Collecting and Analysing Learners Data to Support the Adaptive Engine of OPERA, a Learning System for Mathematics

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Abstract: Learning mathematics has always been (and still is) a major issue. Many students fail to understand the basic concepts and/or are unable to apply them. These students end up moving to other subject areas or simply dropping out. One of the major reasons for this problem is the fact that the educational system is only prepared to apply standardized teaching methods that do not respect or fit the individual characteristics of each student. This paper presents the OPERA learning adaptive system that provides the foundations for further mathematics learning while addressing the diversity of the users/learners. OPERA collects learner interaction data to monitor the learning process in an active and contextualized way and to identify the users' difficulties and achieved knowledge in each stage. Based on the data analysis, OPERA then reorganizes the sequence of contents and provides the precise information needed to progress which makes learning much more efficient.

1 INTRODUCTION

Like many other Western countries, Portugal is confronted with a declining number of students in science, mathematics, engineering and technology (STEM) careers. This problem will hamper the future country development if no measures are taken. Different approaches have been suggested to increase the motivation of students to learn mathematics and follow STEM careers and the use of technology to support learning has been one of them. According to Folden (2012) technology-based learning (e-learning) has its roots in the so called teaching machines that emerged in the beginning of the twentieth century. Computers became the natural environment for the teaching machines and, with the advent of digital communications and the Internet, the first virtual learning environments where adopted throughout organizations (Folden, 2012; Peres, Mesquita, and Pimenta, 2015).

Nowadays, technology based learning environments are typical in organizations, and adaptive systems are gaining momentum. Adaptive learning systems dynamically change the contents or the way they are presented, based on the user's preferences, responses, and activities, in order to facilitate the learning process and to optimize the students' performance (Oxman and Wong, 2014; Paramythis and Loidl-Reisinger, 2004; Wilson and Scott, 2017).

OPERA is an adaptive learning system that addresses the mathematics topic of operations with real numbers. The strategy is based on an adaptive model in which students solve exercises through a progression scheme adjusted to their level of knowledge and performing skills. OPERA collects data, analyses it and evaluates the performance of the student and when a lack of knowledge is acknowledged the application proposes additional learning, through video-tutorials or documentation.

OPERA is mainly aimed at students from secondary schools and initial courses of higher education. It is also thought for students over 23 years of age that have to do a mathematics exam in order to access higher education. The topic "operations with numbers" is one of the topics that is evaluated in this exam and it is fundamental for other mathematics matters.

2 OPERA CONCEPT

Mathematics is many times perceived as a difficult and abstract subject, which involves learning a lot of

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processes and formulas that seem irrelevant to the students' lives. Therefore, students develop a negative attitude towards mathematics and lack of confidence in ‘being good at it’ which later affects their career choices.

Besides that, improving the students' motivation to learn mathematics is also crucial to the economy and so aiming for a high proportion of graduates' students in technology areas is a very important objective. Appropriate learning methods can develop students' level of understanding mathematical rules and procedures, helping them develop a deeper interest, engagement and motivation.

2.1 Learning with Technology

The emerging computer and network technologies have changed the way we live, work, teach and learn. The learning paradigm took advantage of the new technologies in the development of different education models, changing the teaching-learning process. Over the last years the learning systems have also embraced new educational technologies. The creation of new and innovative teaching and learning resources supported the use of new pedagogical methodologies that are beneficial for teachers and learners. The concept of Open Educational Resources, in spite of the identified problems, has been widely adopted (Vaz de Carvalho, Escudeiro, Caeiro Rodriguez, & Llamas Nistal, 2016). Different initiatives and projects were developed involving interactive web sites, learning applications, online training activities, intelligent tutoring environments and many others. Serious games have also been identified as excellent learning tools (Andrade, Gouveia, Nogueira, Russo, & Vaz de Carvalho, 2015).

However, most of the learning systems still provide the same inputs and similar learning resources to all students not taking into consideration their different characteristics. In those systems all the students have the same learning path, independently of their distinct background knowledge, different needs, individual methods or preferences.

