Fitting Spatial Ability into Intelligent Tutoring Systems Development

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Abstract. Building effective learning environments is an art that can only be perfected by a great deal of explorations involving the environments' audience: the learners. This paper focuses on taking into account the learners' spatial ability into the development of Intelligent Tutoring Systems. We modified ERM-Tutor, a constraint-based tutor that teaches logical database design, to provide not only textual feedback messages, but also messages containing combinations of text and pictures, in accordance with the multimedia theory of learning [1]. Results of a preliminary study performed show a promising indication for further explorations. We plan to use these results as the basis for another evaluation study in early 2007.

Introduction

Intelligent Tutoring Systems (ITSs) are effective learning tools due to the adaptive pedagogical assistance they provide. Students differ in their capabilities for learning and processing information. This paper describes a project which focuses on spatial ability, a psychometric construct essential to activities related to spatial reasoning, such as the ability to manipulate images or spatial patterns into other arrangements [2]. Learners with high spatial abilities perform better with graphic or spatially-oriented content than those with low spatial ability. It is worth noting, however, that a low spatial ability score is not a deficit; there is evidence that it can be improved through training and practice [3]. Nevertheless, enhancing ITSs to accommodate low spatial ability learners could be beneficial for their problem solving skills. As a consequence, learners with different spatial abilities should receive different types of content.

The theory of multimedia learning [1] states that "*[multimedia] design effects are stronger for low-knowledge learners than for high-knowledge learners and for high spatial learners rather than from low spatial learners*" (p. 161) [1]. Low-spatial learners must devote much of their cognitive capacity to process multimedia information. High-knowledge and low-spatial learners are able to use their prior knowledge to compensate for the cognitive load needed to integrate the information received by the dual-channel. Therefore, it is the combination of the learners' spatial ability and level of knowledge that influences their meaningful/deep learning.

We present an approach to support the learners' spatial ability in ERM-Tutor [4], a constraint-based ITS that teaches logical database design (i.e. the algorithm for mapping conceptual to logical database schemas). The next section presents the modifications made in this project. We then describe the preliminary study and the results obtained, followed by conclusions and future work in the final section.

1. Spatial Ability Support in ERM-Tutor

Influenced by Mayer's work, we created a new version of the system. The original ERM-Tutor provides only text-based feedback. Following the multimedia learning theory, we decided to incorporate a pictorial aspect in the messages; for each feedback message, we created a graphically annotated (multimedia) version.

Each feedback message in ERM-Tutor is associated with a constraint. In other words, each constraint has a feedback message which is returned when the constraint is violated. Consequently, each message provides a hint on how to satisfy its particular constraint. To make the original and the newly created messages comparable, we kept the text identical in both versions. The only difference is the addition of a pictorial representation in the new version.
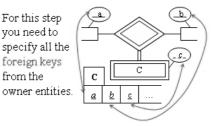

Figure 1. An example feedback message in multimedia representation

Figure 1 shows an example message in multimedia representation. A total of 112 images were created, each corresponding to a single feedback message. In addition, ERM-Tutor was modified to cater for both versions of feedback and prepared for an evaluation study described in the following section.

We also explored two cognitive tests for testing spatial ability [5]: a ten-item Paper Folding Test intended to evaluate a component of spatial ability called visualization, and an eighty-item mental Card Rotation Test which evaluates spatial orientation. Each test has a three-minute time limit and is suitable for ages 13-18.

2. Experiment

We preformed a preliminary study with students enrolled in an introductory database course at Canterbury University in March 2006. Our hypothesis is that students with a high spatial ability level will benefit more from multimedia feedback than students with a low spatial ability, given the same background knowledge. As each student's spatial ability level (either high or low, as opposed to the actual value) is determined relatively to the sample group, it was decided to compute it post-hoc. The students were randomly allocated to one version of the system, providing either textual or multimedia feedback. The assumption was that each group would ultimately include students with high and low spatial abilities. Therefore, the experiment allows for a 2x2 comparison: textual messages for high (TH) and low spatial ability students (TL), and multimedia messages for high (MH) and low spatial ability students (ML).

The study was conducted in two two-hour sessions of scheduled labs on ER mapping, straight after students had attended lectures on the topic. Each participant attended one of the sessions, and worked with ERM-Tutor individually, solving problems at his/her own pace. The pre-test was collected at the start of the session, while the post-test was administered after two hours of interaction.

55 students participated and completed both spatial tests. The test score for the paper fold test was 6.89 out of a possible 10. The total possible score for the card rotation test is 80. We computed the total test score by dividing the score by 8, thus giving a range of 1–10. The students scored a mean of 6.43. To compute the spatial

ability of each student, we added both test scores giving a possible range of 1–20. Using a median split, a total of 28 students scored above the median and were classified as high spatial, and the other 27 students were classified as low spatial.

The system recorded all student actions in logs. Due to a technical problem however, the logs from the first session could not be used. A total of 17 students used the system for more than 10 minutes. On average, students attempted 3.4 problems and completed 33% of them.

Only 13 students completed both tests, scoring a mean of 1.92 (sd = 1.04) on the pre-test, and 3 (sd = 1.15) on the post-test, resulting in significant improvement of their performance (t=3.09, p < 0.001). The scores for the four groups are given in Table 1. These preliminary results (although with small numbers) seem to refute Mayer's prediction that high spatial learners will benefit most from multimedia messages. However, it seems that the participants from the TH and MH groups who completed both tests started with higher pre-existing knowledge, and therefore the theory may be more pertinent in that low knowledge individuals will have a higher gain.

The numbers of valid logs in each condition are too small, and we are therefore unable to closely analyze the effect of the students' spatial ability on their performance. Analyses of the questionnaires showed that students who received multimedia feedback rated the overall quality of the feedback messages 25% higher (mean of 4 out of a possible 5) than those who received textual feedback (mean of 3 out of a possible 5).

Table 1. Pre/post test results for the students who sat both tests

Feedback	Low spatial			High spatial		
	No.	Pre-test	Post-test	No.	Pre-test	Post-test
Textual	TL: 4	1.5 (1)	3.5 (0.6)	TH: 3	2 (1)	2.3 (0.6)
Multimedia	ML: 2	1.5 (0.7)	3.5 (0.7)	MH: 4	2.5 (1.3)	2.75 (1.9)

3. Conclusions

This paper has looked at the potential of accounting for spatial ability in ERM-Tutor. Results from a preliminary study show an overall improvement in the students' domain knowledge level after two hours of interaction. We could not however report any findings on the correlation between spatial ability, content representation and the learning experience due to a technical problem. Although the amount of data collected was small, the results show a promising indication for further explorations. We plan to use this study as the basis for another evaluation study testing the same hypothesis.

References

1. Mayer, R., *Multi-media Learning*. 2001: University of California.
2. Carroll, J., *Human cognitive abilities*. 1993, England: Cambridge University Press.
3. Baenninger, M. and N. Newcombe, *The role of experience in spatial test performance: A meta-analysis.* Sex Roles, 1989. 20(5): p. 327-344.
4. Milik, N., M. Marshall, and A. Mitrovic. *Responding to Free-form Student Questions in ERM-Tutor.* in *Proceedings of 8th International Conference on Intelligent Tutoring Systems.* 2006. Taiwan: Springer.
5. Ekstrom, R., J. French, and H. Harman, *Manual for kit of factor referenced cognitive tests.* 1997: Princeton.