Computers & Education 78 (2014) 333–343

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Touch Arithmetic: A process-based Computer-Aided Assessment approach for capture of problem solving steps in the context of elementary mathematics

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A R T I C L E I N F O

Article history:
Received 18 February 2014
Received in revised form
23 June 2014
Accepted 24 June 2014
Available online 2 July 2014

Keywords:
Elementary education
Human-computer interface
Interactive learning environments
Computer-Aided Assessment

A B S T R A C T

Technology today offers many new opportunities for innovation in educational assessment and feedback through rich assessment tasks, efficient scoring and reporting. However many Computer-Aided Assessment (CAA) environments focus on grading and providing feedback on the final product of assessment tasks rather than the process of problem solving. Focussing on steps and problem-solving processes can help teachers to diagnose strengths and weaknesses, discover strategies, and to provide appropriate feedback. This study explores a method that uses trace links on an interactive touch-based computing tool for the capture and analysis of solution steps in elementary mathematics. The tool was evaluated in an observational study among 8 and 9 year old primary school children ($N = 39$). The approach yielded similar performance scores as compared to paper-and-pencil tests while providing more explicit information on the problem-solving process. The output data was useful for scoring intermediate and final answers as well as feedback information on types and time efficiencies of strategies used. An implication of this study for teachers and researchers is that they can more accurately assess students' understanding of important concepts, and be in a better position to provide rich and detailed feedback while motivating students with interactive tasks.

1. Introduction

Assessment and feedback is one of the most powerful influences on learning and achievement (Black & Wiliam, 1998; Hattie, 2008). Through assessment teachers gather data about their teaching and their students' learning (Hanna & Dettmer, 2004). Computers and electronic technology today offer numerous ways to enrich educational assessment and feedback both in the classroom and large-scale assessment situations. The practical benefits of Computer-Aided Assessment (CAA) include automatic scoring, rapid feedback, and increased accessibility (Conole & Warburton, 2005). Interactive computer based tasks are also engaging through the immediate appeal of their graphics and the sustained appeal of their interactivity (Richardson et al., 2002).

Although extensive academic research has explored CAA systems and their benefits to teaching and learning (Conole & Warburton, 2005), the focus of many CAA systems has been the final answer or product of assessment tasks. Multiple Choice Questions (MCQ's) and selected responses item-type tasks appear to be dominant. This is mainly because such tasks are readily scored by a variety of electronic means. This approach sometimes limits creative problem solving as students often have to choose an answer in a limited range of options. Some researchers have argued that such implementations only test surface learning (Hommel, Colzato, Fischer, & Christoffels, 2011; Ward & Bennett, 2012). Considering the development process leading to the answer enables better understanding of the rationale behind the product (Baker & Mayer, 1999). A process has been defined as a systematic series of actions directed to achieve a result (Pinheiro & Goguen, 1996). Process oriented systems aim at telling the story of a problem-solving effort. Many studies on process-based CAA systems have focused on problem-solving

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http://dx.doi.org/10.1016/j.compedu.2014.06.015
0360-1315/

behaviour (Chung & Baker, 2003; Williamson et al., 2004; Zoanetti, 2010). Investigations have centred on how, and the sequence problem-solvers completed task. However, little attention has been paid to making the problem-solving process explicit by showing how different parts of a solution effort relate with each other. A major purpose of using computer for assessment that is relevant to the research reported here is to increase efficiency without diminishing the validity or credibility of results (Baker & Mayer, 1999). The introduction of new technology often leads to concerns about the extent to which students' scores differ between computer-based and paper-based tests (McDonald, 2002). Against this background, the purpose of this paper is to contribute to the present understanding of how assessment environments may be designed to capture problem solving process data to better inform assessment and feedback practices. The present study explores a trace-based approach for capture of the essential details of a problem-solving process and the relationships between the various parts of the solution. A trace is a path or history showing how some particular state came to be (Pinheiro & Goguen, 1996). The study is divided into two parts; the first part describes a method for capturing solution steps from traces of interactions produced by students on a touch-based prototype tool while solving arithmetic word problems. The second part of the study focuses on the evaluation of the tool and considers concerns of usability and also the applicability of providing feedback on arithmetic strategies. Specifically the evaluation answers the following questions:

- Does the tool impede students' accuracy and efficiency when solving mathematical word-problems?
- Can the use of process data output lead to the detection of arithmetic strategies?

The rest of this paper is structured as follows: First, a review of literature on related studies is provided. This is followed by discussions on the research approach, the design and implementation of this approach on the prototype tool and an observational study evaluating the tool. Following this, the results from the study are presented and discussed. Finally, implications and directions for future research are offered.

2. Review of literature

2.1. Process and product assessments

Assessment has been defined as activities that provide teachers and student with feedback information and interpretations about the difference between the current status and learning goals (Hattie & Timperley, 2007). Black and Wiliam (1998) showed that improvement in classroom assessment has a strong effect on students' achievements. In their article Hattie and Timperley (2007) argued that feedback on assessment activities can be in four categories: tasks, processes and strategies, self-regulation and the person. The study argued that process-level feedback was most effective in assessment situations. For instance while task-level feedback is concerned about whether the task or product is correct or not, process-level feedback looks at the procedure used to create the product or complete the tasks. It addresses the questions like what is wrong and why? What strategies did the learner use? What is the explanation for the correct answer? What relationship exists with other parts of the task? What is the learner's understanding of the concepts related to the task? To answer these questions the paths to the solution need to be clearly visible (Baker & Mayer, 1999).

2.2. An example

Word or story problems are commonly used in schools to train and test understanding of underlying concepts within a descriptive problem as well as to test student's capability to perform arithmetic manipulations (Hegarty, Mayer, & Monk, 1995). Fig. 1 shows a two-step arithmetic word problem that involves summing double digits and single digit numbers i.e. 34, 18, and 6 on paper. The question is a two-step arithmetic problem which requires an intermediate result and a final answer. Four student solutions are shown in the diagram.

Solution 1 shows a final answer of 58 without showing explicitly how the answer was arrived at. Solutions 3 and 4 show the workings using vertical and horizontal arrangement for the addition. Solution 3 is less clear; the number 14 is not in the problem text but appears in the solution thereby making the student's thinking less obvious. Too often, the opportunities to provide meaningful feedback are missed when student's responses to these types of assessment tasks are not detailed or clear.

2.3. Conceptual understanding and arithmetic strategies

In many fields of study students are taught important concepts and correct procedures. Conceptual knowledge has been defined as explicit or implicit understanding of the principles that govern a domain and the interrelations between them while procedural knowledge

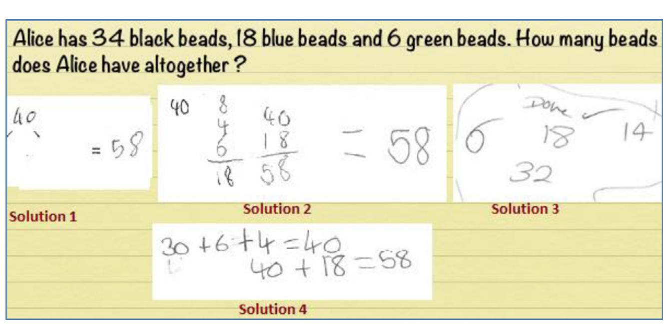

Fig. 1. Record of solutions.