Evaluation of Multimodal Input for Entering Mathematical Equations on the Computer

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Problem Statement

Current mathematical Cognitive Tutor (CT) lessons use keyboard-and-mouse, menu-based interfaces. Learning and using the interface could increase **cognitive load** and distract from the primary task: learning math. **Handwriting** is a more **natural input method** for mathematics and therefore, may help **improve learning** and increase transfer to paper. In addition, **spoken self-explanations** help learning more than written ones, so support for speaking math may be important.

Experiment Motivation

No prior work on advantages of alternate modalities over standard keyboard-and-mouse interfaces for the math domain.

What modality combination works for users?

Experiment Design

- Enter given equations in 1 of 4 modalities
- 7 equations per condition + 2 practice
- 48 participants – CMU students, diverse backgrounds and majors
- All novice users – like students using CT
- 4 conditions described below

| Condition	Description	Sample Equation	Sample User Input
Keyboard-and-mouse	Used keyboard and mouse with Microsoft Equation Editor	$\frac{1}{\|x\|+1} - \frac{x^2}{2} \le y$	$\frac{1}{/1/+1} = \frac{x^2}{2} \le y$
Handwriting only	Wrote on TabletPC Microsoft Journal program; no computer recognition of input.	$f(x) = 5(y_2 - y_1)$	$f(x) = 5(y_2 - y_1)$
Speech only	Dictated into microphone; no computer recognition or visual feedback.	$\frac{y-4}{y^2 - 5y + 4} = 9$	"y minus four over y squared minus five y plus four equals nine"
Handwriting-plus-speech	Both spoke and wrote either in series or in parallel (user choice); no recognition as above.	$\sum \left[c_k^2 - 2c_k - 10 \right]$	$\sum \left(c_k^2 - 2c_k - 10 \right)$ subscript k squared minus two c subscript k minus ten close parentheses"

Results of User Study of Modalities
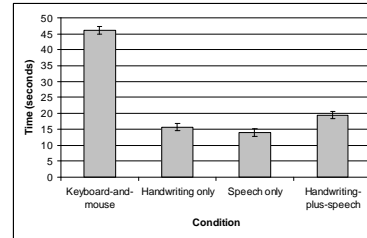
Average time in seconds per equation by condition. Error bars show 95% confidence interval.
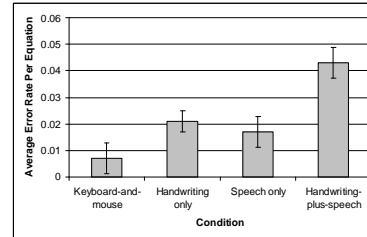
Mean number of errors per equation by condition. Error bars show 95% confidence interval.
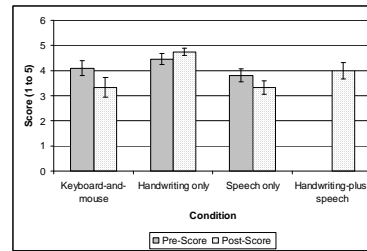
Pre- and post-test questionnaire rankings of each condition on a 5-point Likert scale (1 = low, 5 = high). Error bars show 95% confidence interval.

Current Findings

- Handwriting faster and better liked by novice users than standard keyboard-and-mouse interface.
- Handwriting-plus-speech faster and better liked than keyboard-and-mouse, too; not much slower than handwriting alone.
- Multimodality does not make task more difficult – no more errors in HW+SP than we would expect from HW plus SP.
- User errors in handwriting and in speech tend to be uncorrelated – should help **co-training**.

Future Work: Enabling Technology

- Development of language model to consider:
  - User speech does not differ significantly in surface features when speaking alone vs. when also writing.
  - User speech is highly ambiguous when expressing mathematics.
- Prototype implementation and user testing.
- **Co-training** to allow handwriting and speech engines to perform better in tandem than alone.

Phase I, II of PSLC Proposal entitled "A Multimodal Interface for Solving Equations"