Insights into Students' Conceptual Understanding of Operating Systems: A Four-Year Case Study in Online Education

Sonia Pamplona, Isaac Seoane, Javier Bravo-Agapito, and Nelson Medinilla

The authors provide insights into why students have misconceptions in an online course on operating systems. Specifically, this study presents a four-year qualitative case study of 78 online students in order to identify misconceptions and the causes that generate them. Their results indicate that students experienced misconceptions with the concept of interrupt.

ABSTRACT

For decades, instructors and researchers have been trying to improve or enhance the learning process of students. In this process, it is important to know whether students have misconceptions in their conceptual understanding. The study of these elements is becoming a relevant research area in science and engineering education. This article provides insights into why students have misconceptions in an online course on operating systems. Specifically, this study presents a four-year qualitative case study of 78 online students in order to identify misconceptions and the causes that generate them. Our results indicate that students experienced misconceptions with the concept of interrupt. In fact, this study reveals that the natural-language meaning of the term interrupt is a hindrance to understanding this concept. In addition, a methodology for discovering misconceptions and their causes is developed.

INTRODUCTION

Student misconceptions and conceptual understanding represent an important research area in science and engineering education. The development of this area initially began in the last century in physics with the design and development of the Force Concept Inventory (FCI) [1]. The main objective of a concept inventory (CI) is to identify possible student misconceptions through multiple-choice questions. Although Hestenes *et al.* produced promising results, relatively little research has been conducted focusing on engineering curricula [1]. Specifically, research into conceptual understanding can be found in the communications curriculum. For instance, Bristow *et al.* developed a CI in control systems [2], and Goncher *et al.* evaluated conceptual understanding and identified possible student misconceptions in signal processing [3]. In addition, Webb *et al.* developed a CI to explore students' misconceptions of operating systems [4]. Even though these studies analyze conceptual understanding and student misconceptions, they do not perform in-depth analyses of the causes that generate difficulties in student understanding. In fact, a key question that remains largely unanswered is what makes some concepts so difficult to learn and some misconceptions so difficult to repair [5].

The main goal of our article is to provide insights into this question. Indeed, this work looks at why students lack conceptual understanding or have misconceptions in the syllabus of an operating system undergraduate course. The aim of this study overlaps with the goal of an important area of engineering education research: identification of threshold concepts. We are looking for troublesome concepts, and troublesomeness is one of the characteristics of a threshold concept according to Meyer and Land [6]. In particular, these authors identify five characteristics of a threshold concept: troublesome, transformative, irreversible, integrative, and bounded. Therefore, our results also make a contribution to the field of threshold concept research.

E-learning provides new ways to transmit, organize, and present educational content, but the adoption of e-learning is slow by many universities. A reverse trend is observed, however, in online universities, since educational content must be integrated into virtual classrooms. Online education does not provide a direct interaction between teachers and students, and students learn at their own pace. Moreover, instructors are not fully aware of the student learning process. For this reason, these learning difficulties could be higher in online education than in face-to-face education. Our work tries to find the misconceptions of 78 online students about operating systems. For this purpose, a qualitative case study was carried out to discover the hidden understanding difficulties of students, and to identify the causes that produce these difficulties.

The work in this article is a longitudinal study started in 2012. Our initial results were presented at the Koli Calling Conference [7]. This initial work only provided results for 14 online students and focused on finding difficulties of understanding, and so did not include in-depth analysis of causes. The current work continues this analysis with a larger sample and provides insights into what might generate student misconceptions.

