Using ICT to support constructive learning

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Abstract: In light of our dialectic constructivism, we have developed a set of instructional software on word problems in elementary mathematics. We managed to use ICT to create a constructive learning environment from four perspectives: (1) Challenge and support learners' higher-order thinking; (2) Promote learners' deep and flexible understanding on the base of introductory knowledge acquisition; (3) Enhance learners' conversation and collaboration through micro-community; and (4) Facilitate learners' self-regulation during learning. Some principal considerations will be explained in detail.

1. DIALECTIC CONSTRUCTIVISM

Constructivism highlights a potentially more hopeful direction for educational reform including the use of ICT in education. However, some constructivists went too far in some arguments, including overestimating learners' agency at the cost of ignoring the importance of teachers' teaching and guidance and overemphasising that learning should be always situated in authentic and complex environment. On a number of occasions (Chen et al. 1998; Chen and Zhang 1998), we have clarified our dialectic view on constructive learning, to include the following relations which are critical for learning and teaching.

1.1 The view of knowledge

Knowledge does not consist of static reflections of the environment, but dynamic constructions achieved through our acting and thinking on the environment. However, we should not deny the objective world and the

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truth that reflects the law of outside world even though it is relative and dynamic.

1.2 The learning process

Learners should construct their knowledge through higher-order thinking. On the one hand, since they are still growing human being, they need guidance and help from the teacher and support from the culture and society they live in, especially at the introductory stage of knowledge acquisition. Learners construct their own knowledge. In this sense they are the centres in learning process. On the other hand, a teacher still plays a critical role in the classroom. As the organiser, facilitator, information source and monitor of instruction, the teacher has to co-ordinate all the variables related to the learning and teaching processes, such as, the instructional contents, the student's individual differences, the teaching methods and the learning environments. The teacher is the director for whole instructional practice. This point does not conflict with our argument that the learner is the centre in the learning process. the teacher, their students have to be placed on the centre because every decision needs to be made based on students' understanding, thinking, feelings and actions. While for the classroom interactions, both teacher and students are actually actors interacting with each other and all aiming at the success of learning. Students construct their own meaning with ICT and teacher (courseware designer) providing scaffolding for student's learning.

1.3 Individual or social learning

Neither individual students' activities nor social interactions can be accounted for adequately except in relation to the other. Individual students' activity is always located within both the classroom cultural background and the broader society systems. On the other hand, only when individual learners are involved in active and constructive learning activities, which is the internal base, can social interaction add the external power and enhance their knowledge construction.

1.4 The relation between concretion and abstraction.

Knowing is a dynamic and effortful process, stepping from sensory intuition to essence abstraction, and eventually to the most advanced stage, the materialisation in thinking. Accordingly, certain kinds of abstraction and generalisation are needed for the introductory stage of learning. While at the advanced stage of knowledge acquisition, it is more necessary for learning to be situated in a more authentic and complex environment.

2. FRAMEWORK OF THE LEARNING ENVIRONMENT

In light of Dialectic Constructivism, we have designed and developed a set of CD instructional software on word problems in primary mathematics, including Two-Step Word Problems in Primary Mathematics and Typical Word Problems in Primary Mathematics. We managed to use ICT to create a constructive learning environment from the following four perspectives.

2.1 Challenge and support learners' higher-order thinking.

Lower-order thinking occurs when students are required to receive or recite factual information, or to employ rules and algorithms through repetitive routines. Higher-order thinking requires students to manipulate information and ideas in ways that transform their meaning and implications, such as combining facts and ideas to synthesise, generalise, explain, hypothesise, or arrive at some conclusion or interpretation (Newmann and Wehlage 1994). During constructive learning processes, students are often engaged in higher-order thinking, for instance, solving problems actively and generating new meanings and understandings. Teaching should be done by inquiring at the leading edge 'of the learner's thinking', rather than just telling students what to do and how to think (Fosnot 1989). In this sense, ICT should be used to stimulate and facilitate learners' higher-order thinking, rather than merely to transmit more information. Unfortunately, there has been very little consideration on this point in instructional design in China. Also, it is not very easy for all learners to think actively and generatively. Therefore, we should give them adequate support and guidance in order to ensure their success in problem solving and knowledge construction.

2.2 Promote learners' deep and flexible understanding on the base of introductory knowledge acquisition.

Students with deep understanding can make clear distinctions, develop their own arguments, construct their explanations for related phenomenon, and solve more complex problems creatively. Those with merely some superficial and fragmented understanding can only recall and apply the knowledge in rote ways. Accordingly, there is no doubt that we should promote learners' advanced knowledge acquisition in ill-structured domains (Spiro et. al, 1995; Jonnasen 1993). However, advanced knowledge acquisition needs to be based on learners' achievement in introductory knowledge acquisition stage, in which learners may need more basic training.

2.3 Enhance learners' conversation and collaboration.

Knowledge is socially negotiated. More substantive conversation and collaboration among learners and between learners and the teacher are needed in order to pursue constructive learning and teaching. The importance of a learning community where ideas are discussed and understanding enriched is critical to the design of an effective learning environment (Savery and Duffy 1995). ICT should be used to enhance learners' social interaction, which is another critical perspective of knowledge construction.

