Human-information interaction: An emerging focus for educational cognitive tools

Paul Parsons¹; Kamran Sedig²

¹ Department of Computer Science; The University of Western Ontario, Canada.
² Department of Computer Science, Faculty of Information and Media Studies; The University of Western Ontario, Canada.

Educational cognitive tools are interactive, computer-based tools that augment one’s mind to facilitate learning. Examples of these include interactive mathematical software, interactive physics simulations, and interactive biology visualizations. While using these tools a learner’s mind becomes coupled with the tool, forming a cognitive system, such that cognitive processes are distributed across this system. The coupling of this system is strong, as the cognitive tool actively contributes to information-processing tasks by serving a representational function. By representing information at their interface, cognitive tools provide learners with access to information. Additionally, as cognitive tools are interactive, learners can perform actions upon the represented information. These actions serve an epistemic function and can be considered part of thought itself. Epistemic actions are basic actions that a learner may perform on any interactive cognitive tool and thus are technology-independent. Therefore, there is a need for designers and educators to focus on the ways in which learners use, interact with, and think with information, independent of the technology that is mediating the interaction. This chapter examines the dynamics of human-information interaction as an emerging area of interest, the implications for educational cognitive tools, and some of its emerging research efforts.

Keywords cognitive tool; human-information interaction; epistemic action; distributed cognition; interactivity; learning

1. Introduction

Humans have been creating and using technology since before recorded history. Technology can be broadly defined as the creation or use of artifacts, tools, and procedures to assist in achieving a goal. Such artifacts, tools, and procedures have different functions—some assist our bodies, and some assist our minds. The latter type may be referred to as cognitive tools. Similar to how a hammer augments one’s physical abilities, a cognitive tool (CT) augments one’s mental abilities, facilitating the performance of tasks that could not be done easily without the tool. Examples of such tools include language, mathematics, scrolls, abacuses, slide rules, calculators, and computers. As the focus of this volume is on current and emerging technological efforts, the definition of CTs in this chapter is restricted to interactive, computer-based tools that augment one’s mental abilities. More specifically, this chapter is concerned with educational CTs—that is, interactive, computer-based tools that augment one’s mind to facilitate learning. Examples of these include interactive mathematical software, interactive physics simulations, and interactive biology visualizations. In addition to augmenting one’s mind to facilitate learning, CTs have another necessary characteristic: maintaining and displaying information. That is, cognitive tools mediate access to information. As CTs are inherently interactive, they allow learners to interact with information to perform cognitive activities such as reasoning and problem solving. Many of the ways in which learners interact with information—and the epistemic benefit of the interactions—are consistent across all types of CTs. Therefore these interactions are not dependent upon the technology; rather, the function of the technology is to mediate interaction with information. The emphasis that has been placed on interaction with technology is insufficient for providing a strong basis to guide the design of educational CTs, especially as new technologies are developed and current ones become less prevalent. The design and analysis of future educational CTs requires careful consideration of the ways in which humans interact with information for the purpose of learning.

Many researchers across domains have recognized the need to focus on human-information interaction (HII) as a distinct area of investigation. A focus on HII can motivate the creation of educational technologies that are based on an understanding of how the mind uses and interacts with information to perform cognitive activities. As HII is technology-independent, its characterization is resilient to change, and thus can be applied to emerging and future technologies such as interactive table-top computers, tablets, and virtual-reality environments. This is important, as the pace of technological change can render technology-dependent techniques obsolete. This chapter examines the dynamics of human-information interaction as an emerging area of interest, the implications for educational cognitive tools, and some of its emerging research efforts. To this end, we draw upon research from the cognitive, information, computer, and learning sciences. The rest of the chapter is structured as follows. The next section examines recent changes in models of human cognition, the role of actions in cognition, and the implications for educational CTs. The subsequent section describes some current and emerging research efforts in HII, and the final section provides a summary and some future research directions.

¹ Cognitive tools have also been referred to as mindtools, cognitive technologies, and/or technologies of the mind

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2. Dynamics of human-information interaction

