Adaptive Instructional Systems: The Evolution of Hybrid Cognitive Tools and Tutoring Systems

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Abstract. This paper begins with a discussion on framing technology as tools that facilitate a distributed cognition for problem solving and supporting discriminating minds. Specifically, Dewey's advocacy of using technology as a learning tool to support the development of discriminating minds will serve as a framework for understanding the purpose and aim of this next generation of Adaptive Instructional Systems (AISs). This paper reviews the evolution of computer assisted instruction, distinguishing between the iterations of early computer cognitive tools to more effective intelligent tutoring systems, followed by next generation hybrid systems, or AISs, that are a unique blend of cognitive tools and intelligent tutoring. These AISs are the result of improved technological affordances combined with research in education to achieve meaningful learning and discriminate intelligence, an objective aligned with Dewey's framework for using technology as a learning tool.

Keywords: Adaptive instructional systems · John Dewey · ITS · Learning · Computer assisted instruction

1 Introduction

Arguably, a good working definition of technology can be articulated as follows: the practical application of knowledge especially in a particular area or a manner of accomplishing a task especially using technical processes, methods, or knowledge [1]. Gee [2] has framed technology as those tools – including digital tools – that facilitate a distributed cognition for problem solving. Humans are, Gee notes, tool users; and believes it is misleading to even discuss intelligence as an unaided entity. Gee argues that part of what constitutes human stupidity is being left alone without tools or collaboration with other people [2].

Within this context, this paper looks back to Dewey's advocacy of using technology as a learning tool as a framework to define adaptive instructional systems (AISs) for the purpose of supporting the development of discriminating minds. A distinction will be made between early iterations of computers as cognitive tools and how

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the confluence of educational research and current technological affordances allow for more effective, constructivist-oriented hybrids of computer assisted instruction (CAI) that are widely being recognized as AISs. Further, this paper will briefly discuss the history of how CAIs moved from less effective instructional systems to more effective intelligent tutoring systems (ITSs), and to the current state of AISs. Finally, we will close on how examples of these hybrid AISs realize Dewey's belief on the purpose of using technology as a learning tool.

2 Dewey, Technology, and Meaningful Learning

2.1 Dewey and Technology

Although written almost a century ago, Dewey's essay creative intelligence [3] examines the benefit of an educated public and laments the state of public education in existence coupled with the significance of new technologies. Dewey reminds us that at one time in the history of America, education was necessary and appropriate to address a new world burgeoning with new technology, namely the railway, telegraph, telephone, and cheap printing press. However, education in America needed to change as it was transitioning from a landscape of farms and small towns to a world of industry and advanced transportation and communication. Industrialized America, outfitted with ever evolving new technology, necessitated that schools develop their students' expertise in content and skills to navigate technology responsibly.

Dewey's idea of "responsible technology" critiqued the technological culture of the 1920's. In his critique, Dewey defines his view of a balanced technology, which included equipping citizens to develop the skills of consideration and criticism. Essentially, Dewey believes the aim of education is to develop the intelligent learner who can identify and adjust to problems of understanding, and to reconstruct and reorganize their former ways of thinking, or what he termed as intellectual habits [4]. Ultimately, the purpose of learning should support thinking as intellectual discernment [4]—the ability to find solutions to problems through intelligent conduct—or what we term, discriminate intelligence. Dewey wanted students to develop this "discrimination intelligence" to protect them and future generations from what he termed, "bunk," especially "social and political bunk" [5].

Furthermore, Dewey pointed out that one of the reasons that schools were failing to educate our students rested on the misguided belief that by educating students to have an undiscriminating mental habit void of the habit of criticism, schools would produce a "loyal, patriot, a well-equipped good citizen" [5]. But an undiscriminating mind can never fully participate in a democracy. At its core, democracy is hallmarked by negotiation and compromise amongst citizens who are not only knowledgeable about content but can navigate that content within the context of the dialect of personal and social values. As such, a mind incapable of discrimination – reflection and analysis – cannot participate in acts of *parrhesia*: speech activity where one articulates one's beliefs truthfully and courageously to effect change.

Dewey suggests the solution to this problem of producing undiscriminating minds is to be found in a greater confidence in intelligence, inquiry, the use of the scientific method, and the engagement with responsible technology. According to Hickman [6], Dewey's critiques of technology can be found throughout his half century, 13,000 published pages of work. Although Dewey's writing may not systemically reflect this examination, his critique is consistent. Importantly, Dewey sees engagement with technology as a method to support discriminate intelligence and promote autonomy of the individual. Technology, Dewey believed, would include educating individuals to select the materials and the technique of trades for the sake of securing industrial intelligence so that the individual may be able to make his own choices and be master of his own economic fate [3].

This analysis of Dewey is relevant to the discussion of CAIs and the next generation of AISs because it provides a framework to define and design effective learning systems that are becoming ubiquitous in training and learning environments. For educators, it is important to recognize not only how to integrate innovation into training and learning, but we should also consider how we can achieve meaningful learning with technology that supports discriminate intelligence.

