Pen? Keyboard? Voice? Touch?

Interfaces prompt different styles of learning – or seriously undermine them.

For too long and with too little forethought we have handed our students technology to help them learn. New evidence reveals that certain types of technology actually create barriers to thinking, creating and problem-solving. While other types can enhance these same skills.

Computer interfaces and their impact on learning by Sharon Oviatt

About the author

Professor Sharon Oviatt is internationally known for her research in human-centered, educational, mobile, multimodal, and communications interfaces. She is President and Director of Incaa Designs (http://www.incaadesigns.org/). She also is the author of The Design of Future Educational Interfaces (Routledge, 2013), and The Paradigm Shift to Multimodality in Contemporary Computer Interfaces (Morgan Claypool, to appear in 2015).

More information?

For further reading on this topic, and technical details of the studies discussed, see The Design of Future Educational Interfaces by the author (2013, Routledge).

Computers can either enhance a student's ability to think, communicate and learn – or seriously undermine it.

Professor Sharon Oviatt draws on her extensive research, and that of other global experts, to examine the role keyboards and digital pens play in the process of thinking and learning.

The evidence is clear – the way students enter information into a computer makes a big difference. Schools and school systems need to understand that even with great teachers and excellent planning, computers can either enhance a student's ability to think, communicate and learn, or seriously undermine it.

The research also demonstrates that, too often, the limitations of technology lead students to modify or simplify their behavior, which limits their thinking strategies and behaviors to suit the technology. In many cases, a keyboard (on-screen or physical) might seem like the best tool for learning because it can reduce student effort (e.g., typing rather than handwriting), but research has found that typing can actually undermine the learning involved when more effort is expended.

Adding a precise, on-screen digital pen increases a student's ability to produce appropriate ideas, solve problems correctly, communicate and build on complex ideas, make accurate inferences about information, and learn during note taking and knowledge creation. The research shows this is one of the most important components in ensuring the suitability of a computer for learning.

Why it's so important to critically evaluate technology

Studies reveal a "Performance-Preference Paradox," or a mismatch between the interface people say they prefer (e.g., keyboard) and what best supports their performance (e.g., pen) [9]. We need stronger technology fluency curricula in the schools to improve students' ability to critically evaluate technology, and to self-regulate their use of it.

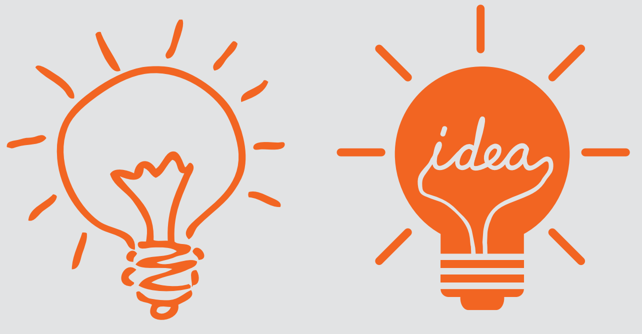
Since adults also have faulty intuitions about how computers influence their performance, evidence-based research is needed to guide selection and use of new technologies.

How do keyboards and digital pens stimulate or undermine students' ability to think?

Over the last decade, our studies and those of others have repeatedly shown that when students solved science and math problems, performance improved significantly when they used a pen interface rather than a keyboard. Using the pen, they produced 56% more nonlinguistic content (diagrams, symbols, numbers), which led to 9-38% improvement in performance [11; 12; 13]. Research showed that knowing a student's level of nonlinguistic communication predicted their ability to produce appropriate science ideas (Figure 1, top).

However, when the same students shifted to using a keyboard, they typed 41% more linguistic content, or words. In this case, analyses showed that expressing more words actually reduced students' ability to produce science ideas (Figure 1, bottom) [11; 12; 13]. This poor performance occurred in spite of the fact that high school students in these studies were millennials, who grew up using computers with keyboard input.

Using a digital pen, students produce...



