confirmation is not simple because it is possible that a student might give a correct answer to a multiple-choice question through chance, or that a student might solve a problem correctly by applying a known procedure, without really understanding why the problem is solved in this way. To be sure that the expected cognitive processes occurred, the multiple-choice questions and the problems were modified as follows:

- For the multiple-choice questions, an additional question was added in which the student was asked to justify their response and explain why they had selected that response.
- For the problem, questions were added with the same intention mentioned above, thus requiring

**Table 3.** Problem 1. Instructional and educational objectives

| | Knowledge | Category | Cognitive process |
|---|---|---|---|
| **Instructional objectives** | | | |
| Understand the concept of CPU use. | Conceptual | Understanding | Interpreting |
| Infer that during I/O time the CPU remains free. | Conceptual | Understanding | Inferring |
| **Related ACM/IEEE educational objective** | | | |
| 1. Describe the need for concurrency within the framework of an operating system. (OS/Concurrency). | Conceptual | Understanding | Inferring |

the student to make their thinking process explicit.

Below, we show an example of a problem. The questions added to the original test are emphasized in italic:

*Problem 2.* Consider a round-robin scheduling with an idle time of 0.25 μs between any two time slices (irrespective of whether the same job continues or a job switching occurs). If three jobs requiring execution times of 6 μs, 3 μs and 8 μs are executed, what is the throughput? Assume that a time slice of 1 μs is allocated in each round.

*What is the throughput if the time slice is 0.5 μs?*
*In which of the two cases presented is performance greater? How would you explain this?*
Source: Exercise 2.4, page 124 [38]

*3.4.2.4 Promoting metacognitive knowledge*
One of the objectives of the course was for students to reflect on their learning. To facilitate this objective, questions were added that expressly required students to undertake this type of reflection, in the words of Flavell [41], to foster metacognitive experiences. Metacognitive knowledge is an element that we consider key to the design of our formative assessment.

Below are some of the questions that we used to foster reflection about each student's particular learning process. These questions were inspired by those used in a reference study of computer education [42].

*Activity 1*

1. What do you think about what we have done in this class until now? Has it been easy? Difficult? Interesting? Boring? Can you explain why?
2. Which exercise for this activity seemed to be the most complicated? Can you explain why?
3. Which exercise for this activity seemed to be the most interesting? Can you explain why?
4. Which concepts or aspects of the subject have seemed to be the most complicated up to this point? Can you explain why?
5. Did these exercises help you to better understand some aspect of the subject? Which? Can you explain why?
6. Did you learn something new from this activity? What? Can you explain how?

### *3.5 Limitations of the study*

This study is subject to the limitations inherent in a qualitative study [31]. One should also bear in mind that one of the researchers, the first author of this study, was also the teacher of the course.

To check the internal validity of the results, they were triangulated with distinct origins of data. Furthermore, the codes generated during the analysis were reviewed by the three study authors and the existing differences were discussed and resolved.

The following facts indicate the study's objectivity:

- The methods and procedures of the study are described explicitly and in detail.
- It is possible to follow the sequence of how the data were collected and processed to obtain the conclusions.
- The results are explicitly related to the original data.

Finally, one has to take into account the fact that the goal of the study is not to generalize its results, but rather, to conduct an in-depth study of a concrete context with the objective of learning from it [43].

## 4. Results

We discovered three effects caused by formative assessment: (1) profound reflection on the concepts of the course, (2) uncertainty about the resolution of the assessment tests, and (3) awareness of progress and difficulties in learning.

### *4.1 Reflection on the concepts of the course*

Empirical evidence suggests that there was profound reflection on the concepts of operating systems. There are two ways that reflection is present in the student responses: explicit and implicit.

*Explicit*

Below is a representative set of the responses that show explicit reflection on the subject of the course. The questions from the assessment that led to these responses involved metacognitive knowledge. Codes E01, E02, E03, etc., identify the responses of each student.

Question: What do you think about the course questionnaires? Did they seem difficult? Easy? Interesting? Boring? Explain the motives for your response.

Response E01: The multiple-choice questionnaires did not seem very difficult, just that you had to think a lot before answering, which seems brilliant to me because often one answers without enough thought.

Question: Do you think that the questionnaires helped you to understand the subject better? Justify your response.

Response E04: There's no question that the questionnaires helped me to better understand the subject because to answer them, I had to think and reflect about the theoretical concepts, resulting in better assimilation.

Question: What do you think about what we have done in the course up until this point? Was it easy? Difficult? Interesting? Boring? Can you explain why?

Response E05: I find the subject very interesting; we are required to think about the main concepts of the course.

Question: Which exercise seemed the most difficult? Can you explain why?

