Benefits of Handwritten Input for Students Learning Algebra Equation Solving

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Abstract. Building on past results establishing a benefit for using handwriting when entering mathematics on the computer, we hypothesize that handwriting as an input modality may be able to provide significant advantages over typing in the mathematics learning domain. We report the results of a study in which middle and high school students used a software tutor for algebra equation solving with either typing or handwriting as the input modality. We found that handwriting resulted in similar learning gains in much less time than typing. We also found students seem to experience a higher degree of transfer in handwriting than in typing based on performance during training. This implies that students could achieve farther goals in an intelligent tutoring system curriculum when they use handwriting interfaces *vs.* typing. Both of these results encourage future exploration of the use of handwriting interfaces for mathematic instruction online.

Keywords. Math learning, handwriting input, intelligent tutoring systems.

Introduction

Many schools throughout the United States now incorporate computers as a regular part of classroom instruction [1] and use intelligent tutoring systems (ITS) as supplements to traditional classroom instruction. Students primarily interact with these systems via keyboard-and-mouse (typing). *Output* modality (that presented to student) contrasts have been studied, including the use of animations, diagrams and talking heads (*e.g.*, [2]), but so far nothing has been reported on *input* modality (that generated by student) and learning. We believe that input modality is extraneous to the problem-solving process. This paper reports evidence in favor of handwriting-based interfaces with respect to learning in algebra equation solving. Past work has found usability benefits of handwriting for entering math on the computer [3]; our results show that handwriting input continues to have benefits when extended to a learning task.

1. Background and Motivation

While ITSes are beginning to explore natural language interfaces (*e.g.*, [4]), students still primarily interact with most systems via typing. This is partly because the technology available to most students is limited to keyboard-and-mouse. This is changing however, as students receive PDAs or TabletPCs in the classroom [1].

However, while advantages of pen-based input have been explored for the math domain in terms of usability measures [3], very little work has been done analyzing the effect of input modality on learning. One study has reported results comparing a variety of pen-based interfaces for solving geometry problems with students [5], but it does not provide a current practice (typing) control condition for comparison.

2. Experiment Design

Do students experience differences in learning due to the modality in which they generate their answers? We present two modalities in this paper: *typing*, in which students typed out the solution in a blank text box; and *handwriting*, in which students wrote the solution using a stylus in a blank space on the screen.

A total of 48 paid participants of middle and high school age participated; 50% were female. Most students had not used handwriting input on the computer before; two-thirds were very comfortable with typing. In spite of the wide range of ages, most participants were at about the same level of algebra skill based on pre-test scores. The problem-solving session used a Wizard-of-Oz design in which the students received feedback on their answer to each problem from the human experimenter. As a scaffold, students alternated copying a non-annotated worked-out example on the computer and solving an analogous equation while referring to the example (*c.f.*, [6]). We controlled for content rather than time. Dependent variables include the total time to complete all problems; time to solve each problem; number of attempts during training to either get the answer correct or move on (max=3); and change in score from pre-test to post-test.

3. Results and Discussion

Time on Task. We measured the total time students took to complete the problem-solving session. In general, typing students took about twice as long as handwriting students. We hypothesized that equations with 2D elements such as fractions would impact time only for typing; our results confirmed this. Repeated measures analysis of the average time students took *per problem* to solve problems with fractions (about half) *vs.* without fractions revealed a significant interaction between *modality* and *appearance of fractions* ($F_{2,36}=5.252$, $p<0.01$). Typing is slowed down more by the appearance of fractions, whereas there is no difference in the handwriting condition when fractions appear *vs.* when they do not. The time-speedup is not a direct measure of learning gain, but implies that students can advance farther in the curriculum when handwriting than typing.

Learning Gains and Efficiency. Despite taking about half the time, handwriting students learned just as much as typing students based on test scores. There was no significant difference between modalities in *learning gain* from pre-test to post-test ($F_{2,35}=0.293$, *n.s.*). This means that, even though students solved the same number of problems and took less time in handwriting than in typing, their learning as measured by performance improved about the same amount (mean=11.75%, stdev=17.34). This measure of learning is relatively coarse, and the standard deviation is high. In future studies we plan to analyze *how* the learning may have differed between conditions based on concept mastery. Although learning gains were of the same magnitude based on pre- to post-test scores, the fact that the time spent per condition was so different suggests that perhaps handwriting was a more *efficient* learning modality than typing. The concept of *learning efficiency* has been used, *e.g.*, in [6], to explore how students may be able to achieve similar levels of mastery but do fewer problems. This is an area we also plan to pursue in future work.

Transfer to Paper. One advantage we hypothesize to using handwriting is that it will allow a greater degree of transfer to paper than typing. We assessed level of transfer in this study by correlating the *pre-test score* and *post-test score* with *performance during training*. We hypothesized that the cases in which there was a *modality switch* (*i.e.*, writing on the pre-test to typing in the interface to writing on the post-test) should have a lower correlation in performance during training *vs.* the tests. We ran separate bivariate correlations of percent of problems solved on the first try during training and the *pre-test score* or the *post-test score*, grouped by condition. The Pearson correlation for typing was not statistically significant for either test (0.343, $p=0.275$ for pre-test; 0.320, $p=0.310$ for post-test), whereas handwriting was significant for both (0.613, $p<0.05$ for pre-test; 0.708, $p<0.01$ for post-test). Because handwriting does not involve a modality switch from training to testing, there is a higher degree of transfer. Performance during testing more closely matches performance during training when the modality of training is similar to that of testing.

4. Conclusions and Future Work

We have reported valuable early evidence in favor of handwriting-based interfaces for ITS in math, especially algebra equation solving. Students are able to solve problems twice as quickly when handwriting than typing by virtue of increased input speed, but they seem to learn just as much as their typing counterparts based on test performance. In addition, students seem to achieve a higher degree of transfer when using handwriting on the computer than when using typing. More work is needed to establish a theory on how to achieve better learning gains using an appropriate interface.

Acknowledgments

Supported by NSF Award #SBE-03554420 and Pittsburgh Science of Learning Center. Thanks: Tom Bolster, Noboru Matsuda, Chris Atkeson, Shelley Evenson, Sue Fussell.

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