Although this study has been carried out in a

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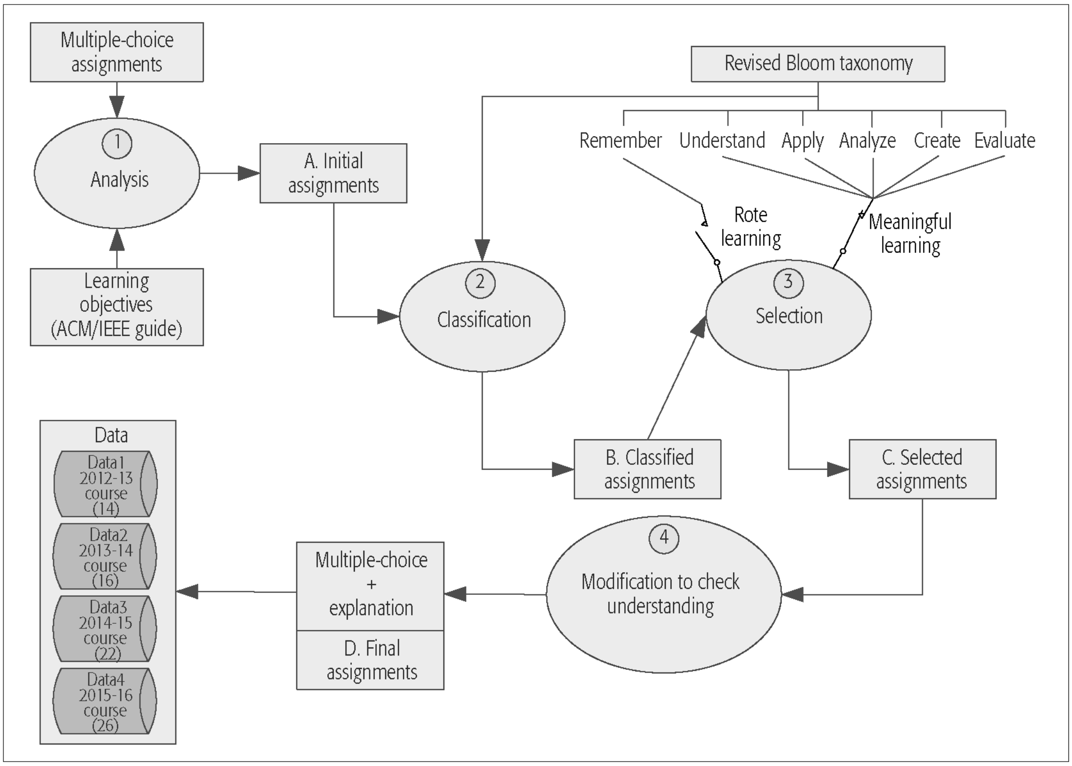

Figure 1. Flow diagram of the assignment design processes.

computer science course, the approach, experience, and results will be valuable to educators in communications engineering. Communications engineering is a multidisciplinary field of study. Knowledge and skills related to design, implementation, and programming of digital systems and devices are provided by a variety of courses across the undergraduate curriculum in order to acquire skills in design and operation of telecommunication networks for communication services [8]. In the case of this study, concepts about basic operating principles of digital programmable devices are included in the first part of the syllabus of the Operating Systems undergraduate course. The main results of the study are focused on misconceptions about the concept *interrupt*, which is an important concept in the communications curriculum.

This article is organized as follows. The next three sections describe the methodology followed in this research. Then we show an example of analysis according to the research methodology. The next section contains the main results and discussion. The final section sets out the main conclusions and future lines of research.

Methodology Description

The research methodology is problem-driven. Exploring misconceptions needs to uncover student thinking at a deeper and more detailed level. Therefore, the nature of the problem implies the use of a discovery-driven research methodology [9]. The methodology chosen for this research is the qualitative case study, which allows us to discover processes that would probably be overlooked if we used other more superficial research methods.

In order to discover the misconceptions and their causes, we have performed a qualitative analysis of the written explanations obtained through the assessment tests designed for this study. This method is based on the first stage of the development of the FCI [1]. The methodology used in this research can be seen in Figs. 1 and 2. The shapes used in the flow diagrams are described below to facilitate the understanding of these figures:

- Circular shapes are used to highlight processes that obtain or transform the information.
- Rectangular shapes are used to mark the inputs and outputs through the process flow.
- Some processes have configuration criteria to parameterize each process operation. These criteria have been drawn as a flag switch to indicate whether they are active.