Response E05: The second exercise was perhaps the most difficult until I understood that the answer is not in the books, but that you have to think about all the concepts to apply them in each case.

Question: Did these exercises help you to better understand some aspect of the subject? Which? Can you explain why?

Response E06: When you solve problems, things are always clearer, and it forces you to think about the next step or process that the processor will execute (depending on the algorithm, etc.).

Question: Which exercise seemed the most complicated? Can you explain why?

Response E08: Most of the exercises don't usually cause problems, although they did involve a lot of thought.

As shown by the questions and responses above, the students made their reflection explicit without having been directly requested to do so. The study data show that almost all of the students who participated in the formative assessment were aware of their process of reflection and considered it positive for learning the subject. These facts indicate that the questions regarding metacognitive knowledge fulfilled the purpose for which they were intended—to make the students aware of their learning processes.

*Implicit*

Below are two representative responses that show students' reflection in an implicit way. Also shown are the questions that stimulated this reflection: a multiple-choice question and a problem. Both questions had concept understanding as an objective: the first question relates to the cognitive process of inference and the second relates to the cognitive process of comparison.

*Multiple-choice question*

Learning objective: To infer the circumstances and events that cause a change of process.

A process switch:

(a) is performed by the scheduler.
(b) modifies the entry in the process table of the process evicted.
(c) is always caused by a clock interruption.
(d) occurs whenever a process leaves the waiting process queue and enters the ready process queue.

Justify your answer.

Response E04: Option 'a' can be discarded because changes in process are performed by the activator.

Option 'c', an interruption of the clock originates a change of process, but is not the only option for origination (Input/Output, lack of memory, etc).

Option 'd' can be discarded because in reality, a change of context is produced when a process is in execution and moves to another state, whether blocked or ready.

Option 'b', one of the actions that occurs during a change of context is the updating of the process table from the process that was in execution, that is to say, it actualizes its BCP (Block Process Control), so that I think that this is the correct choice.'

*Problem*

*Learning objective: To compare two possible implementations of the round-robin algorithm*

Consider a round-robin scheduling with an idle time of 0.25 μs between any two time slices (irrespective of whether the same job continues or a job switching occurs). If three jobs requiring execution times of 6 μs, 3 μs and 8 μs are executed, what is the throughput? Assume that a time slice of 1 μs is allocated in each round. What is the throughput if the time slice is 0.5 μs? In which of the two cases presented is performance greater? How would you explain this?

*Response E02:* For both cases, the smaller the time slice, the worse the performance of the CPU. Thus, the worst case is the time slice of 0.5 μs because the steps between slice time is lost and thus in increasing the number of slices, the performance worsens.

Most of the explanations provided by the students showed that the cognitive processes foreseen by the learning objectives (comparison, inference, etc.) had occurred. Thus, the results suggest that the questions fulfilled the purpose for which they were designed—promoting significant learning. Furthermore, the students' marks on their final examinations support this result because all of the students who completed the formative assessment test passed the course.

### 4.2 *Uncertainty in solving assessment tests*

Analysis of the data suggests that the students experienced a phase of confusion, vacillation, and doubt while taking the formative assessment tests. Below is a set of responses that show the students' discomfort and insecurity.

> *Question:* What do you think about what we have done in the course so far? Was it easy? Difficult? Interesting? Boring? Can you explain why?
>
> *Response E01:* For me this subject is very interesting; this class and programming are my favorites. Perhaps it was more difficult for me to do the activities because I didn't know whether everything would be right, that is, I am not sure that everything that I thought was completely correct.
>
> *Response E03:* It was difficult for me because I invested much time, mostly because there were things that I didn't know. In addition, I think that simplifying the texts makes them more difficult to understand, and also that I missed examples and exercises.
>
> *Response E08:* Up until I had to solve these exercises, I thought this subject was rather attainable—the textbook didn't give me any problems, but the questions in these exercises were hard for me.
>
> *Response E10:* The manual was rather theoretical and the activities were more practical, so that you had to look around a little to know how to do them. My greatest difficulty was understanding how to do the exercises.
>
> *Question:* Which exercise for this activity seemed to be the most complicated? Can you explain why?
>
> *Student E04:* The problems were harder for me, not so much because of the intrinsic difficulty, but rather because I was worried about correctly interpreting the test questions in order to find the right solutions.
>
> *Response E07:* Exercise 1 was difficult, not because I didn't solve it easily but because I had never done exercises of that kind. At any rate, it was easier to solve than it had seemed.