2.1 New models of cognition

In order to discuss learning with technology, one must first be concerned with the general question of how learning happens, and then with the more particular question of how learning happens with technology. As learning is fundamentally a cognitive process, it is useful to examine some recent changes in models of human cognition and their relation to learning. Over the past half-century, cognitive science has departed from the model of humans as discrete information-processing systems. Cognitive scientists now generally subscribe to a more holistic model of humans as situated actors within an environment that strongly influences their cognitive processes [1-7]. This environment includes one’s body, the space surrounding one’s body, and people, artifacts, and other objects external to the mind. In this new model of cognition the unit of analysis of cognition as being solely within the head is superseded to also include all external elements that participate together in a cognitive process [6,8]. One of the outcomes of these changing models of cognition is the theory of distributed cognition, which proposes that cognition is distributed across the mind and the external environment [2,6]. That is, the mind and elements within the environment form a cognitive system that has greater cognitive processing abilities than the mind alone. These elements can be almost anything in the external environment, including the bridge of a ship [2], an airline cockpit [9], or a pen and paper [10, 11]. From this perspective, cognitive processes are emergent phenomena that take place across these elements in the external environment and the mind. This recognition of the distributed nature of cognition has led researchers to suggest that the mind without the help of external aids is actually quite weak (e.g., [3]). It is important to note that these new models of cognition are not just terminological changes, but rather, they effect changes in the methodology of scientific investigation and the explanatory methods of cognition [12]. Additionally, these new models of cognition apply to all cognition rather than any specific type of cognition [8]. As such, they have created a fundamental shift in attitudes towards learning and education. For instance, Salomon [6] has noted, “serious consideration of the notion of distributed cognition opens up a whole range of questions and suggests a long list of provocative implications for education” (p. xv).

2.2 Epistemic actions

One of the consequences of the distributed nature of cognition is the role that our bodies and actions play in cognition. For example, one often performs physical actions on their external environment that serve a cognitive function. Kirsh and Maglio [13] refer to these as epistemic actions. They contrast epistemic actions with pragmatic actions—actions that one performs on the external environment to achieve a physical goal. For example, one opens a door to leave the house or cuts open a package to see the contents. These are actions being performed on the external environment to achieve a physical goal. Examples of epistemic actions, on the other hand, include handling and rotating an object to make sense of it, and rearranging blocks to think about fractions. These actions are not pragmatic, as they are not performed to achieve a physical goal. In fact, it is often the case that epistemic actions seem physically disadvantageous. For instance, one may move a chess piece to a new location on the board, only to move it back to the original location and move another piece instead. Such an action is pragmatically disadvantageous, as it requires extra physical effort than was needed to make the move. However, when viewed from an epistemic perspective, the action makes sense, as it facilitated an epistemic goal—to simplify the problem space in the mind of the player. Clark and Chalmers [12] argue that such actions are so fundamental to cognition that they should not be viewed simply as actions, but as being part of thought itself.

Researchers have demonstrated the existence and utility of epistemic action in the context of education. Kastens, Liben, & Agrawal [14] have observed that students and geologists perform epistemic actions—sometimes going to “considerable effort” (p. 204) to perform them—in order to form a mental model of a geological structure. For instance, students would remove objects from their field of view to decrease their perceptual load, move objects closer together to compare and contrast their attributes, and rotate objects to replace the difficulty of mental rotation, often requiring physical effort that was not pragmatically advantageous. Martin & Schwartz [15] performed five studies in which they examined how epistemic actions could facilitate the learning of fraction concepts in children. What they found was that children could solve problems when they could move pieces (i.e., perform actions), but not when they could only look at the pieces. In addition, the children often moved the pieces much more than was necessary to solve a problem—an other observation of pragmatically disadvantageous, but epistemically advantageous, behavior. Their study results are also consistent with the view of [12] that epistemic actions are part of thought itself, as they conclude that the benefit of action was “due to distributed learning and not simply due to off-loading known operations to the environment.” ([15], p. 602). As the ways in which learners interact with their environment have significant effects on cognitive processes, it is necessary to investigate the role of distributed cognition and epistemic actions for educational CTs.
2.3 Implications for educational CTs

As a learner’s cognition is distributed across their mind and elements in the environment (e.g., CTs), a CT is integrated into the cognitive processes of a learner, and has a constitutive role in shaping cognition [16]. Clark and Chalmers [12] suggest that the performance of epistemic action creates a coupled cognitive system, involving the mind and the external element that is the object of an epistemic action. Brey [17] extends this notion and makes a distinction between weakly coupled and strongly coupled systems. Systems are weakly coupled when external elements of the system are mere objects of epistemic actions, and are strongly coupled when external elements of the system actively contribute to information-processing tasks by serving a particular representational function. For example, tying a string around one’s finger as a reminder of something creates a weakly coupled system, whereas using the string as a measurement device to perform calculations creates a strongly coupled system. In the latter case, the string is contributing to information-processing tasks (e.g., mental calculations) by representing a unit of measurement (e.g., 1 cm). CTs, by forming strongly coupled systems with learners, can act as partners in learning [18], can extend the ability of the mind [19], and have the potential to reorganize learners’ thoughts and facilitate deeper understanding of information [4].