This research has been carried out in two main stages. The first (Fig. 1) focuses on the design of the assignments used in the discovery process. The second (Fig. 2) consists of analyzing the students' answers to these assignments.

Assessment Design

In order to discover misconceptions, we need to probe student thinking. Therefore, we require a set of assignments that trigger cognitive processes beyond remembering, that is, assignments whose main objective is to foster meaningful learning. Meaningful learning is based on transference, which is the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter. In contrast, rote learning is based on retention, which is the ability to remember material at some later time in much the same way it was presented during instruction [10]. In our design, we have used Blooms' taxonomy to distinguish between rote learning and meaningful learning, as we explain later.

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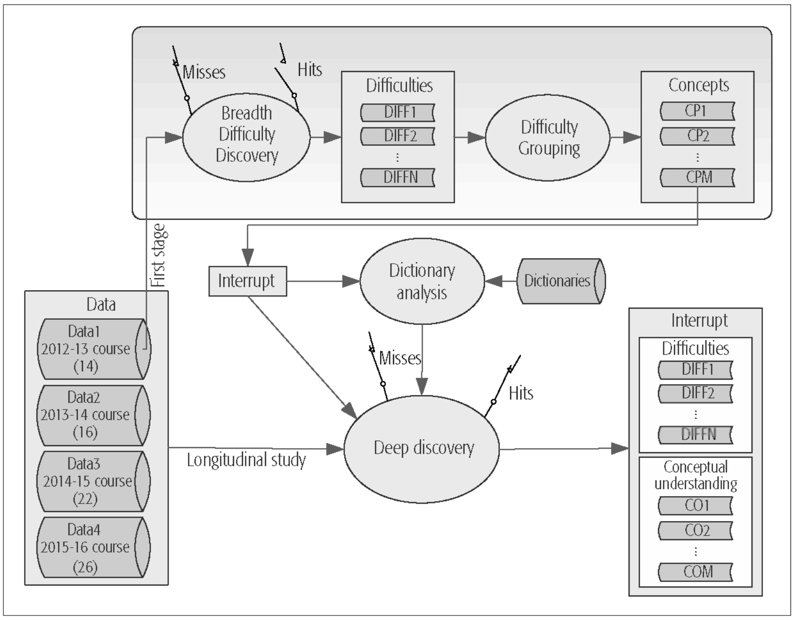

Figure 2. Flow Diagram of the Deep Discovery process design.

What code do you think needs to be run with interrupts inhibited? A. None, because the interrupts could be lost. B. All operating system code. C. Certain critical parts of the operating system code, such as context switching. Justify your answer

Table 1. Final assignments. Example of a question.

We have chosen the revision of Bloom's taxonomy (RBT) [10] because classifying an educational objective according to the revision of this taxonomy is easier than using the original framework. Each of the six major categories of RBT is associated with two or more specific cognitive processes. For instance, the category "understand" is associated with the cognitive processes interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining. Consequently, classifying an objective into the appropriate category is facilitated by focusing on the cognitive processes rather than on the larger categories. Nonetheless, any other taxonomy could be used to distinguish between rote learning and meaningful learning in a replication of this study.

Figure 1 shows the flow diagram for the design of the final assignments. In these assignments, every student has to answer 10 multiple-choice questions and explain why the right answer is right and/or the wrong answers are wrong. Table 1 provides an example of this particular assignment consisting of a multiple-choice question and an explanation.

Final assignments are obtained by following these steps. The first is to analyze (process 1 in Fig. 1) multiple-choice questions and learning objectives in order to select those assignments aligned with the desired learning objectives. Multiple-choice questions are extracted from common operating systems textbooks [11–13]. Learning objectives are selected from the professional society guidance (ACM/IEEE-CS Joint Review Task Force). The output of this process is set **A. Initial assignments**, which will be classified in the classification process (process 2).

