European Journal of Teacher Education
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713421837

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Online Publication Date: 01 May 2009

To cite this Article Olkun, Sinan, Altun, Arif and Deryakulu, Deniz(2009)'Development and evaluation of a case-based digital learning tool about children's mathematical thinking for elementary school teachers (L-TEST)',European Journal of Teacher Education,32:2,151 — 165

To link to this Article: DOI: 10.1080/02619760902783875

URL: http://dx.doi.org/10.1080/02619760902783875

European Journal of Teacher Education
Vol. 32, No. 2, May 2009, 151–165

Development and evaluation of a case-based digital learning tool about children's mathematical thinking for elementary school teachers (L-TEST)

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It is important for teachers of mathematics to know how pupils react to certain mathematical situations and what these reactions imply, in order to design more effective instructional environments based on their learning needs. This study reports the development processes of a digital learning tool (Learning Tool for Elementary School Teachers (L-TEST)) that shows children's mathematical thinking for the ages of 4–11 years across certain problem situations. L-TEST is designed as a support tool to be used in teacher education. A case-based instructional model was used in designing the instructional tool. Video recordings were digitised to provide a rich environment where learners observe exemplary cases. These exemplified videos included children's mathematical development in the subjects of numbers and shapes, combined with discussions in line with the current research findings. Finally, a usability test for the learning tool was carried out.

Keywords: mathematical thinking; information technologies; mathematics education; classroom teachers

Introduction

Pupils acquire most of their basic mathematical knowledge, skills and attitudes during their elementary school years. In order to serve children's mathematical needs better at elementary level, elementary school teachers' education should be based on recent developments in the field of education and educational research. Recent developments in education in general and in mathematics education in particular call for some specific training needs on the part of elementary school teachers. For example, how do pupils deal with problem situations involving small numbers, increasingly large numbers, fractional numbers, shapes and different sorts of data? A learning tool that combines both theoretical and practical aspects of children's mathematical thinking may help teachers to visualise and understand more about pupils' developmental trajectories and cognitive milestones.

As teachers graduate from universities and enter the school systems, they are required to manage the whole class, which is not always a smooth transition. One model of combining this transition (from pre-service education to classrooms) is the induction model. According to Horn, Sterling and Subhan (2002), induction provides additional support to teachers in meeting their professional needs and reducing the likelihood of encountering problems as beginning teachers. Horn and colleagues (2002) categorise the dimensions of induction into nine components:

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ISSN 0261-9768 print/ISSN 1469-5928 online

DOI: 10.1080/02619760902783875
http://www.informaworld.com

orientation; mentoring; adjustment of working conditions; professional development; release time; opportunities for collegial collaboration; teacher assessment; programme evaluation; and follow-up into the second year.

Each component in this model requires careful instructional design and planning decisions. These components can be addressed individually or organised in various combinations, depending on the needs of the teacher/student. In this study, video cases were designed to provide school teachers with professional development support and orientation to the teaching profession (e.g., Lemke 1994; Fideler and Haselkorn 1999). For experienced teachers, these cases can also be considered as a follow-up in their later years, since most new teachers still require assistance into their second year of teaching (Fideler and Haselkorn 1999).

The aim of this project was twofold. First, it aimed at eliciting responses of pupils at different ages to a variety of mathematical situations involving such domains as number, arithmetic operations and shape. For this purpose, pupils' actions and verbalisations were captured on video, edited, interpreted and recorded on a CD in a systematic order based on pre-established developmental trajectories (Carpenter and Moser, 1984; van Hiele 1986; Carpenter, Moser, and Bebout 1988; Peterson, Fennema, and Carpenter 1989; Olkun and Toluk 2002) to form a standalone learning tool for teachers (Learning Tool for Elementary School Teachers (L-TEST)). The L-TEST included captures of pupils on video while solving certain mathematical problems and descriptive explanations of their problem-solving strategies. Second, a usability test for the learning tool was carried out with the potential users of the CD. The results of the usability test were reported.

In this section, firstly, the literature on children's mathematical thinking on number, arithmetic, and shape is synthesised. Secondly, how pupils think mathematically and how we understand their mathematical thinking is elaborated. Finally, the major premises of case-based instruction and the use of video cases in teacher education are provided.

