

# Chapter 2

## Computer Interfaces Can Stimulate or Undermine Students' Ability to Think

Sharon Oviatt

**Abstract** Computer input capabilities, such as a keyboard or pen, substantially influence basic cognitive abilities, including our ability to produce appropriate ideas, solve problems correctly, and make accurate inferences about information. Compared with keyboard interfaces, computer input tools that can be used to express information involving different *representations, modalities, and linguistic codes—or expressively powerful interfaces*—can directly stimulate human thought and performance. This chapter summarizes how and why the quality of a computer interface matters. It also discusses implications for establishing a new generation of digital tools that are far better at supporting thinking and reasoning, with special implications for designing more effective educational technologies.

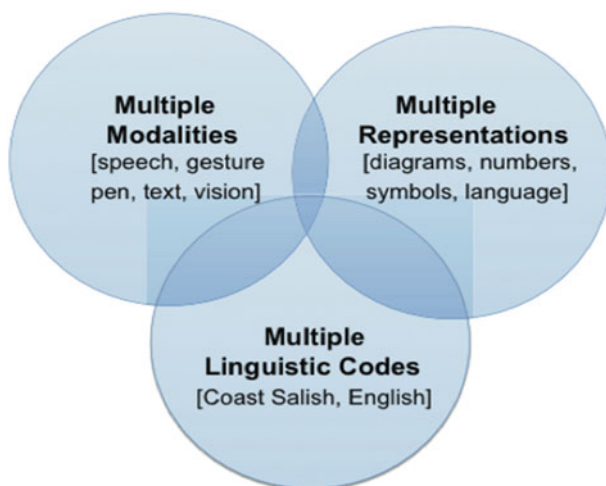
### 2.1 Introduction

During the last decade, mobile devices that incorporate new input modes have eclipsed keyboard-based graphical interfaces as the dominant computer interface worldwide [20]. There likewise has been a shift toward expanding users' options for entering input to a computer, including using a digital stylus, gestures, multi-touch, speech, gaze, facial expressions, a multitude of sensors, and multimodal combinations of these input modes. These changes are expanding users' expressive power to create and manipulate digital information. They also are making it possible to select an input tool that is best matched for a particular task. These changes in computer interface design are enabling critical improvements in the design of new educational technologies.

In a very basic sense, any high-quality educational interface must be a rich communications interface, as illustrated in Fig. 2.1. From a communications perspective, expressively powerful interfaces support users' ability to convey information involving different modalities, representations, and linguistic codes. Since language is a carrier of thought, more expressively powerful interfaces are capable of directly and

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**Fig. 2.1** Richly expressive communication interfaces that support multiple modalities, representations, and linguistic codes (copyright Lawrence Erlbaum Assoc., *source* [17] used with permission)

substantially stimulating human cognition. The aim of research on designing more expressively powerful computer interfaces is to develop a new generation of far more effective thinking tools [18].

## 2.2 Why Pen Interfaces Support Thinking and Learning

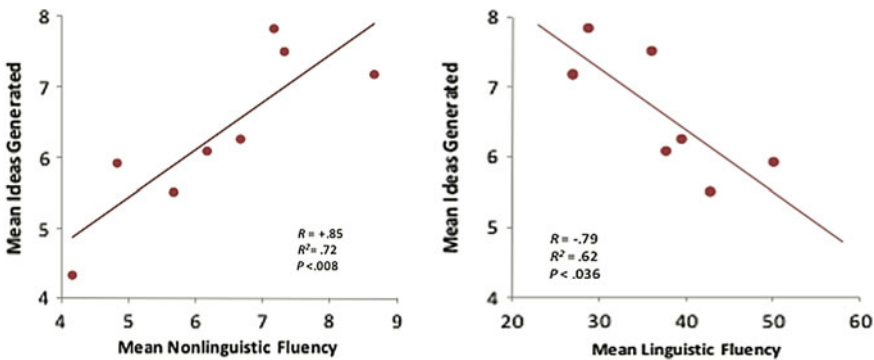
Educational interfaces need to be designed as rich communications interfaces that increase students' engagement, communicative activity, and related thinking and reasoning in the domains about which students are learning. One reason that pen interfaces are a promising input tool for facilitating active learning is that they support expression of a broad range of linguistic and nonlinguistic representational content, including numbers, symbols, diagrams, and words (Fig. 2.1, right side). They also provide a single input tool for easily shifting among different types of representation while working on a problem. For example, when given a geometry word problem, a student may first diagram the relation between objects, then generate algebraic expressions using symbols and numbers, and finally summarize their calculations using linguistic content. Such a flexible flow of expressions helps to preserve students' focus of attention and working memory resources while solving a problem. In an important respect, a digital pen that facilitates casting information in different representations, and translating among them, also supports perspective shifting in thinking about a problem.