2.4 Facilitate learners' self-regulation during learning.

We should help learners to plan and monitor their own learning processes, evaluate their learning outcomes, and regulate their learning activities towards effective knowledge construction.

Word problem solving is an important and relatively difficult part in primary mathematics. Our courseware was focused on general two-step word problems whose solution involving a unknown medium variable, and some typical word problems concerning domain-specific knowledge (e.g. about speed, price). We designed six modules altogether in the courseware (see Figure 1). Two of them are designed for the introductory knowledge acquisition stage, including Sample Word Problems whose function is to help students learn to solve word problems concerning a kind of new mathematical relationship, and Basic Practice designed to strengthen learners' knowledge and skills just acquired. The module of Sample Word Problems was designed mainly based on theory of learning through problem solving, but with more guidance and support. The module of Basic Practice, although looks like training and practice in traditional courseware, was designed to strengthen learners' understanding by modifying the known data and goal in word problems (as will be detailed later). For the advanced knowledge acquisition stage, we designed another two modules: Advanced Problem Solving and Authentic Tasks. Besides, considering children with particular needs, we designed the module of Particular Skill Training to help them from particular perspectives, including representation of word problems and understanding of key words and sentences that can give us more information about mathematical relationships. The last module is Thinking Tools which offers open tools that learners can use to represent, analyse and solve certain kinds of typical word problems, such as those concerning speed or working rate.

Figure 1. Framework of the learning environment design

3. PRINCIPAL CONSIDERATIONS IN LEARNING ENVIRONMENT DESIGN

3.1 Supported problem solving

In traditional education, we used to regard knowing and doing as two distinct things. Only when students have been told about certain knowledge, can they solve the corresponding problems. Dewey (1933) moved from this tradition and stated the importance of ‘learning by doing’. Contemporary constructivists stepped forward from this point to assert that learners construct their own knowledge, and put forward different models for learning and teaching, such as project-based instruction, problem-based learning (Schmidt 1995), anchored/situated instruction, and a cognitive apprenticeship model (Brown et al. 1989). Despite the distinct differences, there is an important common principle across these models: learning through problem solving. During the problem solving process, learners will activate their knowledge to understand the problem situation, make their inference and hypothesis, and generate their strategies. Therefore, problem solving often leads to learners’ acquiring new insight into the phenomenon.

The theory of learning through problem solving is also very important for mathematics educational reforms (Hiebert et al. 1996). In our software on word problems, we also designed the module of Sample Word Problems in light of this theory. Rather than simulating a teacher’s explanations and demonstrations in classroom, at beginning of learning process, we advise

learners to try thinking over and solving the sample word problem by themselves first. Nevertheless, as our dialectic constructivism argued, learning through problem solving does not mean learning all by discovery. External guidance and support, which may be different from those in traditional teaching, are still very important in this circumstance. Therefore, as the learner solves the problem, the programme will keep monitoring their activity and offering various kinds of support and guidance to facilitate their problem solving activities and hence the construction of knowledge on the new mathematical relationships. The supports and guidance include the following.

Thought-provoking feedback and guidance: for example, if a learner types a formula involving a typical error when solving the problem, the software will offer them the corresponding feedback and guidance that may promote their thinking, such as, 'Attention! What is the goal of the problem?' or 'Which number means the total?'.

Tutor-Online: When a learner has tried for three times but still can not find the solution, the software will advise them to click a button, Tutor-Online, where three kinds of supports are available: (1) some corresponding preparatory problems concerning the prerequisite skills and knowledge; (2) a tutor's explanations on the structure of the sample word problem and the strategies to be applied; and (3) the right answer to the problem. A learner can select the needed supports from the above ones by clicking buttons. Whenever they feel that enough support have been received, they can return to continue solving the problem by themselves. Some low-achievers may need to solve some preparatory problems and get more support, while those high-achievers can solve the problem more by themselves with less guidance. Also, it is likely that learners with different learning styles (e.g. field-dependent vs. field-independent) may like different types of support during their problem solving process. This hypothesis will be tested in our later studies.

Reflection prompts: A learner's problem solving activity does not lead to knowledge construction automatically. As some research has manifested, it depends on various factors, of which learners' reflective abstraction may be the most important one (Gabrys et al. 1993; Hmelo and Ferrari 1997). Throughout problem solving processes, learners need to reflect on the underlying problem structure and the strategies used, and as a result to grasp the mathematical relationship more mindfully and systematically. In our software, as learners try solving the problem, we will give them some questions to prompt their reflection on their problem solving processes. For example, when a student has accomplished the first or the second step during the problem solving process, the programme will ask a question such

as ‘what’s the sub-goal of this step?’ to help them rethink over their solutions.

As we have asserted, support and help are necessary and essential for constructive learning and teaching. What more? If a learner really has no intention to work by themselves, they can directly start from Tutor-Online to solve the preparatory problems, listen to the explanations, and see the right answers, just as a learner used to do in traditional mathematics classroom. This might meet with some teachers’ or students’ needs on particular occasions.