The responses above suggest that students were not accustomed to engaging in reflective thinking to respond to assessments. On the contrary, students' habitual method of responding to questions and performing exercises seemed to be as follows:

- To respond to multiple-choice questions, the students sought keywords directly from the course manual, which was available in PDF.
- To respond to problems, the students sought identical problems and copied those problems' solutions without thinking about why it was necessary to undertaken certain steps.

The students found the assessments difficult to solve because the tests given in our course could not be taken using this type of behavior. Because our objective was to promote meaningful learning, the responses to the multiple-choice questions could not be found directly in the book, and students had not done problems exactly like those presented in the assessments.

### 4.3 *Awareness of progress and difficulties in learning*

The results suggest that in addition to reflecting on the concepts of the course, students became aware of their learning processes and their progress and difficulties became explicit.

#### *Progress*

Below is a representative set of responses that make explicit students' awareness of their learning progress:

> E04: There is no question that the questionnaires helped me to better understand the subject because to do them, I had to think and reflect about the theoretical content, which means that the content was better assimilated.
>
> E05: The problems helped me to better understand global structure through processes and how the system distributes play for optimal performance.
>
> E06: The problems helped me to understand concepts such as dwell time and performance.

The responses above show that one of the students believes that the questionnaires forced him to reflect on the concepts of the course, which led to better understanding. Two other students explain that the assessment allowed them to better understand certain course concepts, such as process, dwell time, and performance. Analysis of all the data indicates that most students were aware of their progress and could explain how the formative assessments improved their learning.

#### *Difficulties*

Below is a representative set of responses that make explicit the students' awareness of their learning difficulties.

> E10: The questionnaires helped me to better understand the subject because I realized that in some cases I had not understood the concepts from reading the manual.
>
> E02: The most complicated exercises were num-

> bers 1, 3, and 4 because I think I need to understand their concepts better. I have difficulties with the concepts of performance, processor use, input/output use, and response time; I have a problem with understanding concepts to be able to calculate them.
>
> E03: The fact is that all of the problems, being so different, helped me to learn and understand the subject because they all asked about something different. Problem 4 is the most difficult because I did not understand how to place each process in its proper time.

In one of the responses above, a student states that the questionnaires helped him to detect concepts that he had not understood when he read the course manual. Another student states that he was unable to calculate the concepts for performance, processor use, input/output use, and response time because he did not understand them. A final student declares that he was unable to place the processes at the right time. Analysis of all the data indicates that the majority of students were aware of their difficulties, and that formative assessment helped them to detect the specific areas in which they needed to improve.

In addition to the questions related to the subject of operating systems, the students show that they learned questions related to their manner of studying. One of the students states that he would change the way of dividing his study time, applying a round-robin, process-management algorithm.

> E03: It was interesting to see how the various planning algorithms function, something that I will use in dividing my study time among courses. I learned that in the future, I will dedicate a particular amount of time for each subject, after which I will go on to study other subjects.

Another student learned that comprehensive reading of the manual might not be sufficient, but that it was necessary to test his knowledge, as in the course's formative assessment:

> E08: I learned not to trust my theoretical knowledge. You need to put theory into practice to see whether you understood it properly.

Discovery of the last two effects of formative assessment (uncertainty and awareness of progress and difficulties) corroborates the utility of questions in the area of metacognitive knowledge because these questions lead to the desired result: student reflection on the learning process.

## 5. Discussion

For this study, we created a formative assessment for an operating systems course taught at an online university, and we have discovered three effects of this assessment on the students' learning experience. The following discusses the contributions of this study to formative assessments in online environments and education in operating systems.

Most of the research published on online formative assessments refers to assessments performed with the aid of technology, but in in-person settings. There is a major difference between an in-person course that uses technology and a course that is carried out completely online. Simplifying the scenarios, one could say that, in the first case, the issue is how technology improves the professor's limitations (increasing the hourly schedule, automating the feedback process, etc.). In the second case, the issue is how the professor can improve the limitations imposed by the technology (the loss of face-to-face interaction between students and the professor with all the corresponding implications.)

In our online environment, one of the effects of the formative assessment was an in-depth reflection on the concepts of the subject. This fact means that the formative assessment we created has fulfilled one of the purposes for which it was designed—to promote meaningful learning.

Other studies of formative assessments have promoted meaningful learning in different contexts and with different means [13, 14]. In the first cited study, a tool was used in the in-person classes that permitted synchronous problem-solving sessions with students. In this context, the technology's contributions included the students' anonymity in asking the professor questions and a graphic representation of the problem on the computer screen. The second cited study was conducted at an in-person university and consisted of a computer-assisted formative assessment with questions based on the case study method. In this context, the technology's contributions included providing automatic feedback to students and making the test available online. For our study, different types of assessment tests were used that were selected through Revised Bloom's Taxonomy. In order to adapt our study to the limitations of an online environment, we modified the selected tests as explained in the methodology section. The modifications have been successful and can serve as a reference for designing other formative assessments in online environments.