CTs form strongly coupled systems by actively contributing to information-processing tasks by representing and allowing access to information. More precisely, it is the interface of a CT that represents and allows access to information. The New Oxford American Dictionary defines interface as “a point where two systems, subjects, organizations, etc., meet and interact” [20]. As such, the interface of a CT is the place in which the mind of a learner meets information—its epistemic locus [17, 21]. In fact, it is only through representations that learners have access to information in CTs. Due to their malleable nature, CTs allow learners to interact with information through representations at their interface, facilitating the performance of different perceptual and cognitive operations [22].

Through interaction, the expressiveness of representations can be extended and enhanced, by allowing the dynamic explorations of the information that is being represented. By allowing interaction, CTs can: extend the memory, interpretation, and other higher-order cognitive abilities of learners [17]; affect how learners construct knowledge and promote deeper processing of information [23]; and, influence and change the very way learners think and work with information, thus changing the nature of cognition and human mental activity [17, 24]. The interactive nature of CTs allows learners to perform numerous epistemic actions upon representations of information and to receive some response back to interpret. This effectively allows learners to engage in a discourse with information, such that they can explore the information by posing questions or formulating hypotheses, acting upon the represented information, and receiving some answer back from the CT.

2.4 Human-information interaction rather than human-technology interaction

Whether learners are exploring geometric shapes, timelines of history, or the structure of a cell, the function of a CT is to represent information and to allow interaction with the represented information. That is, CTs mediate learners’ access to information and allow the performance of actions upon the represented information. The highly interactive nature of CTs allows for a discourse with information that has hitherto not been possible with previous static cognitive tools. Much of the focus on the use of computers in education thus far has been on the technology itself—for example, hardware, software, input and output devices, and interaction techniques. As important as these are, there is a fundamental component that is missing—an understanding of the ways in which we use, interact with, and think with information, independent of the technology that is mediating the interaction. For instance, one may perform an epistemic action on a desktop computer, a touch-based tablet, or a virtual reality environment. In all three cases the implementation is different, but the action and the epistemic benefit is the same. That is, the learner is performing the same conceptual action upon the represented information in each case. As such, for the effective design of educational CTs, there needs to be a principled investigation of how learners interact with information, rather than a focus only on the technology itself.

When designing CTs, if their fundamental aspects and components are not recognized and taken into consideration systematically, then they may not achieve their pedagogical goals, and can even have negative effects on learners [16]. Research on HII in the context of educational CTs is a young area. Consequently, there is no existent lucid and comprehensive characterization of the components of HII. Numerous questions regarding HII in the context of learning remain unanswered in the scientific literature. For instance, what are the fundamental epistemic actions? What are the respective benefits of each action for learning? What are the ways in which epistemic actions can be operationalized, and what are their effects on learning? The next section discusses some of the emerging research efforts in HII in general, and then discusses some attempts to create frameworks and taxonomies that characterize the components of HII.

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1 All information has to be given some representational form. For instance, information about a chemical compound could be represented with an image, a table of data, an abstract diagram, a plot, or written natural language. The representation is what communicates the information to the learner and it is only through the representation that a learner perceives and has access to information.

2 The characterization of information here is broad and comprehensive, and can refer to both concrete sources of information, such as a cell or a galaxy, and abstract sources of information, such as mathematical or philosophical bodies of information. The important point is that any object of learning is a source of information, and in CTs these sources must be represented to provide learners with access to the information.
3. Emerging research efforts in human-information interaction

3.1 Recent focus on HII as a distinct area of research

Researchers in many disciplines, such as information science and personal information management [25, 26], communication [27], and HCI [25, 28, 29], have recently recognized the need for a focus on HII as a separate area of study. For instance, Raya Fidel, from the University of Washington, states: “the relationship between HII and the C[omputer] is a two-way street. The operation of HII indeed depends on [the] C[omputer], but its conceptual side has to be independent of it.” ([25], p. 67). Michael Albers, from East Carolina University, suggests: “a design which ignores the intricacies of HII risks poor usability, poor communication of its ideas, and poor human performance in the situations for which the information is provided.” ([27], p. 118). And Stuart Card, from Xerox PARC, claims: “it is useful to face the facts directly and to develop a new body of knowledge around human information interaction, concerned with how to design machines and environments in which people interact with information” ([25], p. 66). These statements highlight the emerging realization, across disciplines, of the need for a focus on HII as a distinct area of research.