To be effective, the learning environment must be student-centred and the student's differences should be contemplated. In a student-centred learning system, the student builds his/her knowledge by interacting with correctly chosen learning objects that suit his/her skills and previous performance. This increases the effectiveness of the learning and the learner´s motivation since the system converges to his/her needs. Several categories of adaptation can be identified, and one of the most used, named as Adaptive Course Delivery, is designed in order to obtain courses tailored to each one of its users, fitting the course contents to the users characteristics as much as possible (Paramythis and Loidl-Reisinger, 2004).

An adaptive system can be considered as similar to a biological system, which changes its behavior in response to its environment, and this change is relevant to achieving a certain goal (Brusilovsky and Peylo, 2003; Michalewicz, Schmidt, Michalewicz, and Chiriac, 2007; Wilson and Scott, 2017).

According to Paramythis and Loidl-Reisinger (2004) four types of models can be typically found in adaptive learning systems, namely: i) the domain models, which is a representation of the course being offered including contents and possible learning paths; ii) the learner models, which maintains diversified information about the user; iii) the group models, which identifies similar students to dynamically create groups of learners; and iv) the adaptation model, which defines what, can be adapted and when and how it can be adapted. Oxman & Wong (2014) consider that there are three core elements above which adaptive learning systems are built, namely, the content model, which is similar to the domain model referred by Paramythis and Loidl-Reisinger (2004), the learner model, similarly to the leaner model of Paramythis and Loidl-Reisinger (2004), and the instructional model, which is similar to the adaptation model of Paramythis and Loidl-Reisinger (2004). Wilson and Scott talk about the “knowledge of the domain (the domain model), knowledge of teaching strategies (the pedagogic model), knowledge of the learner (the learner model), and rules for interaction (the communication model)” (2017, p. 3).

The instructional or adaptation models uses a set of data about the user, and can be rule-based, with if-then statements and heuristics, or algorithm-based, with advanced mathematical formulas and applying machine learning techniques, such as data mining (Medina-Medina and García-Cabrera, 2016; Oxman and Wong, 2014; Paramythis and Loidl-Reisinger, 2004). This can be considered as Prescriptive Analytics. “One can view analytics as the process of developing actionable decisions or recommendations for actions based upon insights generated from historical data” (Sharda, Delen, and Turban, 2014, p. 56). Prescriptive analytics concerns the determination of the best course of action, providing a decision or a recommendation (Sharda et al., 2014; Turban, Sharda, Aroson, and Liang, 2007).

Adaptive learning systems present some challenges as well as some potential advantages when compared with traditional systems. As challenges we can identify the following ones: i) content can be too easy, which can demotivate the students, or too hard, which can be frustrating; ii) students can have different prior knowledge; iii) the costs of education can make hard for the students to access the systems (Oxman and Wong, 2014). As potential advantages, we can identify the following ones: i) reduce the number of students that give up: ii) achieve outcomes more effectively; iii) achieve outcomes faster; iv) help faculty to focus.

Several applications of adaptive systems are known in educational contexts with success, from elementary and secondary to higher education levels (Brusilovsky and Peylo, 2003; Guo, Palmer-Brown, Lee, and Cai, 2014; Hamann, Saul, and Wuttke, 2015; Kara and Sevem, 2013; Oxman and Wong, 2014; Paramythis and Loidl-Reisinger, 2004; Tsai, Lee, HSU, and Chang, 2012).

An important aspect of the process relates to the use of standardized data collection and result reporting methods to allow interoperability with other applications, namely Learning Management Systems. The two major specifications supporting this process are SCORM (Shareable Content Object Reference Model) and xAPi (also known as TinCan API).

SCORM is a collection of specifications developed by ADL (Advanced Distributed Learning) for e-learning systems through the web. Among other things, SCORM defines the rules of communication between educational content (in the form of Learning Objects - LO) and the host application, usually in the form of a LMS. In this way, it is possible to standardize the way in which the educational contents relate to the systems that support them and allow the LOs to be independent of these systems (Rustici Software, 2016).