2.2 Meaningful Learning with Technology: Standards and 21st Century Skills

Howland, Jonassen and Marra [7] outline a number of learning objectives that should be considered when pursuing meaningful learning with technology. These objectives speak to anchoring learning and instructional activities through tools that are engaging and supportive of authentic, active, constructive, intentional, and cooperative learning. These objectives are also mirrored in a 2017 report by the Institute for the Future [8] that analyzed the requisite proficiencies and abilities that will be required across different job and work settings in the next era of human/machine partnerships. These human proficiencies and abilities include: vision, perseverance, and creative problem-solving [8].

Within these frameworks of proficiencies and abilities necessary for the future workforce, the overarching aims of learning should include integrating technology-based tools that prepare individuals for future work. These tools should also contribute to critical thinking and social skills that are the hallmarks of discriminate intelligence, enabling individuals to meaningfully participate as engaged and reflective Democratic citizens. Thus, educators need to address the inclusion of technologies that can support both the short-term goal for knowledge mastery in a specific domain as well as develop proficiencies and skills necessary to support creative reasoning and problem solving. Achieving this lies in thoughtful application of innovative technologies that support authentic engagement in an educational experience. In examining the history of CAIs, there has been a steady progression towards achieving this end, with the current iteration being systems that not only support tools that allow for inquiry and constructivist learning, but have additional capabilities of tailoring instruction based on the needs and traits of its learners. These hybrid systems that combine the early generation of computer cognitive tools with the next generation of AISs.

3 Evolution of Computer Cognitive Tools to Adaptive Instructional Systems

3.1 Computers as Cognitive Tools

In the early '90's, educational psychologists Jonassen and Reeves [9] and Lajoie [10] advocated for using computers as cognitive tools. Jonassen and Reeves's [9] defined cognitive tools as: "technologies, tangible or intangible, that enhance the cognitive powers of human beings during thinking, problem solving, and learning." Lajoie [10] identified four types of cognitive tools[1], which included tools that would not only enhance cognitive powers but would be platforms for constructivist learning, e.g., through simulations and generating solutions to gaps in knowledge and understanding.

Historically, most of the positive learning effects from early CAIs included memorization, understanding, and application of facts, concepts, and procedures as reported by Vinsonhaler and Bass [11] and later confirmed by Kulik [12] whose meta-analysis reviewed 97 studies of basic computer-based instruction effectiveness, finding an average effect size of 0.32. Upon closer examination, Kulik [12] noted great variation in the differences in learning between CAIs and classroom instruction: some differences exceeded 1.00 standard deviations, whereas others reported zero standard deviation of difference. More complex systems, known then as instructional tutoring systems, showed greater overall improvement in learning outcomes.

Further, Dodds and Fletcher [13] noted comparative effect sizes for learning via computer-based training at 0.39, whereas multimedia platforms had an effect size of 0.50, and for ITS, 1.08. From this, we can infer that the effectiveness of ITSs was not only due to the capabilities of the advancing technologies, but arguably increased success could be attributed to the informed design of systems based on evidence driven methods that promote deeper, more constructive learning activities.

3.2 Intelligent Tutoring Systems

ITSs have been defined as computer-based systems that seek to capture the capabilities and practices of a human tutor who is both a subject matter expert and intelligently respond to the learner and their actions [14]. In a review by Van Lehn [15], step-based ITSs produced an average of 0.76 standard deviations in improved learning outcomes. Kulik and Fletcher [16] found similar results of improvement in their examination of 39 ITSs. While Kulik and Fletcher [16] also showed great variation in results – from marginally negative to greater than 2.00 standard deviations – they suggested that the poor performance of some ITSs was due to insufficient teacher support when students used ITSs, and in other cases misalignment of assessments against objectives assessed in an ITS. However, what is most interesting about the findings of Kulik and Fletcher [16] includes a report on repeated evaluations of an ITS that focused on learning

[1] (1) support cognitive processes such as memory and metacognitive processes; (2) offset cognitive load for lower level cognitive skills to free up resources for higher order thinking skills; (3) platforms for learners to engage in cognitive activities that would otherwise be out of their reach, such as simulations; (4) allow learners to engage in problem solving by generating and testing hypotheses.

outcomes of basic facts and simple procedures vs. more deep and conceptual learning. Their findings included evidence that ITSs were better suited to supporting and promoting deep, conceptual learning rather than basic, procedural learning. This is not a surprising outcome, for the salient element of an ITS is that content and assessments can be authored to automate steps in the system that adapt to the states (performance or emotional states) of a learner.

However, the actual proliferation of these systems is not as ubiquitous in schools as they are in industry and military training. ITSs are increasingly being utilized in skills training and decision making in industry (e.g., air pilot training) and in the military (e.g., land navigation, medical care). Further, ITSs have been built primarily to support training and education for individuals. However, there are efforts underway to build ITSs to support collective training for teams, crews, and units that are essential in meeting the needs of organized military missions to address collaborative problem solving [17, 18].