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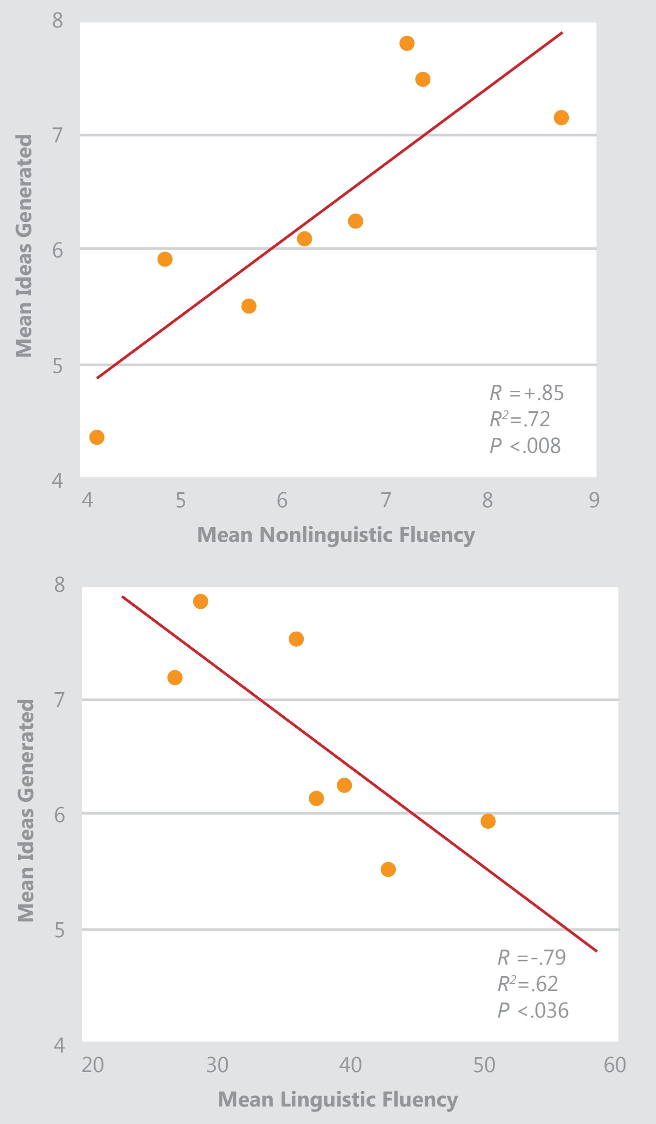


Figure 1. When students communicated more nonlinguistic content, they produced more science ideas (top); When they communicated more linguistic content, they produced fewer ideas (bottom).

How do interfaces influence language learning?

For many languages, as well as symbolic subjects (e.g., music, math, physics, chemistry, engineering), keyboards inhibit expression while pen interfaces easily support it. Keyboard interfaces present a major handicap for expressing 80% of languages that are not Roman alphabetic, including Mandarin and Hindi. These languages can be spatially intensive and include more linguistic units, which makes it difficult to map input to discrete keys.

In these cases, keyboard inefficiencies slow down students' input, increase cognitive load, and elevate task-critical errors [3; 7]. In one study, Japanese users completing the same tasks made 14 times more errors using a keyboard than a pen, demonstrating a far larger disadvantage than for English speakers [3]. As a result, pen and multimodal interfaces that include them are better options for students who use or study these languages.

Why do pen interfaces have cognitive advantages?

Pen interfaces are more expressively powerful than keyboard interfaces. They more accurately accommodate how we think. They can convey all types of representation, including words, symbols, numbers, and diagrams. When students are solving a problem, they can shift flexibly among them. For example, diagramming a genetics problem, then writing formulas with numbers and symbols to solve it, and summarizing their answer in words. In subjects like math, about 80% of what students write is nonlinguistic content, rather than words.