In general terms, xAPI is a free, open source technical specification for the implementation of a global architecture including the definition of a Learning Record Store (LRS) and 4 complementary APIs. xAPi was conceived with a much more open view of the learning process. In fact, learning is acknowledged as happening everywhere, not just in the digital world of an LMS and is often self-managed by the student. This has entailed a change in the way learning systems are organized so that it is necessary to monitor and integrate the different learning experiences and data gathered from these various sources. Thus, xAPI is agnostic about the type of learning content being used and allows flexible monitoring of learning activities and experiences regardless of the model, including formal e-learning courses, performance systems, group learning, social or even informal learning scenarios (Rustici Software, 2016).

xAPI allows following and assessing micro-behaviors, states and contexts of learning experiences such as (ADLnet, 2016):

- Reading an article or interacting with an e-book
- Watching a video lesson
- Using a simulation
- Running a mobile application
- Talking to a tutor
- Acquiring physiological data, such as heart beats
- Evaluating team performance in a serious game
- Recording real-world performance in an operational context

In fact, the flexibility of xAPI is so great that it can be used in contexts that would not seem relevant before. For instance, Long et al used the specification to collect military sniper performance data in order to create an adaptive training system (Long, et al., 2016). Several other studies contributed to the development of the specification and its application in different settings.

Berg et al analyzed the experience of the application of xAPI in several projects including the use of LRSs (Berg, Scheffel, Drachsler, Ternier, & Specht, 2016). The main conclusion was that the lack of a unique source of validation could lead to the appearance of inconsistent implementations and the consequent abandonment of the specification. Bakharia et al evaluated the use of the specification in conjunction with a specific tool, the Connected Learning Analytics Toolkit, in order to verify if it would contribute in any way to facilitate the collection of the necessary information for this process (Bakharia, Kitto, Pardo, & Gasevic, 2016). The main conclusion was precisely the need to complete the existing specification. Another proposal to extend the specification was made by De Nies et al who proposed the W3C PROV model in order to improve the interoperability of systems using xAPI (2016). Traore also identified some limitations of the specification when implementing it in the SOFAD authoring system (2016).

Vidal et al proposed a semantic approach to the analysis of the specification through a representative ontology that in the future may contribute to the verification of the conformity of a given application model of the xAPI (2015).

Manso-Vázquez et al proposed a model to improve student / trainee monitoring in self-learning processes (2015). The model was based on xAPI and somehow demonstrated the extensibility of the specification as new applications emerge. However, this extension may imply the aggravation of the problem detected by Berg.

In a similar approach, Poonam et al used xAPI as a support architecture to capture and monitor user interactions and store them in an LRS (2016). In a more comprehensive approach, Amrieh et al used the specification to capture student interaction with an e-learning platform and tried to correlate this factor with the student performance (2015). They concluded that there is, in fact, a strong correlation between the two. In a similar perspective, but for a completely different audience, Murphy et al used the specification to monitor the performance and efficiency of military training (similar to the Long approach) and thus demonstrated the usefulness of the specification (2016). Kazanidis et al presented ProPer which combines technologies from both Adaptive Educational Hypermedia Systems (AEHS) and SCORM compliant LMS. To help teachers and students alike to locate possible weaknesses it monitors and visualizes user progress through instruction. To motivate students to continue with their study an immediate feedback and comparative techniques are presented. (2009).

Looking at this compilation of studies, it is safe to say that technology seems to be ripe and fitted to the objectives of OPERA.

2.2 OPERA Model

OPERA is an adaptive learning system that addresses the topic of operations with real numbers. The application goals were defined as:

- Flexibility with an adaptable learning environment designed to consider the student's performance;
- Accessibility to course materials at any time and from anywhere;
- Merging to the individual needs of the student.

The OPERA strategy is based on an adaptive model in which students solve exercises through a progression scheme adjusted to their level of knowledge and performing skills. The system supports the learners' individual needs, assuming specific tutoring strategies for efficient and effective learning. The students' individual needs assessed are cognitive as problem solving and independent reasoning; personal as self-guidance, time management, self-assessment; and affective as development of positive attitudes through attaining goals.

The core of the OPERA strategy is based on the continuous collection of information on a particular student´s performance while solving problems and challenges. The student model is continually being updated throughout the session and a corresponding adapted progression (difficulty and themes) scheme is provided. The model combines domain specific information discriminating all the expected knowledge to be acquired, by topic, and domain independent information which, in this case, is related to the personal skills (also identified in the literature as personal traits) to be acquired/already developed. For instance, some of the challenges are identified as contributing to critical analysis, problem solving, time management, etc. The way students solve (or not) those challenges contribute to the identification of their personal traits in the model.