Pen interfaces and the durable ink trace they create help students to view information, group related information, and retain it in memory—which facilitates reasoning about new domain content. The ability to use a pen to sketch or diagram information is considered to be a foundation for thinking and reasoning [8]. Diagramming objects and relations facilitates a more precise and elaborated understanding of the information depicted, and supports insight. It also deepens and improves students’ transfer of learning to new contexts [15, 23, 24].

### 2.3 How Pen Interfaces Influence Communication and Cognition

Recent research has revealed that the same students accomplishing the same tasks communicate more when using a digital tool than an analogous non-digital one [22]. That is, digital tools elicit more total communicative fluency. This research also demonstrated that different input capabilities, such as a keyboard versus digital pen, have affordances that prime qualitatively different types of communicative content. Students expressed 44 % more nonlinguistic representational content (e.g., numbers, symbols, diagrams) when using pen interfaces. In contrast, when they used a keyboard the same students now expressed 36 % more linguistic content (e.g., words, abbreviations) and also more complete sentential constructions. These differences in communicative fluency generalized across tasks involving different types of thinking and reasoning, and were replicated in both low- and high-performing students [22].

These differences in communication pattern corresponded to striking changes in students’ cognition. In particular, when students used the digital pen and wrote more nonlinguistic content, they generated 36 % more appropriate biology hypotheses. The regression analysis shown in Fig. 2.2 (left) reveals that knowledge of individual



**Fig. 2.2** Regression analysis showing positive relation between nonlinguistic communicative fluency and ideational fluency *left*; Regression showing negative relation between linguistic communicative fluency and ideational fluency *right* (copyright ACM, source [22] used with permission)

students' level of nonlinguistic fluency when using different interfaces accounted for 72 % of all the variance in their ability to produce appropriate biology hypotheses [22]. That is, interface support for expressing nonlinguistic content predicted most of the variance in students' ability to generate appropriate scientific ideas.

However, when the same students used the keyboard interface and communicated more linguistic content, the regression analysis shown in Fig. 2.2 (right) indicates that they experienced a substantial drop in science ideation. In this case, knowledge of students' level of linguistic communication had a negative predictive relation with their hypothesis generation. It accounted for 62 % of the variation in students' *inability* to produce science hypotheses.

In other tasks involving science problem solving, students using a digital pen rather than keyboard interface made more structured diagrams and elemental "thinking marks". Thinking marks are informal pen marks that students make, for example on text or visuals when they are preparing to solve a problem, in which they count, select, order, group, label, and mark up relations between problem elements so they can understand what the problem means. This type of elemental ink marking occurs at substantially higher rates in low-performing students, and it has been associated with 24.5 % more correct problem solutions [22]. Likewise, a higher rate of constructing diagrams in this research was associated with 36 % more correct problem solutions.

These results emphasize that pen input facilitates active marking, whether in the form of structured diagrams or more elemental ink marks. In this regard, pen interfaces are effective in helping students to externalize their thinking in spatial forms. Pen interfaces also lower the barrier for both low- and high-performing students to become actively engaged trying to solve problems. The spatial constructions that students produce in turn help them to understand and solve problems with substantially improved success.

## 2.4 Limitations of Keyboard Interfaces for Thinking Tasks

Keyboard interfaces were never designed as thinking tools. In fact, they constrict the representations, modalities, and linguistic codes that can be communicated when using computers [18]. For example, keyboards support textual information, but not multimodal transmission involving sketch, writing, speech, gesturing, body language, and other rich modalities. In addition, they support expressing language and numbers, but are poorly designed for constructing spatial representations like diagrams and symbols.

Keyboard interfaces also present a major handicap for expressing world languages that are not Roman alphabetic ones, which includes about 80 % of languages such as Mandarin, Hindi, and Japanese. Such languages can be complex, spatially intensive (e.g., diacritics, logograms), and include a large number of linguistic units that require many-to-one mappings with each key [4, 9]. Estimates indicate that less than 15 % of the world's 6,800 languages are supported by keyboard Unicode mappings, so most languages are not used on the Internet or computers at all [11, 25]. For all

of the above reasons, keyboard interfaces are better suited for conducting relatively mechanical tasks, such as text processing, emailing, and searching the Internet. They are less well suited for completing extended thinking and reasoning tasks.

## 2.5 Neuroscience Findings on Writing Versus Typing

In the course of evolution, people's use of new physical tools has shaped related brain functions [27]. For example, the advent of stylus implements 6,000 years ago stimulated writing and reading skills that launched literacy and modern education. The manual action of writing symbols, and then reading them, led to structural specialization of the brain region for visual object recognition [3, 14]. The visual cortex reorganized in response to reading activity, creating the visual word form area (VWFA) that now supports literacy.