Pen interfaces are better suited for expressing spatial content than keyboards (e.g., diagrams, symbols), which is considered the foundation of thought [6]. In studies including our own, where students diagrammed before solving a problem, their science scores were 25-36% higher than when they did not [13]. In other research, students who used a pen interface constructed and viewed more diagrams, which improved their inference accuracy [13].

Pen interfaces enhance performance by minimizing cognitive load more than a keyboard interface. Work practice using a pen is already largely automated in our brains, so a pen interface can easily leverage these existing patterns. Interfaces that minimize cognitive load enhance average performance, and they also reduce the performance gap between low- and high-performing students [9].

Active writing with pen interfaces directly shapes brain functions. In research, children who drew letters, rather than viewing and naming them, performed better at recognizing them visually later. fMRI scans revealed that the motor act of writing increased neural activation in the brain area for visual letter discrimination [5], which facilitates word comprehension during reading (Figure 2) [1,4].

Figure 2. Writing activity changes neural basis of letter recognition and reading comprehension

Do these research results apply across different students and subjects?

The results summarized above have been replicated extensively across different students (ages, ability levels), subjects (science, math, language arts), types of cognition (problem solving, inferential reasoning, idea production), and computer hardware. In the area of language arts, students working on composition tasks produced 30-60% more ideas and better sentence coherence when using a pen compared with a keyboard [4].

In a major study by Mueller & Oppenheimer, students who took lecture notes with a pen actively summarized, paraphrased, and concept mapped – generative behaviors that lead to deep encoding, retention, and transfer of learned information [2; 8]. When using a keyboard-based laptop, they typed more words but their notes contained more verbatim copying, which is associated with shallower encoding and conceptual understanding [8]. Figure 3 shows that longhand writing with a pen had the largest positive impact on retaining and comprehending conceptual content, compared with using a keyboard.

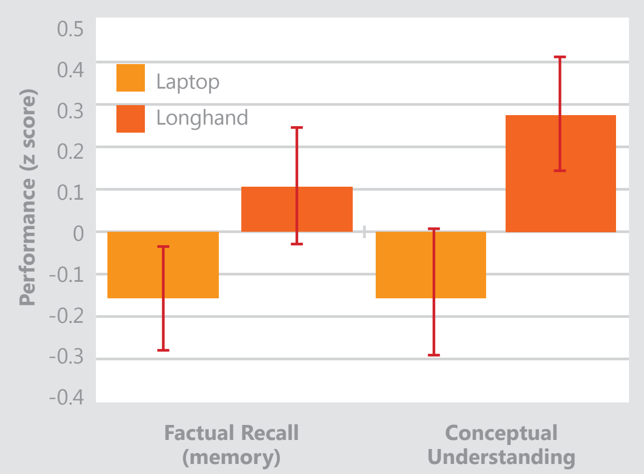


Figure 3. Performance on factual-recall versus conceptual-application questions as a function of writing with a pen or using a keyboard-based laptop while taking lecture notes, from Mueller & Oppenheimer.

Are all pen interfaces equally effective?

Students build comprehension by practising skills and communicating about ideas. Studies show that students communicate more using a computer than pen and paper. Since language is a carrier of thought, increased communication stimulates cognition. For example, in one study students made more diagrams, constructed them more correctly, and made more accurate inferences about the content displayed when using a digital over a non-digital pen (Figure 4) [13].

Often students use a keyboard-based computer together with supplementary pen and paper. However, these separate tools don't support integrating and reusing ideas as effectively as a digital pen. A digital pen supports distributing, sharing, archiving, annotating, revising and reusing content – including with remote collaborators.

Compared with interfaces that accept finger input on touch-enabled tablets, a high-fidelity digital pen supports more precise writing and elaboration of ideas. Students can construct complex diagrams that help them think about a problem, or add fine-grained annotations and marks to elaborate the meaning of existing text and visuals. Elaboration of ideas is required for conceptual differentiation, deeper encoding, and learning during K-12. A digital pen interface uses advanced technology at the hardware and software layer, including palm canceling so writing and touch are not confused and the experience feels more like writing on paper.