In the classification process (2), the RBT is used to classify the A output into six categories. These categories are: "remember," "understand," "apply," "analyze," "create," and "evaluate." The result of this second process is the same set of assignments (**B. Classified assignments**), but classified following Bloom's six cognitive process categories [10].

After the classification process, the third task is the selection (3) of only those assignments that assess meaningful learning. This action is shown in Fig. 1 using a switch flag, indicating that only categories related to meaningful learning will be chosen. According to the RBT these categories are "understand," "apply," "analyze," "create," and "evaluate." Hence, the result of this process is set **C. Selected assignments**.

Finally, to ensure the discovery of misconceptions, the final task (4) modifies set **C. Selected assignments** in order to check understanding. This set consists of a list of modified multiple-choice tests where students were asked to explain why the right answer is right and/or the wrong answers are wrong. These explanations would help to reveal students thinking in order to uncover students' misconceptions and check their understanding.

These tests were translated into Spanish. Regarding the language involved in the study, the students were from Spain and took the tests in Spanish. However, most of the reference texts of the course are in English or are translations of textbooks whose original language is English.

In conclusion, three tests were designed with 10 multiple-choice questions plus an explanation in each (**D. Final assignments**). The tests correspond to the course content as follows:

- Questionnaire I. Introduction to operating systems and process management.
- Questionnaire II. Process scheduling. Process communication and synchronization.
- Questionnaire III. Memory management. I/O.

Qualitative Case Study

The second part of the study is shown in Fig. 2. The flow diagram shows the processes involved in the discovery of misconceptions and their root causes. Data analysis was carried out in two stages, which are described separately below. We performed a qualitative analysis [14] of the students' explanations included in the assignments using ATLAS.ti qualitative analysis software. In particular, we analyzed the answers to the second part of the questions (justify your answer) as shown in Table 1.

First Stage

The aim of the first stage is to identify concepts difficult for students to understand. The study began by researching the set of tests of a cohort of 14 students from 2012–2013. The process is shown in the upper part of Fig. 2. The first step consists of looking for the difficulties shown in the students' answers to the final assessments. (Fig. 1, **D. Final assignments**). We have called this process "breadth difficulty discovery" because we search for any type of conceptual difficulty.

To perform this first discovery process, the incorrect multiple-choice questions are used to analyze its corresponding textual explanation. This is shown in Fig. 2 as two input switches, one closed (for the mistakes) and the other open (for the hits), indicating that correct answers are not being analyzed in this initial process. In particular, if the student's explanation was incorrect, a code [15] was created whereby the justification and the answer to the multiple-choice questions were combined (e.g. "I think that all operating system code needs to be run with *interrupts* inhibited because..."; see question from Table 1). The result of this process is a set of difficulties obtained from the students' textual explanations.

Finally, the codes obtained from the previous process related to the same concept were grouped. Hence, these groups show the concepts that are involved in misconceptions and are the results of the first stage. These results are detailed in the next section.

Results Obtained After the First Stage

At this stage of the research, and after the cohort corresponding to the academic year 2012–2013, the main result is that virtually all learning difficulties found were represented in the concept *interrupt*. This fact suggests that there might be a problem with the conceptual understanding of *interrupt*. Therefore, the second part of the analysis will focus on the difficulties arising from this concept and their causes.

The fact that almost every learning difficulty was related to the concept of *interrupt* should not be surprising because *interrupt* is a key concept in the knowledge of operating systems, since an operating system is a kind of software assisted by *interrupts* [11]. An operating system wakes up at certain moments to attend to several kinds of events: key strokes, software signaling to the hardware and vice versa, and so on. Each time the operating system needs to run an operation, it pauses whatever tasks the computer might be involved in to attend to the event properly, performing whatever task routines should be done depending on the nature of the event.