The progression model also provides hints and other automatic feedback following the students' knowledge status. For instance, the student is linked to oriented video-tutorials, which students watch when they have doubts about the exercises they are solving. The construction of knowledge is done in an efficient and motivating way, differently from the traditional classroom, much more attractive and engaging since it always requires the student interactivity.

Students become independent, proactive and 'learn by doing'. Student-knowledge is created by a constructive process, oriented and articulated according to the students' understanding and fulfilling the guiding role that should be carried out by the teacher.

2.3 OPERA Contents

The "OPERA – OPErations with ReAl numbers" project contains four main topics, namely, rational numbers, real numbers, absolute value and intervals, each topic being divided into several subtopics. The choice of this theme is due to the fact that, although it is one of the basic subjects in mathematics, it always generates difficulties. Table 1 presents a summary of the subject contents evaluated in the OPERA model.

Table 1: Summary of topics and subtopics evaluated in the OPERA model.

Topics	Subtopics
Operations with rational numbers	➢ Addition ➢ Multiplication ➢ Potentiation ➢ Number expressions
Operations with real numbers	➢ Addition ➢ Multiplication ➢ Potentiation ➢ Number expressions
Absolute value	➢ Operations
Interval operations	➢ Intersection ➢ Union ➢ Complementation

Table 2 outlines the essential mathematical skills and competences that a student will acquire at the end of each topic.

Table 2: Summary of learning outcomes in the OPERA model.

Topics	Learning outcomes
Operations with rational numbers	***Perform calculations*** involving operations (addition, multiplication, and potentiation) with rational numbers.
	Solve problems with rational numbers that involve addition, multiplication, and potentiation.
Operations with real numbers	***Perform calculations*** involving operations (addition, multiplication, and potentiation) with irrational numbers.
	Solve problems with irrational numbers that involve addition, multiplication and potentiation operations.
Absolute value	***Solve problems*** involving the absolute value of real numbers.
Interval operations	***Determine sets*** that result from operations with intervals of real numbers.

3 OPERA ADAPTIVE SYSTEM

The OPERA system adapts the learning experience to the user's abilities by reorganizing the content presentation sequence (questions) according to the given answers. The user's model is therefore behavioural, since it does not have any pre-existing information about the user when the user first accesses the system. This model is updated according to the questions answered by the student.

3.1 Opera Interface

In Figure 1, we can see the welcome screen, with the theme to be studied and a button to start the course.

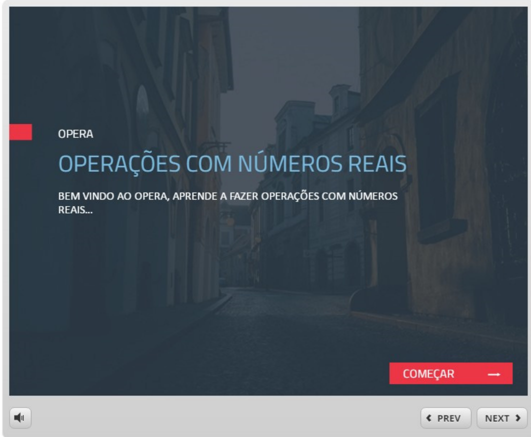

Figure 1: OPERA Input screen.

OPERA presents a hierarchical approach to the issues, according to the thematic areas (Figure 2). The number of difficulty levels in each topic is set by default to two, but can be changed. All these definitions (questions, groups of questions, progression schemes) can be changed according to different courses and audiences. A progression scheme is directly connected to the topic, which means that it can include questions from different modules.

Figure 2: Thematic organization of OPERA.

A progression scheme is defined as a sequence of steps that the student has to do. The number of exercises, the correct number of answers that the student has to give, and the maximum amount of time allowed define each step.

The questions can be numeric, multiple choice, true/false or graphic. The questions are randomly chosen from those available in the database. The sequence can be set so according to the student behaviour at a given time: for example, if the student correctly solves all the questions at a given step/level in a short period of time, he can level up when compared to a student who had completed this same step with fewer right answers and over a longer period of time. In a given step, the behaviour of the progression scheme in function of the student's failure can be configured as: the student can repeat the step, be re-assigned to the previous step or additional information to study can be provided. Instructions are displayed on the screen so student understands how it will work (Figure 3).

