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Conceptualization, development and implementation of a web-based system for automatic evaluation of mathematical expressions

Nancy D. Pacheco-Venegas [a, *], Gilberto López [a], María Andrade-Aréchiga [b]

[a] Department of Computer Science, CICESE, Ensenada B.C., Mexico
[b] School of Telematic Engineering University of Colima, Colima, Mexico

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ABSTRACT

Assessment and feedback are important parts of the teaching and learning of mathematics; and in general, the process can benefit by the introduction of technology. MathDIP is a web-platform which provides automatic evaluation and feedback of each step of the solution of a math problem. The system incorporates a Computer Algebra System to perform the evaluation and a mathematical expression editor which allows the user to interact with the system using his/her own handwriting. This paper reports on the design, development and evaluation of the system. The usability results of its implementation on an Introductory University Mathematics course show good performance in design and functionality issues. Also, results show that in general, the students participating in the study have a high level of acceptance for the system and perceive that its use motivated and strengthened their learning of the specific math topics covered in the course.

1. Introduction

Over the past two decades, there has been a change in the way student's learning is conceived. It has gone from being characterized as a process of transmission of knowledge from teacher to students, to being a process in which students construct their own knowledge (Nicol & Macfarlane-Dick, 2006). In this context, it becomes more important that students get more involved in activities that make them understand their strengths and weaknesses in order to improve their own learning.

Different studies stress the importance of formative assessment in the learning process (Black & Wiliam, 1998; Madison et al., 2007; Nicol & Macfarlane-Dick, 2006). This assessment allows the students to contextualize and regulate their academic work. In practice, the teacher's heavy workload, or the large number of students attending class, makes it difficult to provide appropriate and timely assessment and feedback. In order to aid in the process, one can look in the direction of Computer Aided Assessment (CAA) systems.

The introduction of CAA systems in the process of teaching and learning mathematics has been done in a variety of ways (Beeson & Nicaud, 2002; Blyth & Labovic, 2009; Sangwin, 2013; Townsley, 2009). The simplest form of these systems are those in which students have to choose the correct answer from a number of options (multiple choice questions). In other cases, students simply enter the final answer to a particular exercise and the system evaluates it. Although, these two type of system do provide automatic assessment, the feedback provided only refers to the final solution and disregards the steps followed in the process.

Recent research has focused on the study of systems that can provide a more thorough assessment (Heck, Boon, & van Velthove, 2008; Jones, 2008; Sangwin, 2007). These systems evaluate the whole procedure that the student makes to reach the solution of an exercise. In any case, the process requires that the student interacts with the computer by entering mathematical expressions. However, most CAA systems do not provide convenient user interfaces necessary to input the required mathematical symbols.

Currently, two different methods are commonly used to enter mathematics into the computer. In the first one, the user inputs text using some pre-established syntax such as LaTeX or a Computer Algebra System language. Other systems work under the “What You See is What

* Corresponding author. Tel.: +52 6461750500.
E-mail address: npacheco@cicese.edu.mx (N.D. Pacheco-Venegas).

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You Get" paradigm utilizing menus containing the most commonly used mathematical entities such as special math symbols, fractions, exponents, etc. Although this is a more intuitive method, it can be a burdensome process when it has to be repeated many times.

In this paper, we present an approach to provide support to formative assessment through MathDIP, a system that offers automatic evaluation of mathematical exercises. The system was designed, developed and deployed in the form of a web-based system that incorporates innovative technologies to provide step by step feedback to students solving mathematical exercises. The system includes a mathematical expression editor with handwriting recognition capabilities that allows users to directly write math expressions in the computer, while a Computer Algebra System (CAS) performs the evaluation of the mathematical expressions. Through the system's interface a response is delivered, which represents an immediate automatic response to the student's work.