An important result from this first stage analysis is that students' understanding of the natural-language meaning of interrupt appeared to interfere with their adoption of the technical meaning of the term. For this reason, in-depth analysis of the meanings of the entries for *interrupt* in two baseline dictionaries was undertaken.[1] The results showed that *interrupt* has six different meanings, as seen in Fig. 3. In other words, students could understand the concept of *interrupt* as any of these six meanings.

The next part of the analysis studies the meanings of *interrupt* to which students are referring in their answers. The six codes shown in Fig. 3 are used: "1.-Signal," "2.-Feature," "3.-Act," "4.-State," "5.-Anything," and "6.-Intermission." The answers provided by students are tagged and grouped by these codes.

Second Stage: Longitudinal Study of the Dataset and Deep Discovery Process

The aim of this stage is to identify the difficulties that students have with the concept interrupt and the meaning that students associate with the term in each question ("conceptual understanding" in Fig. 2). These data led us to discover misconceptions about the concept *interrupt* and their possible causes.

In order to contrast this process with the previous one ("breadth discovery"), we have called it "deep discovery" because although we only search for explanations related to the term *interrupt*, we take into account any type of answer (correct and incorrect). This can be seen at the bottom of Fig. 2. The reason for searching within all answers is that we wish to know the meaning understood by students in each answer, correct or otherwise, in order to know if this meaning varies over the questions or stays constant.

The longitudinal analysis was conducted over four academic years of an undergraduate online course on operating systems. Four student cohorts were tested with a total number of 78 students. Each cohort belongs to an academic year. Cohort 1, from 2012–2013, had 14 students, Cohort 2, from 2013–2014, had 16 students, Cohort 3, from 2014–2015, had 22 students, and finally, Cohort 4, from 2015–2016, had 26 students.

An example of this process is described in the following section.

Example of the Question Analysis Process

In order to illustrate the analysis process of the second stage, some student answers to the second question from Table 2 are analyzed in the following sections. Table 2 contains the questions included in the final assignments and are related to the concept of interrupt. Each question belongs to a category and fosters a cognitive process following the RBT [10].

In this question, students should infer whether *interrupts* would or would not improve processor utilization. Given that the lecture notes used do not make an explicit statement, students should infer the answer by connecting the information they have read. From the readings, they could infer the meaning of concepts such as polling input/output (I/O), and interrupt-driven I/O. By using *interrupts*, the processor is able to run other processes and routines while an I/O operation is ongoing. Therefore, it can be said that, indeed, *interrupts* help to take advantage of the waiting time in I/O transactions. Consequently, the correct answer is "a) True." This question is important because it forces the student to consider deeply the advantages of the *interrupt* mechanism.

Discussion About the Meanings of Interrupt in the Example Question

Reviewing the answers to the second question of Table 2, there appears to be a misconception related to one of the given meanings of *interrupt*: the state of being interrupted (fourth meaning shown in Fig. 3). A student could understand the meaning of the term *interrupt* in this way, giving

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[1] Entries of interrupt retrieved from: Collins, https://www.collinsdictionary.com/es/diccionario/ingles/interrupt, accessed Apr. 14, 2017, and Merriam-Webster; https://www.merriam-webster.com/dictionary/interrupt, accessed Apr. 14, 2017.

After reviewing the answers given by students to the question, and the comments written by them to justify their answers, the main results of the analysis show that they usually understand one of these two meanings of the concept interrupt and use it for their answer.