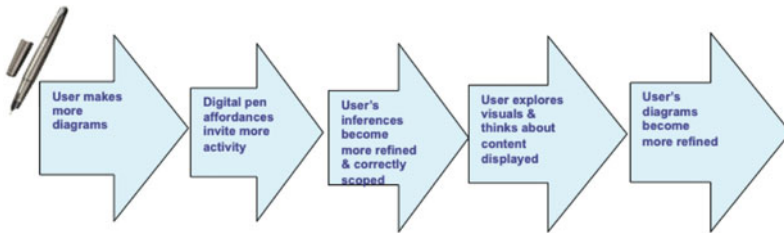
In both children and adults, actively writing letters has been shown in fMRI studies to increase brain activation to a greater extent than passively viewing, naming, or typing them [6, 7, 10, 12, 13].

Compared with typing, writing letter shapes also improves the accuracy of subsequent letter recognition, a prerequisite for successful comprehension and reading. These studies have been replicated in children learning their first language, and in adults learning a second one. They also have been replicated in Roman alphabetic languages (e.g., French, English) and in Asian languages that are not Roman alphabetic ones (e.g., Bengali, Mandarin).

This research has emphasized that physical activities directly prime perception and comprehension of related content. This action-perception loop represents an Embodied Cognition theoretical view of learning [1]. Writing complex letter shapes creates a long-term sensori-motor memory, which is part of an integrated "reading neural circuit" [16]. This writing activity leads to a more elaborated and durable ability to recognize letters later when we read them. Further research has documented the impact of writing versus typing on spelling and other aspects of written composition, as well as on the content of ideas expressed during written composition [2, 5].

## 2.6 How Digital Tools Can Facilitate Thinking

As introduced in Sect. 2.3, people communicate at higher levels when using a digital tool than an analogous non-digital one. In one study, the same students solved the same problems about science, but used an Anoto-based digital pen and paper for half their tasks, and a regular pen and paper for the other half. The physical tools that students used (i.e., pen and paper) looked nearly identical in both cases, but they understood that the digital pen was a small computer that could transmit and process their input. Perhaps surprisingly, when using the digital pen to complete inference tasks, students drew more total diagrams and more correct Venn diagrams. They also



**Fig. 2.3** Chain of activity—ideation refinement, in which pen interface elicited more diagramming, more correctly formed diagrams, and more accurate inferences about the displayed content than an analogous non-digital pen (copyright ACM, source [22], used with permission)

made more accurate inferences about the related domain content [22]. When using the digital pen interface, compared with the regular pen, students constructed and visually explored the diagrams they had made, which stimulated thinking about the content and a higher level of inference accuracy.

The summary in Fig. 2.3 illustrates this enhanced chain of activity-ideation refinement. One implication is that non-digital materials (e.g., pen and paper) are not more optimal for supporting education than digital tools. In the research described, a digital pen analogue of non-digital materials elicited a higher level of communicating, which facilitated students' cognition and also improved their performance.

## 2.7 Students' Lack of Metacognitive Self-Awareness About Computer Interfaces

Although students often are adept at operating computers procedurally, many studies have shown that they are unaware of when and how to use computers to best support their own performance. This research has uncovered a "*Performance-Preference Paradox*", or a mismatch between the computer input tool that students say they prefer to use and the one that best supported their performance during the study. During these studies, students first had the opportunity to use a variety of different interfaces. Then they were interviewed about which interface they preferred to use if they had to perform their best on a high-stakes Advanced Placement exam. All studies uncovered a mismatch between students' stated beliefs and the interface that actually supported their performance the best [19, 21, 22].

For example, students often reported a preference to use a keyboard-based interface, even though their performance dropped a whole grade point when using it compared with alternatives like a pen interface. Longitudinal studies have revealed that the Performance-Preference Paradox becomes more accentuated over time, rather than attenuating as students gain experience with different interfaces. The Performance-Preference Paradox has been observed in both high- and low-performers, although

it is more prevalent in low-performing students whose meta-cognitive skills are weaker [26].

New technology fluency curricula in the schools could improve students' ability to evaluate technology critically and self-regulate their use of it. When technology classes are taught, too often they focus on basic procedural skills involving the use of elementary applications like Excel, rather than critical evaluation of technology, its features and design, and its impact on performance. The aims of technology fluency training should include dispelling unrealistic expectations about computer technology, and improving students' judgment, self control, and critical thinking skills so they can use it more productively.

## 2.8 Conclusions

To stimulate thinking and learning in students, high-quality interfaces are required that can support complex content creation activities, including students' ability to construct diagrams, complex letter shapes, and other forms related to curriculum goals. Pen interfaces, and multimodal ones that incorporate pen input, are especially good candidates for achieving this objective. Such interfaces are more expressively powerful than the keyboard, because they support people's ability to communicate information involving different representations, modalities, and linguistic codes. As discussed in this chapter, interfaces with these properties can directly stimulate human thought and performance, and they are especially well suited as educational technologies. Other promising directions for developing educational technologies include tangible interfaces, conversational interfaces, mobile interfaces, and hybrid interfaces that combine these properties. In the future, one major challenge will be to develop new technology fluency curricula that can teach students to critically evaluate technology, and also to self regulate their use of technology tools to better support their own performance.

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