Pen input often is included in a multimodal interface with other input options, such as speech, touch, and keyboard. This type of interface is even more expressively powerful than pen input alone. It is a good candidate for supporting broad content creation, flexible collaboration (in person or remote), thinking and learning, and the development of effective pedagogy.

The more complex the problem that students need to solve, the greater the benefit of using high-fidelity pen input. Studies show that students spontaneously write more during harder problems, and they also increase their multimodal interaction [10; 14]. In one study, students drew 126% more diagrams as their math problems became harder [10].

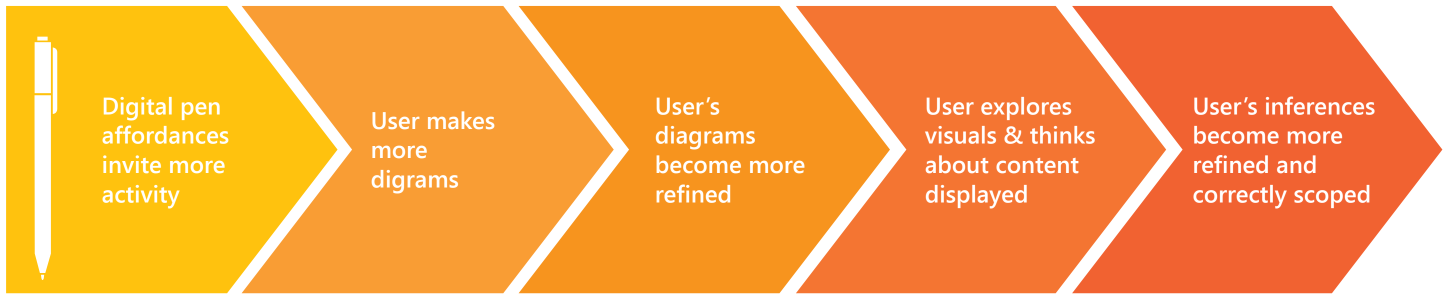
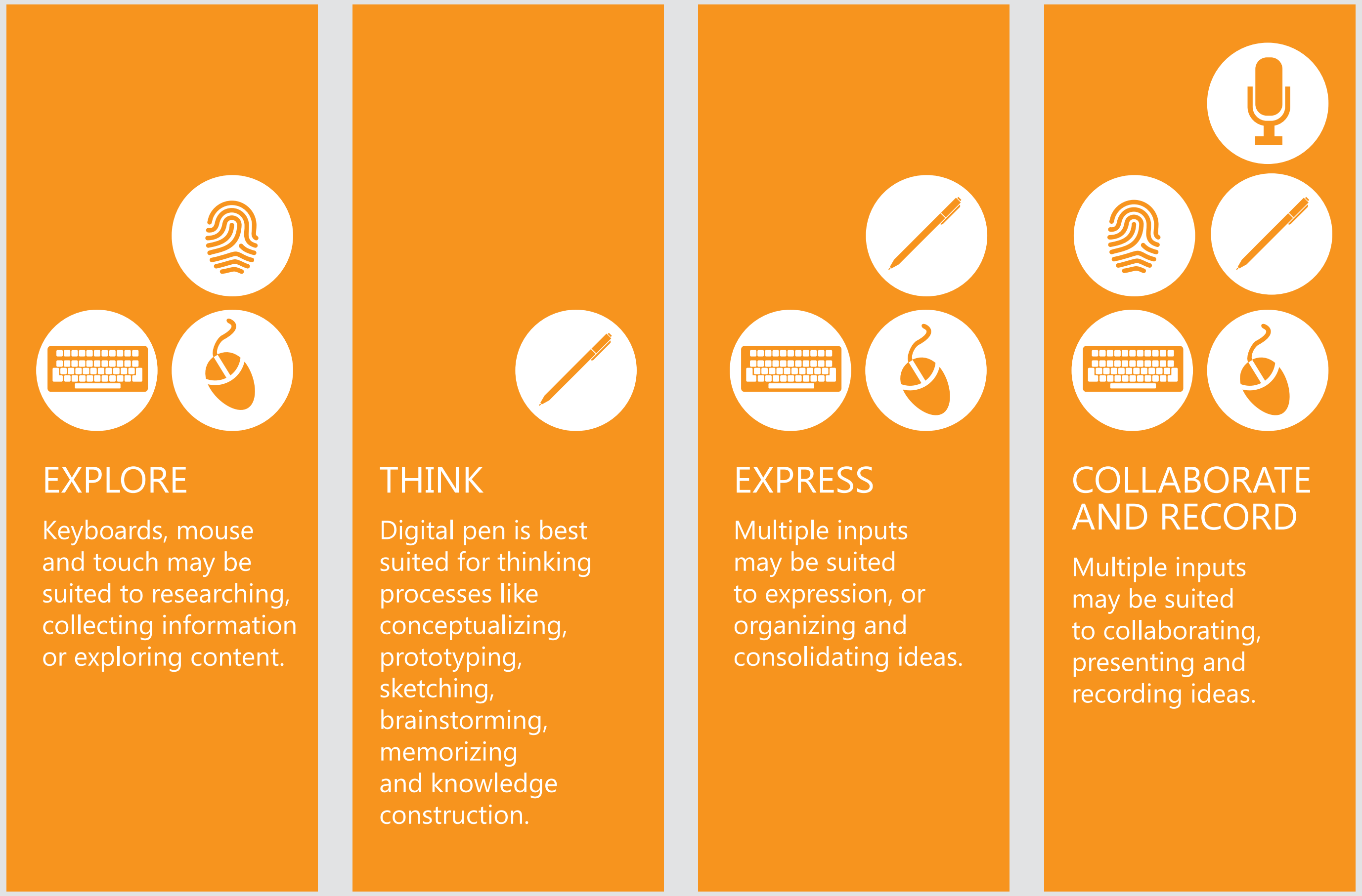