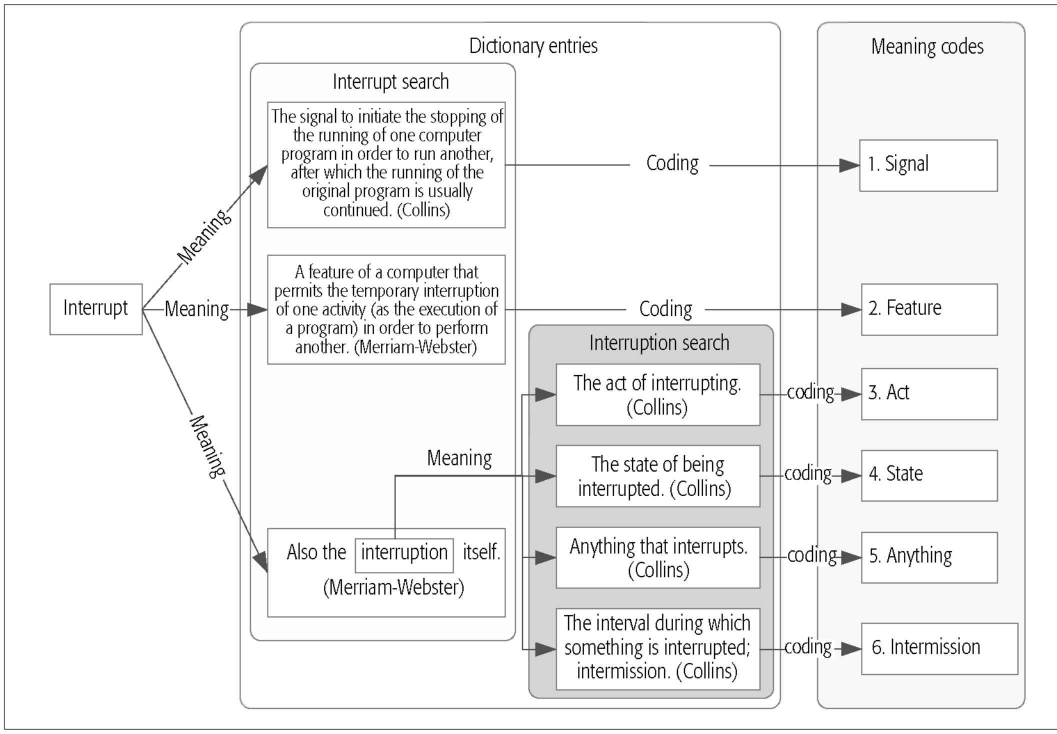

Figure 3. Analysis of the meaning of interrupt in dictionary entries.

a negative interpretation to the *interrupt* mechanism's effect on processor performance because it causes the process to stop.

The students should understand the concept *interrupt* in another way in order to answer the question correctly. For instance, meanings (Fig. 3) related to the signal (Code 1.- Signal), the intrinsic feature (Code 2.- Feature), or even the action (Code 3.- Act) would be more desirable. The key to a proper understanding of the question is to think about how the interrupt occurs, not about the effect it has. *Interrupts* improve processor performance because they free up the processor for a program that is continuously asking whether an I/O process has finished or when there is a hardware problem.

Review Process of the Students Answers

The dataset analyzed consists of the explanations offered by students to the proposed question. The following aspects have been studied:

- Different meanings given to the term *interrupt* by the students
- Difficulties in the process of understanding the concept *interrupt*

After reviewing the answers given by students to the question, and the comments written by them to justify their answers, the main results of the analysis show that they usually understand one of these two meanings of the concept *interrupt* and use it for their answer.

Meaning Number 2: *"A feature of a computer that permits the temporary interruption of one activity (such as the running of a program) in order to perform another."*

Meaning Number 4: *"The state of being interrupted."*

With regard to the difficulties, only one difficulty has been found: students think that interrupts are not good for processor performance.

Example with Regard to Meaning 4: "The State of Being Interrupted"

The following example consists of the answer of a student who has interpreted the term *interrupt* with the meaning of a state. The student says that if many interrupts are generated, the process running gets slower. In this answer, the student associates the meaning of *interrupt* with the state of being interrupted and not with the mechanism that enables the *interrupt*.

Example: "I guess it is false because an *interrupt* is a programmed temporal cutoff, it does not improve the use of the processor but it stops it, and if the degree of *interrupt* is high, it could cause the process execution to be even slower as the processor might be fully focused on attending the *interrupts* but not the rest of the processes."