Although these statements come from different domains, they are still applicable to education and the design of educational CTs. However, while much research from these other domains can be useful for education, it is important to make a distinction between educational CTs and other types of CTS. For instance, the principles underlying the design of a financial analysis tool, which functions to make reasoning with information more tractable, may not be directly applicable to the design of an educational CT, which functions to make learners exert a mental effort in reasoning with information. This type of distinction is of critical importance for the design of educational CTS. Other researchers have noted that, in an educational context, CTS must promote reflective thinking and “mindful engagement” [30]. Additionally, CTs should be viewed not as technologies to disseminate information to learners, but rather as tools for engaging learners in reflective, critical thinking about the information with which they are interacting [31]. Indeed, a lack of this distinction between educational and other types of CTS may lead researchers and educators to conclude that CTS do not promote effortful engagement with information in the same way that learning with previous technologies has done. For example, Karasavvidis [32], while discussing educational CTS, claims: “the possibilities for mindful engagement on the part of the students…are drastically reduced. In fact, learners have to be engaged less because the tool accomplishes more.” (p. 23). On the contrary, the careful design of the micro-level details of HII has been shown to be able to force learners to engage in deep and effortful processing of information. This point cannot be considered lightly—the micro-level aspects of HII design are of crucial importance in allowing a CT to fulfill its epistemological goals. For example, [21] conducted a study that investigated micro-level details of interaction on learning about 3D mathematical shapes. What they found was that different forms of operationalizing actions could engage learners in significantly different degrees of engagement with the underlying information. By changing the way in which a learner interacted with the information, the CT could force learners to engage more mindfully in the learning process. This study demonstrates the importance of characterizing the elements of HII and examining their effects on learning and other cognitive activities.

3.2 Recent contributions toward a characterization of HII

In order to construct a lucid characterization of HII to motivate the design of future educational CTS, the main components of HII must be clearly articulated in frameworks and taxonomies. Conducting research to develop frameworks and taxonomies is crucial to the advancement of any discipline, particularly the analysis and design of computational tools [33, 34]. Frameworks and taxonomies serve to help designers and educators think systematically about, and provide a common language for, a landscape of ideas. Researchers have recognized that the discussion of CTS is often vague [30], and that: “there is a clear need to define an integrated framework for the study and practice of cognitive tools [that] should be conceptually coherent to foster more successful design, application, and research” ([30], p. 213). Additionally, researchers studying HII have stated, “the interaction component of HII needs to be emphasized” ([28], p. 46), and have called for the development of “a science of interaction…[and] a deep understanding of the different forms of interaction and their respective benefits” ([35], p. 73).

Any characterization of HII first requires a clear definition of interaction. Here interaction is defined in terms of two components: action and reaction. That is, interaction involves a learner performing an action upon a representation, and the CT providing a response for the learner to interpret. As cognition is fundamentally distributed in nature, and as action can serve an epistemic function, it is through this action-reaction dialectic that learning occurs. Thus it is important to characterize the ways in which learners can act upon representations and what their epistemic utilities are. The authors are currently devising a taxonomy of epistemic actions, their characterization, utility, and examples for their use [36]. Each of these epistemic actions is conceptual rather than technique-based or technology-dependent, focusing on interaction with information rather than interaction with technology. For example, one of the identified epistemic actions has been called arranging, which refers to acting upon one or more representations to change their
order. The epistemic utility of arranging includes: allowing learners to explore and detect underlying patterns, dependencies, trends, correlations, and relationships in information; aiding with the simplification of a representational space; and triggering associations in the mind by presenting a fresh way of viewing the information [36]. To further exemplify, another identified action has been called filtering, which refers to acting upon a representation to show and/or hide a subset of its elements according to certain criteria. The epistemic utility of filtering includes: decreasing perceptual and cognitive load, allowing learners to focus on a subset of information; supporting selective encoding of information for problem solving; and facilitating the detection of trends and patterns [36]. Figure 1 shows an example of filtering information with a CT for learning about human anatomy, Visible Body (www.visiblebody.com). A learner is initially presented with a large amount of complex information (Fig. 1a). The learner may only be interested in a subset of the information, however, such as the structure of the nervous system. Thus the other information is not necessary, may be a distraction, and/or may result in unnecessary perceptual and cognitive demands. As CTs are inherently interactive, a learner can act upon the represented information to remove any unnecessary information. Figure 1b shows the result of a learner filtering the information according to a specific criterion (i.e., hide everything except the nervous system). These actions—from a conceptual standpoint—are the same whether performed through the mediation of a mouse, keyboard, touch-based tablet, or a gesture. For instance, a user may use a mouse to click a column of a table in order to sort it, a gesture on a touchpad to rearrange some images by alphabetical order, or a stylus on a tablet to select a number of icons and rank them. In each case, the user is performing the same epistemic action (i.e., arranging), although the implementation of the action is different. The action, as a conceptual unit, has a distinct and consistent epistemic utility regardless of the type of technology it is performed on. This is true of each action that has been identified in [36]. With this type of characterization of HII, designers and educators can use such taxonomies to think about actions and their utility in an abstract and consistent manner, without being burdened by the specifics of each technology or technique.