Another effect of the formative assessment was the students' uncertainty while taking the assessment tests. Our tests presented the students with new situations that could not be resolved simply through recognition or recollection, as the students might have desired. This effect, which may seem negative, is difficult to avoid, since the new situations in the assessment are essential to promoting meaningful learning. If you try to avoid uncertainty, you run the risk of the students memorizing procedures for resolving problems and passing the course without ever understanding the subject, as indicated in key research in the field of physics [44].

The two abovementioned effects, reflection and uncertainty, are linked. The results of our study agree with the Dewey Theory, which distinguishes two sub-processes in all reflective thinking: (a) a state of confusion, uncertainty and doubt, and (b) an action of seeking facts that serve to either corroborate or invalidate what was assumed [45].

The formative assessment also had a third effect, which was that the students became aware of their progress and difficulties. The second and third effect, uncertainty and becoming aware of progress and difficulties, suggest that the formative assessment has achieved the promotion of metacognitive knowledge, one of the purposes for which it was designed.

The questions used in our study to provoke students to reflect on their knowledge were inspired by questions from interviews conducted for a reference thesis on Education in Computer Science in an in-person context. In our online context, it is not possible to conduct synchronous activities with all the students and, therefore, instead of conducting interviews, we asked the questions through a questionnaire with open questions. In these adverse conditions, it can be more complicated to obtain information from the students. Nevertheless, the results suggest that the questionnaire was successful in our study and can serve as a reference for designing other assessments in online environments.

The study also makes a contribution in the area of education in operating systems because it presents a method—the formative assessment—that can improve learning of the subject. Furthermore, our research is different from other existing studies because the designed assessment is based on a theoretical framework and characterizes the course in operating systems through an analysis of the learning objectives.

## 6. Conclusions

The objective of the study has been accomplished, the effects of the formative assessment designed for an online course in operating systems have been analyzed, and three effects have been discovered: (1) deep reflection on the concepts of the course; (2) uncertainty about the resolution of the assessment tests, and (3) awareness of progress and difficulties in learning. These results corroborate the findings of the previous studies in this field.

The obtained results suggest that the formative assessment has fulfilled the purposes for which it was designed: to promote meaningful learning and potentiate metacognitive knowledge. Our formative assessment design provides a concrete and effective form for executing the strategies of the formative assessment in an online environment, which may serve as a reference for creating formative assessments for other subjects taught in online environments.

Finally, the study also makes a contribution in the area of education in operating systems because: (1) it provides a new way of overcoming the difficulties of learning the subject of operating systems and (2) it is different from other studies because the assessment we created is based on a theoretical framework that allows us to define and verify whether the proposed learning objectives are fulfilled.

Our future work will study the effects of the formative assessment from the professor's perspective. The professor's vision will complement the students' vision considered in this study. Potential benefits of the formative assessment for professors include discovering misconceptions and identifying problems in the assessment tests and the course materials.

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**Sonia Pamplona** is an Assistant Professor at Universidad a Distancia de Madrid (UDIMA). She is a Computer Engineer with a degree from the Universidad Politécnica de Madrid (UPM) and has worked for over 20 years in different areas of information technology education. She currently teaches the subjects of Operating Systems and Human–Computer Interaction for the Degree in Computer Engineering and the subject of Mobile Learning for the Master in Education and New Technologies. Her area of research is Computer Science Education, with a special interest in online learning.

**Nelson Medinilla** is a Ph.D. Professor at the Universidad Politécnica de Madrid (UPM). He is an Electrical Engineer with a degree from the Universidad de la Habana, with a Ph.D. in Information Technology from the Universidad Politécnica de Madrid. He worked for 20 years as a professor at Instituto Superior Politécnico José Antonio Echeverría in La Habana. For the next 20 years, he taught various subjects related to software design at the Software Engineering Department of the Information Technology Faculty (Universidad Politécnica de Madrid). His areas of research include Software Design and Computer Science Education.

**Pamela Flores** is a Ph.D. student at the Universidad Politécnica de Madrid (UPM). Since 2011, she is a member of the Software Design laboratory in UPM. From that time, she has been a teaching assistant in undergraduate and graduate

subjects related to Software Design. Before this, she got her Master degree in Information Technologies from UPM in 2011, and her Engineering degree in Computer Systems from Escuela Politécnica Nacional del Ecuador in 2005, where she worked as a teaching lecturer for two years. Her area of interest is Computer Science Education, with a particular emphasis on Learning in Software Design.