Children's mathematical thinking

One of the fundamental goals for mathematics education researchers is to understand the nature, development and range of mathematical thinking used by children (Battista et al. 1998). Children's numerical and spatial developments from birth to middle grades have been well documented in numerous studies (e.g., Carpenter and Moser 1984; van Hiele 1986; Carpenter, Moser, and Bebout 1988; Clements and Battista 1992; Wynn 1992; Butterworth 2005). The developmental trajectories of children in number, arithmetic and shape are described briefly below.

Number

Children pass through various levels of understandings for numerical concepts and processes, from primitive to increasingly sophisticated understanding of numerosity and its implications (Butterworth 2005). They first learn to count the numbers verbally, but the numbers may not be in order. Then they realise that the numbers have a stable order (the ordinality principle). Third, meaningful counting starts with the one-to-one principle by which each counted object is assigned one and only one number word. Fourth, they learn that the last number word represents the numerosity of the counted set. They show this (the cardinality principle) by using the

last counting word with the object name: 'One, two, three, four, five, five toys'. Fifth, another capacity that the child must develop is the idea that the number of things in a set is 'conserved', to use the Piagetian term, unless a new object is added to the set or an object subtracted from it.

Arithmetic

Simple arithmetic situations occur naturally when an action is taken on one or two sets which may result in an increase or a decrease in the numerosity of the set or sets. Based on the results of the transformations, 11 different meanings of addition and subtraction have been identified as represented in standard additive word problems. The meanings of operations stem from the student strategies that reflect the semantic structure of the word problem (Carpenter and Moser 1984). In other words, students initially choose the strategies relevant to the actions and relationships described in the problems. There are four main categories based on these relationships: join; separate; part-whole; and compare. Additionally, some subcategories are determined according to which quantity is unknown in the mathematical sentence modelled from a simple word problem. A basic mathematical sentence has three quantities: start; change; and result. Altogether this makes 11 types of word problems (Van de Walle 1998). Multiplicative structures can be thought of as problems that require multiplication and division for solution. Different multiplication and division problems occur in such situations as repeated addition, rectangular arrays, Cartesian product, sharing or partitioning, measurement, and missing multiplicand or divisor. Only repeated addition, missing divisor, missing multiplicand and equal sharing type problems were included in this project.

Shape

Children pass through five different levels of thinking in geometry. They first recognise and identify the geometric figures based on their visual appearances. Analytical differences cannot yet be recognised or perceived at this level. Geometric figures can be likened to real objects. For example, a child might say 'this is a rectangle because it is like a door'. At the second level of thinking, called the analytical level, children begin to recognise such properties of geometric shapes as the number of sides, angles, corners and so on. A child at this level can list the basic properties of familiar geometric figures but cannot see the relationships among the properties. Only the first two levels are included in this study. Video cases are selected to exemplify these two levels.

Case-based instructional design and video cases

Case-based instruction is an instructional design method in which students analyse and solve cases through observation, discussion and reflection (see Ertmer and Stepich 1999). This model of instruction suggests that knowledge and skills are best learned in contexts that reflect the way they will be useful in real life (Ertmer and Russell 1995). A case is a real-life experience, situation or event. Cases are created explicitly for discussion and seek to include sufficient detail and information to elicit active analysis and interpretation by users with differing perspectives (Merseth 1994). The main aims of case-based instruction are to promote students' case analysis and problem-solving skills, thus serving as bridges from theory to practice.

According to Merseth (1996), cases can be used for at least three purposes in teacher education: (a) cases as exemplars; (b) cases as opportunities to practise analysis; and (c) cases as stimulants to personal reflections. Sykes and Bird (1992), on the other hand, propose that cases can be created and treated as (a) instances of theories; (b) problems for deliberate and reflective action; (c) material for the development of narratives; and (d) material for the development of casuistry – that is, the internal and tacit logic developed through the consideration of multiple cases.

In order to prepare teachers for classroom teaching, teacher training programmes often provide classroom observation opportunities for their students. However, sending prospective teachers to schools and anticipating that they can meet and observe all the relevant cases by chance may not always be realistic and efficient. Besides, educators know that even if several students observe the same classroom, each student may tell a different story, because live classroom observation allows neither reviewing nor thinking time, advantages which video and written cases do offer (Dolk, den Hertog, and Gravemeijer 2002). In addition, cases have traditionally been conveyed orally and in writing, but multimedia technologies now provide for case presentation through video, graphics and animation (Edelson 1996). Video cases can capture the complexity of the classroom context and provide a very efficient way to expose the viewer to the authenticity of the classroom (Kurz, Llama, and Savanye 2005).