In addition to action possibilities, it is important to characterize a CT’s interactivity—that is, the quality, feel, or properties of an interaction [37]. Interactivity refers to the way an interaction is operationalized. Although an interaction may be consistent, different ways of operationalizing the action and the reaction have different cognitive effects. For instance, to keep with the example of arranging, this action can be operationalized either by acting directly upon a representation, such as by clicking and dragging with a mouse or a finger, or by acting indirectly, such as by clicking a button or entering a command by keyboard. In either case the interaction is the same—a learner arranges representations of information—but its feel and properties are different, and each may require differing amounts of cognitive effort and engagement with the information. Accordingly, it is necessary to consider not only actions and their epistemic effects in the design of educational CTs, but also the interactivity of a CT. The authors have devised a preliminary framework that identifies some elements of interactivity [38]. As interaction involves both action and reaction, some elements of interactivity apply to action and some to reaction. For instance, the example given above of different ways of operationalizing arranging, applies to the action component. The element of interactivity it deals with is focus, which refers to the locus of attention of a learner while acting upon a representation. Whether the learner acts directly or indirectly upon a representation has been shown to affect the quality of learning. By characterizing interaction and interactivity in the context of HII, educators and designers of CTs can think more systematically about

Fig. 1 An example of an epistemic action—filtering—being performed on a representation of information. The learner is initially presented with a large amount of complex information a), but can act upon the information to filter it b). This action can decrease perceptual and cognitive load to help learners reason and solve problems. Screenshot courtesy of www.visiblebody.com.
higher-level goals of learners and about how to assist them in achieving these goals with proper interaction design. These taxonomies, taken together, can contribute to a comprehensive framework that helps to organize the landscape of HII and to provide a common language that designers and educators can use to discuss HII in the context of educational CTs.

4. Summary and future research directions

This chapter has examined human-information interaction (HII) as an emerging focus for educational cognitive tools (CTs). Educational CTs are interactive, computer-based tools that augment one’s mind to facilitate learning. Examples include interactive mathematical software, interactive physics simulations, and interactive biology visualizations. Recent changes in models of human cognition have shed light on one’s interactions with the external environment as fundamental contributors to cognitive processes. That is, one’s cognition is not confined to the operations of the mind alone, but is distributed across the mind and the external environment. One of the consequences of this feature of cognition is that interactions with the external environment can be considered as part of thought itself. Performing actions upon objects in the world, such as CTs, creates a coupled cognitive system. Design of educational CTs based on a lucid and comprehensive characterization of HII can help to strengthen this coupling, resulting in sound design practices that lead to effective learning situations.

As CTs are inherently interactive, they allow learners to interact with information to perform cognitive activities such as reasoning and problem solving. Many of the ways in which learners interact with information—and the epistemic benefit of the interactions—are consistent across all types of CTs. Therefore these interactions are not dependent upon the technology; rather, the function of the technology is to mediate interaction with information.

As interaction involves a dialectic of both action and reaction, a learner can engage in a discourse with information, by acting upon representations and getting a response to interpret. As these actions are part of a learner’s thought processes, the features of interaction and their effects on learning require careful consideration. This chapter has mentioned two taxonomies that are being developed to contribute to a comprehensive framework of HII, one dealing with interaction and the other dealing with interactivity. The creation of frameworks and taxonomies can help to stimulate research in HII and can motivate the creation of educational technologies that are based on an understanding of how the mind uses and interacts with information to perform cognitive activities. In addition, a comprehensive framework can empower designers and educators to create and assess the utility of educational technologies in a systematic manner. As HII is technology-independent, the features of such frameworks can be applied to emerging and future technologies such as interactive table-top computers, tablets, and virtual-reality environments. HII is a young research area; as such, it requires further systematic development. As the area is given more attention, new components may be added to existing taxonomies and frameworks, and altogether new taxonomies and frameworks may be created. These will stimulate the development of new tools and techniques and can act as catalysts for empirical studies, which will further elucidate and refine the landscape of ideas surrounding HII and educational CTs.

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