The incorrect answer seems to be caused because of the meaning the student has assigned to the question. The association of the term *interrupt* with neither meaning 1.-SIGNAL or with meaning 2.-FEATURE does not enable the student to select the correct answer.

Example with Regard to Meaning 2: "An Intrinsic Feature"

In the example, the student has assigned the term *interrupt* to the following meaning:

Meaning 2.-FEATURE: *"a feature of a computer that permits the temporary interruption of one activity (such as the execution of a program) in order to perform another."*

It is important to highlight that every student who has understood the *interrupt* as a mechanism answered correctly. The answer of the student was as follows:

Example: "[...], peripherals that would use hardware *interrupts* to communicate are more efficient than the main program, using fewer clock cycles, allowing other processes to run while *interrupts*

Source	Question	Category	Cognitive process
Testbank. Chapter 1 Multiple-choice questions Question 6 from [11]	1. In a uniprocessor system, multiprogramming increases processor efficiency by: A. Taking advantage of time wasted by long wait interrupt handling. B. Disabling all interrupts except those of highest priority. C. Eliminating all idle processor cycles. Justify your answer	Understand	Interpreting
Testbank. Chapter 1 TRUE/FALSE questions Question 8 from [11]	2. Interrupts are provided primarily as a way to improve processor utilization. A. True. B. False. Justify your answer	Understand	Inferring
Instructor Companion Site. Testbank. Chapter 3 Question 7 from [12]	3. What code do you think needs to be run with interrupts inhibited? A. None, because the interrupts could be lost. B. All operating system code. C. Certain critical parts of the operating system code such as context switching. Justify your answer	Understand	Inferring
Page 9. Question 1.2.4 from [13]	4. 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 in the ready process queue. Justify your answer	Understand	Inferring

Table 2. Questions according to the concept of interrupt used to build the assignment tests.

Based on the evidence analyzed and the methodology applied, it can be said that the misconceptions around interrupt are not only caused by the complexity of the subject itself, but because of other meanings which are completely accepted by society, and may keep coming up in every course in this area.

are attended. *Interrupts* may notify the processor about I/O from a peripheral, preventing the main processor from periodically controlling the input so as to know if the data is already available or not, rendering the use of the main processor more efficient [...]"

Results on Understanding of the Concept Interrupt

The following conclusions can be drawn after analyzing the data obtained from the answers considered in the research. Four different meanings of *interrupt* can be found from the students' answers from its six different meanings:

- Meaning number 1.-SIGNAL: The signal to initiate the stopping of the running of one computer program
- Meaning number 2.-FEATURE: A feature of a computer that permits the temporary interruption of one activity
- Meaning number 4.-STATE: The state of being interrupted
- Meaning number 5.-ANYTHING: Anything that interrupts

The meanings that students assign to *interrupt* change over time and are different from student to student. This has two consequences:

- Students vary their interpretation depending on the context and not always in an appropriate way, because sometimes they assign a meaning that does not allow them to answer the question correctly.
- Students have not detected any ambiguity in the term *interrupt*, as they have not written any argumentation about it, and they have not asked any question in this regard. Therefore, they think there is no misconception in the meaning they apply in their answer, and they are not conscious of the existence of several meanings, which interferes with their correct knowledge.

With regard to the difficulties in the learning process, seven difficulties have been detected during the research:

- Difficulty 1: They do not define the term *interrupt* fully.
- Difficulty 2: They become confused about the source of *interrupts*.
- Difficulty 3: They state that *interrupts* do not improve the processor performance.
- Difficulty 4: They are not able to justify the reason why some routines for operating systems must be run in a disabled *interrupts* mode.
- Difficulty 5: They think that a change in the running processes is always caused by a clock *interrupt*.
- Difficulty 6: They usually think that *interrupts* are used to make a context switch.
- Difficulty 7: They think that every time an *interrupt* appears, a context switch is made.