By viewing teaching and learning situations in video cases, both prospective and at-site teachers may benefit from seeing examples of how students' mathematical thinking is described (Carboni and Friel 2005). Providing teachers with an opportunity to view collectively, and critique carefully, video cases of various classroom activities can enrich their learning (Stephens et al. 1999). Therefore, specifically chosen and designed video cases may provide effective and efficient learning opportunities. According to van den Berg and Visscher-Voerman, multimedia cases (or video cases) offer ample educational advantages as they:

> stimulate an active learning attitude in a learner-controlled environment; yield the possibility to revisit classroom events in order to make sense of them; show the cases from myriad perspectives; offer procedural support for instructional design and classroom teaching; lessen the gap between theory and practice, by giving practice a more profound and integrated position into teacher education programs. (van den Berg and Visscher-Voerman 2000, 123)

The use of video cases has been shown to be supportive in teachers' realisation of how different children understand mathematics in different ways (Friel and Carboni 1997); conceptual understanding of mathematics teaching (Atkins 1998); movement from a more didactic perspective of teaching mathematics toward a student-centred perspective (Friel and Carboni 2000); construction of pedagogical representation and their ability to identify a problematic situation with multiple perspectives (Lin 2005); and changes in their thinking about teaching mathematics (Carboni and Friel 2005). Connecting video cases to specific research findings about children's mathematical thinking using hypermedia components such as linking texts and tasks to videos may focus the learners' attention to the important aspects of cases.

Construction process of the L-TEST

The aim of the L-TEST is to improve both prospective teachers' and in-service teachers' conceptualisations about how children aged from 4–11 years develop their

mathematical thinking about selected mathematical concepts. In other words, the video cases are selected and designed to exemplify children's mathematical thinking across ages. Based on this aim, cases are intended to fulfil the following functions:

- to demonstrate children's exemplary problem-solving strategies;
- to foster teachers' awareness of children's mathematical thinking levels;
- to encourage reflection on a student-centred approach to teaching mathematics; and
- to support the design of proper mathematics teaching–learning activities for children.

In order to reflect the developmental trajectories of children in mathematics, different age groups from both genders were included in the study. Therefore, the case participants were elementary school students aged from 4–11 years, both boys and girls. Problem situations involving such mathematical domains as number and shape were produced based on current research findings as outlined above. Problems related to number development were arranged in order to elicit the principles of counting and sophistication in pupils' strategies. Shape-related questions were arranged to elicit the differences between visual and analytic thinking levels based on the van Hiele (1986) model. Altogether, 136 small video cases were included in the design. A sample screenshot from the L-TEST is shown in Figure 1, containing a case about counting. The upper left part of the diagram shows the video clip and control panel for the video. Below the video, there is a pull-down menu for the main topics in the system such as number concept, arithmetic and shape. Sub topics and relevant age groups are in the lower left portion. In the upper right corner is the question asked to the pupil. Below is the explanation of the principles or the possible strategies the pupils of relevant age might use.

The difficulty of the problems was arranged according to different age groups, while keeping the mathematical demand consistent across problems. For example, small numbers were used for lower grades and larger numbers for upper grades. Only standard word problems with additive and multiplicative structures were included in the study.