3.2 Grasping mathematical relationships by modifying the word problem

For constructive learning and teaching, the question is not how many word problem learners have solved, but how well they can understand the fundamental relationships in word problems. Since the mathematical relationships will be more obvious in comparison, or say, during its changing, in the module of Sample Word Problems and Basic Practice, we prepare a button ‘Change It’ to modify the given data or goal in the original word problem. For example, the original problem is: ‘There are 24 kg apples in a shop. *Pears are 4 times heavier than apples.* How many pears and apples are there altogether in the shop?’ The modified problem is almost the same except that the second sentence has been changed to ‘*Apples are 4 times heavier than pears*’ In order to solve the changed problems, learners have to find out the subtle differences and think over the influence on mathematical relationships. This may help learners understand the structure of word problems clearly and grasp the key information promptly. Asking learners to analyse the differences between two or more cases may help them notice relevant features and prepare them for an explanation about why those features are significant.

3.3 Promoting learning through advanced problem solving and authentic tasks

The problems in the modules of Sample Word Problems and Basic Practice are typical and relatively simpler ones that can help learners grasp the basic mathematical relationships. In order to further learners’ understanding and promote the transition from an introductory knowledge acquisition stage to an advanced knowledge acquisition stage, we designed another two modules in the software, Advanced Problem Solving and Authentic Tasks. In the module of Advanced Problem Solving, more complex problems characteristic of ill-structured domains (Spiro et al. 1995) are offered including problems involving redundant data, or concerning two

or more knowledge sections and other novel problems that can help learners gain new insight into mathematical relationships. These problems were chosen not because they are difficult and can frustrate learners, but because they can improve learners' understanding about the mathematical relationships in word problems, and hence can facilitate the transfer of learning in broad domains.

Besides, partly based on the theory of situated learning, we designed another module, Authentic Tasks, to further learners' understanding towards the transfer in more general and real situations. This module begins with the animation of a story concerning certain mathematical relationships. For example, two boys carried books for three times. They carried 120 books for the first time and the same for the second time. For the last time, they carried 10 books more than the first time. All the data was embedded in the plots. Then the story breaks off with a question asked by one of the boys, such as 'how many books have we carried already?' The first task for learners is to verbalise the story appropriately as a word problem rather than as a general story. They should choose the most appropriate one from four figures' narratives. The other task for learners is to think over how to solve the problem in the story. We designed four simulated partners (as will be detailed in later section) who have different understanding and strategies over the problem. Learners are required to understand and evaluate the four solutions and choose the right one from them. When a learner has made their decision, the animation will continue to check whether the solution is right or not according to the story itself. The Authentic Tasks may help learners see what the mathematical relationships are actually like in the real world.

3.4 A micro-community to enhance social interaction

It is a pity that instructional software usually does little to enhance learners' social interaction. As a trial in our software, we designed four simulated partners representative of different learning styles to act as learners' partners, for instance, an impulsive boy and a reflective girl. In the modules of Sample Word Problems, Advanced Problem Solving and Authentic Tasks, learners can have a discussion with the four children by clicking a button, Partners-Online (see Figure 2). They can select a child and listen to their explanations of their thoughts on the word problem, and then evaluate these ideas critically. In this way, learners can see several different ways to analyse and solve a problem, and reflect on the distinct differences among these methods. They can also see some typical errors made by the partners in word problem solving. This may help learner in another way. Besides, as we have mentioned, in the module of Sample Word Problems, learners can visit Tutor-Online to seek supports and helps for word problem

solving from the simulated tutor. We hope that the interactions among learners and the simulated partners and tutor may function partly as a micro-community in computerised learning environment.

Figure 2. Partners-Online

3.5 Self-regulation through process tracing and advice offering

As masters in learning process, learners need to monitor and regulate their learning activities and manage to make good use of the resource (e.g. time) available in learning process. In order to facilitate learners' self-regulation, we added the function of process tracing in our software. The software can collect real-time data during a learner's learning process, including the time they have spent, the content they have visited, the scores they have gained, and the errors they have made in equations or calculations. Learners can fetch this valuable information about their learning when they need it. This may help learners to reflect on their learning accurately and hence regulate their learning effectively. In addition, the software will give learners some advice based on this information. As years of research on CAI has proved (Chen 1994), it may be more effective to let learners control their learning process under some guidance than programme-control or learner-control single-handedly. Whether these real-time data and suggestions can support learners' self-regulation needs to be proved by further research.

In addition, some other considerations are also of great significance in our learning environment design, such as enabling learners to represent

word problems appropriately, and supporting learners' problem solving with thinking tools. They can not be detailed here for the limitation of length.

4. CONCLUSION

Educational reform based on constructivism should enable a step forward from traditional education, which still has its own advantages although confronted with great challenges. The design of a constructive learning environment needs to focus on learners' needs in foregoing learning processes, and to try to facilitate and support their higher-order thinking and deep understanding. It is important to engage learners in reflective problem solving and enhance the interactions in a micro-community to achieve the above goals. Particularly, we should take learners' different learning styles and levels of capability into account, so that we can create a learning environment that is open and supportive for all learners.

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BIOGRAPHIES

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