Figure 3: Presentation of the OPERA model.

Summing up, learning will be essentially done through the resolution of exercises (Figure 4). The questions can be formulated in a formal way or in a realistic way trying to facilitate the transfer of acquired knowledge (Figure 5).

Figure 4: Example of an OPERA question.

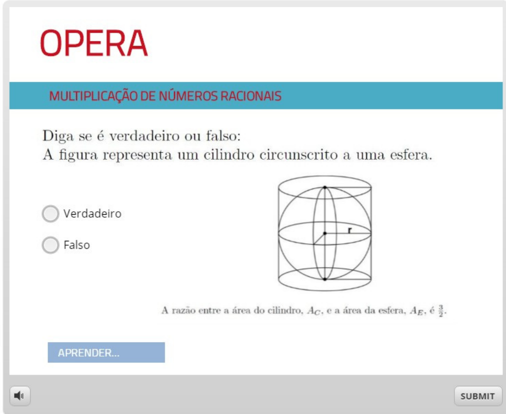

Figure 5: Formal OPERA question.

As the student is answering (or not) the questions, the application identifies their difficulties and proposes them the information needed to deepen the subjects addressed there. The heuristics used are relatively simple, but they allow approaching the use of the application to the real needs of the students.

Some examples of rules used:

- An immediate resolution of a simple exercise allows moving immediately to a complex exercise. Its immediate resolution allows to move to the next module;
- If the student completes two consecutive modules without errors, moves directly to the difficult level of the next module. As long as he doesn't make any mistakes, always moves to the difficult levels of the following modules;
- Two consecutive mistakes at a simple level results in a suggestion that student should access video-lessons;
- Two consecutive mistakes on the difficult level brings back to the simple level.

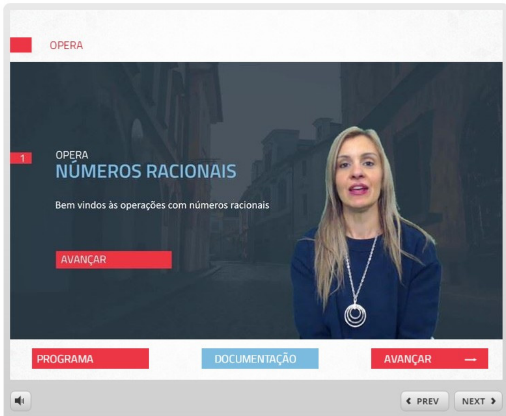

Figure 6: Video-presentation lesson of the real numbers module.

The information will be available in the format of video lessons, print documents or consolidation exercises (Figure 6). Note that, after a wrong answer, OPERA also immediately provides detailed feedback on the error and on the correct resolution.

The student can use the documents available or watch the proposed video-lessons to consolidate the knowledge worked. These activities aim to strengthen and consolidate learning.

At the end, students will be able to take a global test containing several questions related to the course syllabus. After this a feedback is given to inform the student about the performance achieved.

3.2 Technical Requirements

In terms of development, the tools used were Panopto, Camtasia Studio, Articulate Storyline and Javascript. This conjugation allowed to create a multiplatform learning object (runs on mobile devices, web environments and, natively, on Windows systems).

In addition, OPERA is produced in accordance with the SCORM and xAPI specifications, which allows its integration into Learning Management Systems (LMS) in such a way that the results obtained by the students can be part of a formal learning evaluation process. SCORM is used for the packaging of the learning object and the interoperability with the LMS, allowing the transfer of data to the host grading system. xAPI is used to standardize the collection and storage of the discourse learning analytics data and therefore also supports the student model.

4 CONCLUSIONS

In this paper we have presented the learning system “OPERA – OPErations with ReAl numbers”.

OPERA mainly intends to identify the subjects in which the students have more difficulties, and thus help them to have a better perception of their own level of knowledge. As the students' difficulties are identified, the application provides them with the necessary tools to overcome these difficulties (through video lessons, print documents or consolidation exercises). It makes the learning more efficient and more motivating. OPERA is therefore a rule-based adaptive learning system following an adaptation model.

Extensive testing will take place in the next few months but preliminary results indicate that the system can provide results close to the original objectives.

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