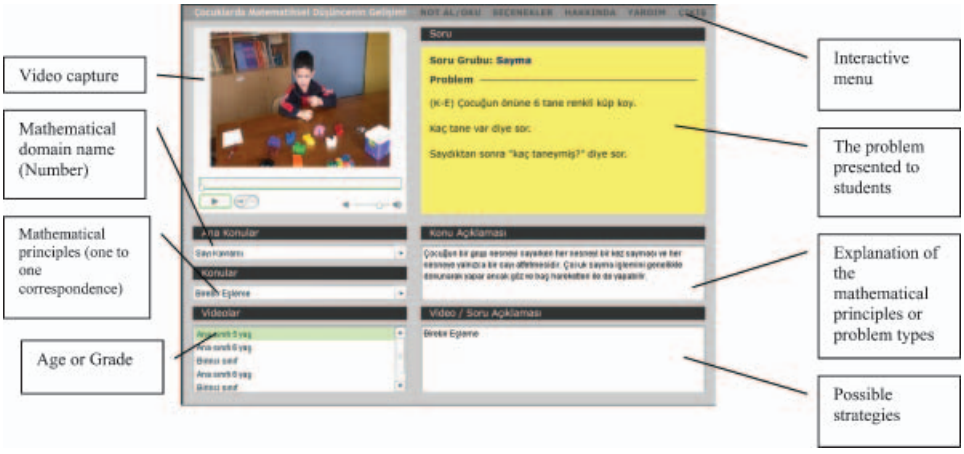

Figure 1. A screenshot from the L-TEST.

Each child was interviewed in a separate room and video-taped to account for his/her actions and verbalisations. Video clips were produced and edited to make them serve the aims of the study. By the end of video production sessions, a total of 20 hours and 15 minutes of recording in 21 1.4 GB-DVDs had been produced.

In order to make the environment updateable and expandable, a relational database was designed and integrated into the system. By using a relational database, users have been provided with flexibility in locating and transporting each video with the corresponding textual information into a multimedia and/or the internet environment. Hence, each datum could have been either entered into or pulled from the database from a user interface. Moreover, the system becomes expandable in nature.

Method

This section provides information about data collection instrument, participants, data collection and analysis processes.

Data collection instrument

The content of the CD was put on the internet for user evaluations based on a questionnaire consisting of five open-ended questions. These questions included (1) users' perceptions about the usability and interface design; (2) their perceptions about the functional use of the tool; (3) their perceived benefits from the system; (4) the extent to which the system helped them to make connections with their existing knowledge; and (5) their suggestions for further improvements of the system.

Evaluators as participants

Evaluators were the potential users of the learning tool – that is, teachers and teacher candidates. The instrument has been sent via e-mail inviting junior and senior level student teachers and graduate level students from three large public universities to participate voluntarily in this study. In addition, three public schools from the same city with these universities were randomly selected. The same e-mail was sent to classroom teachers at these schools.

A total of 225 out of 430 users responded to our survey involving both demographic information and open-ended questions about the content and interface of the system. Among the participants, 189 were junior level student teachers, 13 were senior level student teachers, 10 were classroom teachers and 13 were graduate students majoring in mathematics education.

Student teachers are trained in the faculty of education to become classroom teachers. As part of their curriculum they take a mathematics methods course along with other pedagogy courses. In this methods course, they learn mainly how to teach mathematics to pupils.

In order to ensure the anonymity of evaluators, no information about their identities were requested and the responses were stored in the server as anonymous users. None of the evaluators had earlier exposure to the L-Test.

It should also be noted that one of the ways to begin the construction of a website is to have many different people propose design solutions (parallel design),

and then to follow up using an iterative design approach. Therefore, the system developers were part of the evaluation process from the beginning to the end of the study.

Data collection procedures

The content of the L-TEST has been evaluated by pre-service classroom teachers, teacher educators, and classroom teachers. One way of exploring a website's effectiveness and usability includes heuristics and web-based or paper-and-pencil questionnaire surveys (i.e., Davis 1989; Nielsen 1994). The web-based surveys may come in different forms, such as via e-mail, password-protected web pages and automatic data generators (see Heerwegh and Loosveldt 2002 for a detailed discussion on web-based surveys).

In this study, the evaluators were able to send their answers to an e-mail account via an online form. Their opinions about the content and interface were elicited in order to obtain empirical evidence about the effectiveness and efficiency of the learning tool. Each participant could have access to the questionnaire once and could complete the questionnaire during their free time by themselves. Approximate time for each user was between 10–20 minutes. By the end of data collection procedures, a total of 143 pages (51,907 words) of verbal data had been gathered via e-mail responses.

Data analysis

Data were analysed using both qualitative and quantitative techniques. Miles and Huberman's (1994) matrix technique was applied in analysing the verbal information. The research questions were placed in the left column and responses on the right-hand side of the matrix. While placing the data on the matrix, irrelevant information was put aside. The data were then coded according to the patterns that occurred in the text. During this process, the repeated expressions were combined into a common theme.