In order to evaluate different aspects of the system and its different components, the platform was introduced into a formal University level math course where a series of tests were performed. The main goal was to look for an estimate in the overall functionality and usefulness of the whole system, while looking for an insight of its potential to have motivational effects in the user. The importance of considering usability evaluations in the development and deployment of e-learning applications has been well documented since it determines users' satisfaction with the system which can significantly affect the learning process (e.g. Ardito et al., 2005). A functional system could also influence user's motivation which is directly related to the effects on different cognitive processes that are relevant for learning mathematics (Moenikia & Zahed-Babelan, 2010).

The paper is organized as follows. After the introduction, important considerations in the assessment process of mathematics and the current role of technology are discussed, including a brief description of the technological guidelines of the development. Later, a detailed description of the web-based system for automatic evaluation of mathematical expressions (MathDIP) is given in section 3, followed by the results of the system evaluation. Finally, we summarize and make general conclusions on different aspects of the development of the system and the results.

2. Computer support in the assessment of mathematics

Many factors are involved in the use of technology to help in the assessment process of mathematics, and a wide range of possibilities for delivering effective feedback to the learners using technology can be envisioned. The educational setting where the technology is going to be implemented, the aspects of student achievement that will be assessed and how the technology is going to be used in the process, must be clearly identified in order to enhance the computer support in the learning experience.

In order to try to use technology in the assessment process of mathematics, we must first try to identify and understand certain aspects of the process that result in effective exchange of information that is valuable for learning mathematics. Also, a strong compromise between the available technological tools and the specific assessment activities must be established.

2.1. Assessment and feedback in mathematics

Assessment in mathematics courses is fundamental to the whole educational process. As a first instance, lectures want to monitor their students' progress by measuring their development toward established learning objectives mainly motivated by grading purposes. Even though this type of assessment is a common practice in teaching, it has a lean contribution to the teaching/learning process, especially in University Mathematics. On the other hand, formative assessment must be perceived as an integral part of the conceptual understanding of mathematics. This process needs to be understood as a procedure to provide information to the teacher about the overall level of competence of the students and to inform individual students of the slack level in the mathematical knowledge they should have at certain stage, so that individual and joint actions can be taken to remedy the situation (Black & Wiliam, 1998; Madison et al., 2007; Shute, 2008).

The College Board Mathematical Sciences Academic Advisory Committee in the United States (Madison et al., 2007) brings up important issues of the role of formative assessment by recognizing the relevance of in-class communication of student thinking and the use of students' feedback to inform what teaching strategies are needed. Other important factors have to be considered, these include stressing the relation between assessment and motivation (Ball, 2003; Nicol & Macfarlane-Dick, 2006) and those related to the source, the beneficiaries, and the educational and physical setting of the feedback.

Typically, inside the classroom the teacher exemplifies a topic by solving a specific exercise, often with the participation of the students. This implies the transmission of evaluative or corrective information between the teacher and the students. The post-lecture communication between the instructor and the students is also very valuable in university math courses. In a traditional setting, a common practice is to schedule time outside of class in which the teacher and/or teaching assistants meet with students in order to give them supplementary support.

Another common practice is when students solve exercises and problems independently, either as part of homework assignments or in autonomous study, getting involved in more elaborate and challenging assignment projects. Hopefully, in the process, the students undertake relevant educational tasks such as applying mathematical ideas, obtaining results and meditating about their answers; situations where they might need to acquire special mathematical concepts.

In peer assessment, students express themselves on each other's work, so they learn from and support each other, eventually engaging in group work and collaborative practices. Sometimes, assignments are more elaborate math projects in which students get involved in more complex problems.

In these scenarios distinguishing features and essential elements in the assessment process in university mathematics courses can be identified. Some are implicitly defined and are natural to the process, other constitute activities sought to achieve significance in the assessment process:

- Exchange of information is produced. The nature of the information requires the use of special symbols and rules, i.e. the mathematical language.
- The process involves gathering, analyzing, interpreting and using this information.
- Assessing University Mathematics is about solving (applied or theoretical) mathematical problems, the action, its practices and its consequences.