Figure 4. Chain of activity – ideation refinement; Pen interface elicited more total diagrams, correctly formed diagrams, and accurate inferences about displayed content

How do I choose interfaces?

In choosing educational interfaces, we should ask: What are the most promising thinking tools that stimulate high rates of exploratory activity, construction of "possible worlds," and productive innovation? One key is more expressively powerful input, so students can construct, refine, and think about content as they actively inquire and learn about the world.



A general guideline for interfaces to enhance common learning activities.

Key interface features and solutions important for learning

REQUIRED INTERFACE FEATURES	EXAMPLES OF PROMISING INTERFACE SOLUTIONS
1. Maximizes students' ability to create & refine rich content	Pen interfaces that support all representations, including sketching and writing in different languages Multimodal interfaces that support combining modalities with complementary strengths (speech & writing)
2. Encourages physical activity & communication during learning	Mobile interfaces support exploring physical environment during fieldwork Tangible interfaces support manipulating and exploring physical materials; for example, during lab work Speech, conversational & multimodal interfaces support inquiry, collaborating with peers, & remote group work Pen interfaces support exploring & thinking about content by sketching it
3. Well matched with content of learning task	Pen interfaces for math to express nonlinguistic content like symbols, diagrams & numbers
4. Well matched with students' language	Pen interfaces for languages that are not Roman alphabetic to express spatial properties & large number of linguistic units
5. Well matched with students' ability level	Pen interfaces minimize cognitive load for weaker students and avoid expanding performance gap with higher-performing peers
6. Well matched with cognitive requirements	Pen & multimodal interfaces for extended problem solving, reasoning, composition & "thinking" tasks Keyboard interfaces for text editing, email, web search and mechanical tasks
7. Minimizes cognitive load by supporting simplicity & lack of distraction	Any interface that minimizes focus on formatting or appearance of work, rather than content Any interface that minimizes multi-tasking on other activities that distract or encourage avoiding effortful learning

Table 1. Checklist of Interface Features Important for Learning

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