A three-phase coding system was used during the analysis. In the first phase, the whole text was read twice and the units of ideas were collected under the relevant titles. In the second phase, the text was re-read to check for any missing coding and data. In the third phase, the coded data were read again to assign them to higher order themes and arrange the themes in tables or charts.

For the validity of the study, patterns were sought within the similarities and differences of the ideas coming from different users such as teachers, teacher candidates and mathematics educators. To assess the reliability of the study, inter-rater agreement was sought.

Results and discussion

The users' ideas about the tool were accumulated under five themes relevant to the open-ended questions in the questionnaire. These are: (1) appearance and user-friendliness of the interface; (2) the purposes for which the content could be used; (3) whether the users learned anything new from the tool; (4) whether the users deepened their prior understandings; and (5) the issues they think should be changed or added to the tool.

Appearance and user-friendliness of the interface

Most of the users thought that the tool was user-friendly and easy to use, and had the necessary visual content. Only three out of 225 evaluators stated that they found the interface too small to watch. Only two out of 225 users stated that they found the colours unattractive, and they further thought that the video clips could have been shot closer. Others generally mentioned the positive aspects of the tool's appearance.

For whom and for what purposes could the content be used?

The analysis of the users' opinions about the potential uses of the tool revealed 11 categories as summarised in Table 1. The rows in the table indicate the purposes for which the tool could be used. Potential end-users are specified in the columns of the table. As seen from Table 1, the evaluators thought that the tool could be useful for different professional educators as well as parents and pupils. Evaluators, for example, discerned that pupils could benefit from L-TEST to be aware of different problem situations and to see the importance of concrete materials. Some end users have a null correspondence with perceived usage in the table. This indicates that evaluators did not mention such usage for those specific end-users.

A third-year undergraduate student majoring in classroom teaching and taking the mathematics methods course stated his ideas about the tool as follows:

> This tool can be useful for teachers in deciding on how mathematics could be differentiated for children with different levels of understanding. The tool can be used by classroom teachers, other teachers, as well as students of different ages.

These kinds of ideas show that the tool could be used by teachers, parents and students for different purposes. The excerpt also stresses the importance of individual differences with respect to both children's prior knowledge and experiences, and developmental levels.

Did the users learn anything new from the tool?

Most of the users stated that the tool was very informative. However, some of the evaluators, especially classroom teachers, claimed that they already possessed much of the knowledge included in the CD. The topics that were new to teachers, according to them, were the geometric content and the approach taken towards teaching geometry subjects.

When the users' opinions were examined, their ideas could be categorised under two main themes: (1) realising individual differences in terms of mathematical behaviours, and (2) teaching strategies and techniques that comply with these differences. These themes and relevant subtopics are depicted in Figure 2.

The following quotations came from two third-year undergraduate students majoring in classroom teaching, and taking the Mathematics Methods I course:

> I compare the things I learned in methods course and the approach taken in the tool. So I find a chance to say if I were the interviewer I would ask the question like this and this putting myself in the place of the interviewer. Additionally, I learned a lot of student strategies such as counting all, counting on the larger etc. These are the examples of student strategies I learned from the tool.

Table 1. Perceived usefulness of L-TEST across end-users.

		End-users								
	Perceived usage	**Parents**	**Child development specialists**	**Classroom teachers**	**Teacher candidates**	**Pre-school teachers**	**Programme developers**	**Researchers**	**Textbook writers**	**Pupils**
1	To know about the students' conceptual development	*	*	*	*	*	*	*	*	
2	To guide students' learning	*	*	*	*	*				
3	To use for in-class activities			*	*	*			*	
4	To use for out-of-class activities	*	*				*	*	*	
5	To recognise individual differences	*	*	*	*	*	*	*	*	
6	To learn about students' difficulties	*	*	*	*	*		*		
7	To assign subjects to grade levels		*				*	*	*	
8	To understand the new curricular approaches	*	*	*	*	*	*	*	*	
9	To visualise students' thinking processes				*			*		
10	To be aware of different problem situations	*	*	*	*	*	*	*	*	*
11	To see the importance of concrete materials	*		*	*	*	*		*	*

Table 2. Perceived benefits of interacting with L-TEST.

