

Digital Pens in Diagram Research

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Abstract. In cognitive science, diagrams are often treated as tools for thinking. They may be both reflective of, and active in, our cognitive activities. Unfortunately, our tools for analyzing diagram construction are limited and often difficult to scale. In this brief I will introduce a potential line of research utilizing digital pen systems to explore the production of diagrams. I will discuss the affordances of digital pen technologies and how these might be utilized in diagram research. Finally, I will discuss potential research questions and directions for future work.

Keywords: digital pens, observation, spontaneous production, diagram construction, ethnography, student productions, visual content analysis

1 Analysing Diagram Construction

While the topic of diagram comprehension has received attention in cognitive and learning sciences for some time (see [3]), as Manalo and Ueseka note [4], less attention has been paid to the process of constructing diagrams. Yet just as we are as interested in the process of decision-making as we are in the resulting decisions, so too should we be as interested in the construction of diagrams as we are in the resulting representations.

In previous work, researchers have examined the quantity [4], spatial arrangement [5], and type [1, 5] of information contained in diagrams compared to other representational forms (e.g. text) in differing contexts (e.g. recording for ones self, communicating with others). One aspect that is largely neglected, however, is the timing of constructing a diagram. *What marks does the individual place first on the page?*

One can imagine numerous ways that the temporal dynamics of diagram construction might differ—between individuals, with respect to expertise, diagram type, and even communicative intent. There may be differences in the duration of time allocated to different elements in the diagram, which might be indicative of attention: areas of expertise, or possibly confusion. There may also be differences in the sequence of drawings: which marks are recorded first, and second, and so on, and how these marks are related—by semantics or by features. In order to address such questions we require more robust and scalable methods for observing and recording individuals in the process of constructing diagrams.

2 Digital Pen Technology

Digital pen systems seek to address the divide between analog and digital affordances in information storage and retrieval. Many individuals prefer the convenience and feeling of writing (or drawing) with paper and pen, while preferring the persistent storage, portability, and searchability of digital archives. Digital pen systems offer "the best of both worlds", affording users the familiarity of pen and paper along with digital storage and searchability [7]. A number of pen systems are commercially available for less than \$200USD, including the LiveScribe (based on Anoto technology), Neo N2, and Equil pens. The first two feature a small on-board camera which captures pen marks on special grid paper, transmitting the information to a mobile device. The latter operates without special paper by utilizing a dedicated infrared camera mounted on the paper of choice.

At a minimum, the pen systems record and store the timing and position of each stroke of the pen. This means that in a diagram construction exercise, a researcher can access a digital copy of the resulting diagram without having to manually collect and scan paper drawings. In addition, the timing data allows researchers to "replay" the construction of the drawing like a video. Some systems also record audio, which might be useful for think-aloud or "explain to your partner" protocols. The resulting data can then be processed in software such as Chrono-Viz [2] which support interactive navigation and annotation of multiple streams of time-synchronized data. Some pen systems are also capable of exporting content to vector image files. These files can then be processed with image recognition libraries that (depending on diagram content and available libraries) may serve to automate components of the content analysis process.

Importantly, digital pen systems offer higher fidelity writing experiences than those of tablet-based systems, at substantially lower cost. This allows researchers to scale simultaneous recording of multiple participants (limited by number of pens), while retaining the fidelity of the paper-pen experience. In addition to analysis of the final product, researchers will also have access to the temporal dynamics of the drawing process. Pen systems have previously been deployed to improve workflows in cognitive ethnography[7, 6] and computer-supported collaborative sketching [8].

3 Current and Future Work

In aggregate, studies on production of diagrams have shown how the content of external representations can reveal the structure of underlying thought [5]. Analysis of how these representations are constructed, therefore, may offer insight into the processes by which internal representations are transformed into external models of thought. In the coming years, I intend to explore the temporal dynamics of diagram construction by utilizing digital pen systems in my data collection workflow.

In particular, I am interested in exploring how the order in which a diagram is constructed might indicate an individual's level of knowledge. *Does taking longer*

to draw a subset of diagram elements indicate a paucity of understanding? Or, if accompanied by greater detail, does this indicate certainty or confidence? In either case, can heuristics be defined to computationally identify these areas? Such a system might prove to be a powerful aid to instructors using diagrams to assess student knowledge and diagnose errors in understanding.

I am also interested in exploring what the order in which diagrams are constructed can tell us about the structure of the underlying knowledge. *In a process-diagram, does one first depict the entities, and then the processes that act upon them? Or does one draw each element of the diagram in the order the depicted process is expected to unfold in time?* What might these temporal dynamics tell us about the way the concepts are organized, accessed and represented in the mind? In turn, what will these findings suggest about how we should design tools to support communication and learning?

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