Finally, with regard to the possible causes of the difficulties described above, the following conclusions are set out here:

- The first difficulty, an incomplete definition of the term *interrupt*, can be explained by the fact that students are unaware of the several meanings of the term *interrupt*, and they try to explain their own interpretation using the first interpretation they think of when answering.

Future work might be undertaken with the purpose of overcoming the difficulties discovered, and finding new sets of difficulties and misconceptions around other concepts, in order to draft a concept inventory for subjects involved in training in digital systems and design and programming of devices for communications engineering, such as Operating Systems courses.

- The second difficulty, misconceptions about the source of the *interrupts*, might arise from the association between the term *interrupt* with the meaning of state. Because of this, they know the state that *interrupts* cause, but they ignore the sources that cause them. They only think about the consequences, not about the origins.
- The statement that the *interrupts* do not improve processor utilization (difficulty 3) is also related to the misconception of thinking about the *interrupts* as a state. The association of *interrupt* with the effect of pausing or stopping and not with the mechanisms prevent them from inferring the correct answers. As an example, an answer was found saying that "a lot of *interrupts* will cause the execution of processes to become slower."
- Difficulty 4 is not yet clear at the time of writing, and is still a part of the ongoing longitudinal research. The data obtained are not enough for the authors of this research to infer a cause for this difficulty, because the explanation part of the question is left blank in the answers analyzed.
- Finally, the association of *interrupt* with "context switching" (difficulties 5, 6, and 7) seems to originate again with mistaking the term *interrupt* with the meaning of state. They seem to think that context switching originates an *interrupt* in the running processes, and they assign this interpretation to the term *interrupt*.

In conclusion, one of the most important problems in understanding the concept *interrupt* consists of interpreting the term *interrupt* according to its colloquial meaning of "an effect" (meaning number 4 in Fig. 3) instead of the technical noun meanings (meaning numbers 1 and 2 in Fig. 3).

Conclusions

In this article, a qualitative methodology approach, not often used in engineering education research, has led to successfully discovering misconceptions and their causes, during a longitudinal study of four cohorts of students from 2012 to 2016.

The misconceptions discovered in this study involve the term *interrupt*, a key concept within the fields of communications engineering and computer science because of its relevance to the design, implementation, and programming of the digital systems and devices involved in telecommunications systems and networks and for the understanding and design of an operating system.

Based on the evidence analyzed and the methodology applied, it can be said that the misconceptions around *interrupt* are not only caused by the complexity of the subject itself, but because of other meanings that are completely accepted by society and may keep coming up in every course in this area. This should be a key aspect to be taken into account in order to improve the design of learning experiences around this topic in the future.

Implications for Instruction

The first implication of our study is that teachers should be aware of the misconceptions discovered. Hence, they should not assume students attach the same meaning to the concept *interrupt* that teachers do.

Second, although addressing students' misconceptions is always a challenge, teachers and curriculum developers can build learning experiences that challenge misconceptions to promote conceptual change. In particular, the multiple-choice questions about the concept *interrupt* that formed part of our discovery process can be considered as a model when designing these learning experiences.

Regarding the methodology we have used to discover misconceptions, it may serve as a reference for engineering teachers in order to assess conceptual knowledge, foster deep learning, and deal with student misconceptions in any knowledge area. Moreover, although our study was carried out in an online context, it can be used equally well in face-to-face scenarios.

Implications for Education Research

Interrupt is a troublesome concept involved in several engineering disciplines such as communication engineering and computer science. Our results suggest that it can be a threshold concept as well. Evidence is needed to support this statement, that is, the concept *interrupt* has the other four characteristics of a threshold concept: transformative, integrative, irreversible, and bounded.

Future work might be undertaken with the purpose of overcoming the difficulties discovered, and finding new sets of difficulties and misconceptions around other concepts, in order to draft a concept inventory for subjects involved in training in digital systems and design and programming of devices for communications engineering, such as operating system courses.

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