	Reflections from evaluators	Frequency
1	Differences among the conceptualisations of students	108
2	Importance of concrete materials	70
3	Importance of visual presentation	61
4	Differences among student strategies	31
5	Exemplary cases of theoretical issues	24
6	Importance of guidance and questioning in teaching	19
7	Students' difficulties	11
8	Importance of communications with children	5

> Realising the differences in mathematical thinking levels could enable teachers to adjust his/her teaching style to the needs of the students so that he/she can do an effective instruction.

When the evaluations were inspected closely, it can be seen that the evaluators deepened their understanding of the mathematical behaviours of children in certain situations. It also seems that they learned some new concepts about children's mathematical thinking. In particular, they recognised different strategies of students exemplified in the learning tool.

Did the users deepen their prior understandings?

Most of the undergraduate student users stated that they saw the exemplary cases of the theoretical issues in the methods class. Teachers, on the other hand, claimed that they already knew many of the things contained in the learning tool since they already have some years of teaching experience. It is obvious from undergraduates' opinions that they were surprised when they saw that the students behaved as stated in the methods course. They saw very much evidence of students' mathematical behaviours in mathematical situations. The eight most repeated ideas from evaluators' reflections with L-TEST are listed in Table 2.

A third-year undergraduate student majoring in classroom teaching and taking the Mathematics Methods I course stated her ideas about the tool as follows:

> I understand the nuances among the concepts and strategies we learned in mathematics methods course. We did not believe that the students' would behave like this. Now I saw their behaviours were as exactly the same as mentioned in the class. I believe this tool will help teachers understand the students better.

Table 3. Suggestions from evaluators on improving the learning tool.

	Suggestion	Frequency
1	Other maths topics should be added	55
2	Different age groups should be included	38
3	Activities should be varied	18
4	Students' difficulties should be discussed	7
5	Real classroom applications should be included	5
6	Similar environments should be designed for other disciplines	4

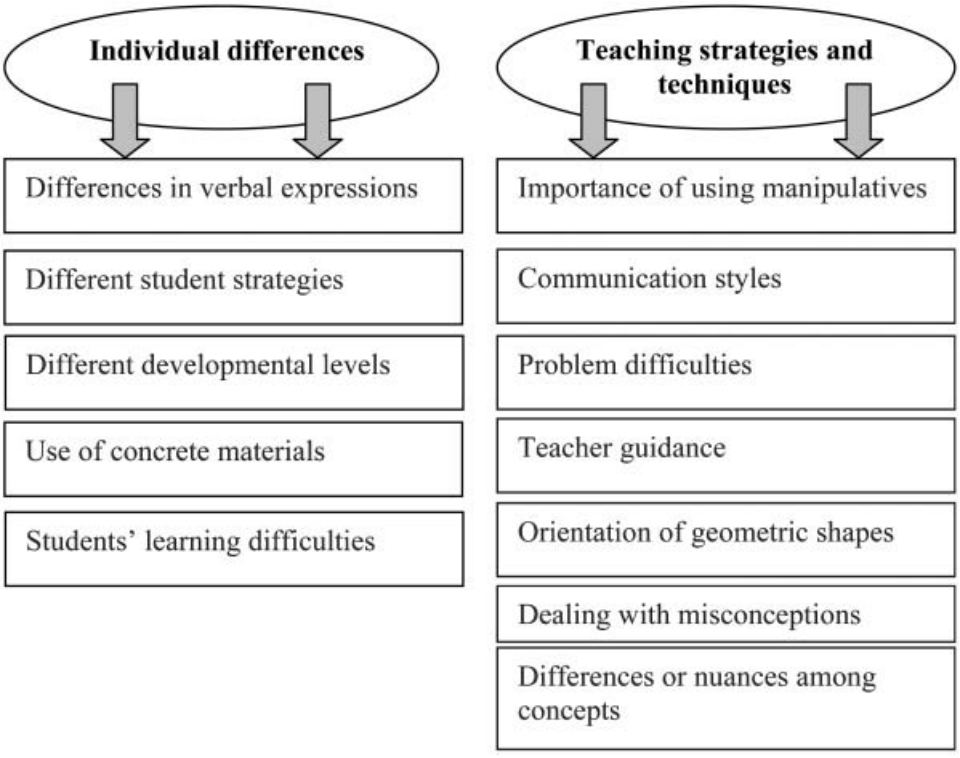

Figure 2. The issues emerging from evaluators' experiences from the learning tool.

It is evident from their responses that the evaluators, especially undergraduate students, saw that what was discussed in mathematics methods classes was real and exemplified in the CD. It seems that the developed learning tool or similar video case-based learning tools could be used in mathematics methods classes as complementary material.

Issues the evaluators think should be changed or added

The majority of the participants indicated that they found the application quite useful. They particularly emphasised that more topics should be added and extended toward a wider range of users. Some modifications were also requested regarding improvement of the system. The frequencies of suggestions are presented in Table 3.

The following excerpts reflect the views of pre-service elementary classroom teachers who attend Mathematics Methods I course:

> This way of seeing the stages children develop their mathematical thinking should be extended to other topics and courses. It helps us remember the topics more efficiently.

> This should be applied to other courses. Teacher candidates should be given such a tool, since it includes effective and concrete evidence. We can observe what types of problems we might encounter and improve our understanding and knowledge by means of using such software.

The evaluations focus mainly on the need to expand the content of CD to a wider range of topics. The fact that 'know your learner' is emphasised is of great importance. This

finding is an indication of teacher candidates' thorough understanding of the 'knowing your learner' motto, which is a prerequisite of any learner-centred curricula.

Conclusions

This project aimed at portraying how children's mathematical thinking develops through the use of a research–development–research cycle. The first stage included the process of determining what type of problem situations could involve which basic concepts, by analysing the literature related to children's mathematical thinking in shape and number. In the second stage, children at the primary school ages were given those problem situations. They were videotaped while solving these problems. These video recordings were then digitally edited, transferred to a CD environment and organised under certain theoretical themes. In the last stage, the designed product was presented to the prospective end-users for their views under five themes. Eventually, the dissemination of the system was offered via web and CD formats.

Our premise in designing this system was that learning occurs more effectively when instruction is presented in line with learners' prior knowledge and learning needs. One of the means of gathering this information about the learners is to create an information repository of how they think and what type of strategies they employ in problem-solving situations. A tool which can merge the theory into practice will both enable mathematics teachers to help children visualise their cognitive processes and also be a support tool when developing sound instructional decisions and materials. The findings of this study indicated that L-TEST created a functional repository for teachers and teacher trainees, who could benefit from real-life cases.

In addition, the findings of this study indicate that such a learning environment provides two main benefits for pre- and in-service teachers. Firstly, pre-service elementary school teachers mostly claimed that the learning tool supported and extended their knowledge about children's early mathematical development. Moreover, they further stated that they learned new information from the learning tool, especially about children's geometric thinking and student strategies.

This study has been based on prospective teachers' and in-service teachers' perceptions about the possible effects of the learning tool. Further research can be done on the real effect of the learning tool on teachers' knowledge about the students' mathematical development. Practically, similar applications can be produced for other topics of mathematics as well as for other disciplines such as science.

The findings indicate that users perceived L-TEST to fulfil its purpose, to enable information sharing, to stimulate learning and to increase interaction. These perceptions also indicate that users found the system to be effective. In addition, the majority of users provided feedback related to extending L-TEST to other mathematics topics in order to further develop the system to be more effective.

Multimedia cases intend to bridge the gap between theory and practice in teacher education (van den Berg, Jansen, and Blijleven 2004). The outcome of this project indicates that interactive video as part of L-TEST multimedia cases makes it possible for prospective teachers to benefit from practice. In their evaluations of four video case-based instructional projects, Stephens et al. concluded that results of the field tests 'show evidence of a shift in philosophy among the users – from a teacher-centred orientation to a student-centred perspective. The most valuable gain,

however, was that the teachers-in-training had an opportunity to collectively explore their future professional world and to share their interpretations of it in a safe, encouraging environment' (1999, 300). As streaming technologies from the internet develop and download times are reduced considerably, developing and utilising such video cases to be used in teacher education opens up new research venues for educators and researchers to explore collective interactions and social networking more in depth.

Acknowledgement

This project was supported by a grant from the Scientific and Technological Research Council of Turkey in 2006 under the Grant number 104K-114.

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