Examples of four widely used adaptive ITS for individual learners include AutoTutor (developed by the University of Memphis), the Authoring Software Platform for Intelligent Resources in Education (ASPIRE; developed by the University of Canterbury in New Zealand), Cognitive Tutor Authoring Tools (CTAT; developed by Carnegie Mellon University), and The Generalized Intelligent Framework for Tutoring (GIFT; developed by the CCDC Soldier Center - STTC) [19]. GIFT, however, is unique amongst this representative sample of adaptive ITSs as it essentially a framework that allows ITS authors to create tutors in any domain, and its functionality is being expanded to help train and teach teams, not just individuals.

While early ITSs were envisioned less as a cognitive tool and more of a tutor, more recent ITSs have evolved considerably since that time, both in terms of functionality but more importantly as to purpose. Functionality and purpose have merged into highlighting authoring functions that feature adaption in communication, teaching content, domain/student knowledge, and knowledge representation to improve and support deep learning [19].

3.3 Adaptive Instructional Systems

While the efficacy of early, basic CAIs was admittedly modest, they were but the first in what is now a more robust domain of adaptive instructional systems (AISs). Lajoie and Derry [10] suggested that computers should be viewed more as a mind-extension or cognitive tool rather than function as a teacher/expert. Additionally, the field of CAIs have expanded in its efficacy of producing greater learning outcomes from tutoring system. This expansion includes advancements in technological affordances available to deliver tutoring capabilities that are responsive to the individual. For example, systems have been devised to be adaptive in delivering feedback depending upon individual sensor-based and sensor-feedback [20]. Natural language processing capabilities can now facilitate and support human/computer dialogue to provide additional adaptive capabilities to tailor instruction based on learner responses.

AISs reflect a current paradigm shift within the field of ITSs. This shift is seen substantively in a newly organized IEEE working group P2247.1 that seeks to define and standardize the nature, purpose, and specs of AISs. At present, this working group has established that AISs will include traditional ITSs, but there is a recognition that it must also include other kinds of operating systems such as human virtual agents, which are a more faithful rendering of using the computer as an agent for constructivist learning. However, to date there is no agreed upon definition that distinguishes AISs from ITSs or any other kind of technology-based learning platform. However, it is expected that this working group will delineate between mere cognitive tools and this new generation of hybrid systems that are part cognitive tool and part tutor.

One such proposed definition includes identifying AISs as systems that are not limited to mere extensions or enhancements of cognition, but rather support discriminate intelligence as hallmarked by expert reasoning and decision making – the aim of educational efforts, according to Dewey [4]. If defined in this way, AISs would be readily recognized as the next evolutionary step starting from computer assisted instruction to ITSs to this new hybrid mindtool/tutor. Ideally, operationalizing AISs would include delineating this generation of technology mediated learning platforms as ones that support educational experiences to promote intelligent learning and discriminate intelligence.

3.4 Efficacy of AISs

The efficacy in improved learning outcomes and supporting discriminate intelligence mediated by AISs resides both in the ability for the system to adapt to the learner based on levels of content complexity and the effect of feedback. These systems also can provide a variety of educational experiences to facilitate authentic and simulated constructivist learning environments. This can be seen in systems such as GIFT [21] that can integrate game-based learning tools such Virtual Battle Space [22] and VMedic [23]. Also, there is use for a virtual tutor by way of tutorial dialogue systems that interact with humans though conversations and adaptively respond to a person's actions, emotions, and verbal contributions, as seen in AutoTutor [24]. Additionally, virtual human assistants such as ELLIE 1.0 [25] can be used to assess mental health. ELLIE 1.0 is a virtual human agent that can "see" an individual's gestures, facial movements, and postures, respond to these changes, as well as engage in natural dialogue to engage a participant in a therapist-type dialogue. Currently, there are efforts underway to create a new and improved ELLIE 2.0, that can not only assist in training effort for the military but can also support ethical decision making of individuals. As noted by Chi and Menekse [26] dialogic learning, which is essentially learning through discussion, is superior to passive, active, or even collaborative learning methods. In this way, ELLIE 2.0 will not only function as an ITS, but it can support constructivist learning to support discriminate intelligence.

This integration of a variety of cognitive tools into tutoring systems are essentially what is being considered as new hybrid systems that serve both as a tutor and as a platform for constructivist educational experiences. Their efficacy lies in the interdisciplinary development of these systems, where teams of computer scientists work with educational psychologists to build and test the efficacy of new AIS designs. In this way, systems are being designed to reflect best practices regarding effective pedagogy to support more than basic, procedural skills training and memorization. Instead, systems are being developed to facilitate educational experiences that employ tools and learning objects that allow for more constructivist approaches to learning, to support discriminate intelligence across a range of disciplinary domains.

What is important to note about AISs is that there is evidence that has shown equivalent learning effects as compared to expert human tutors, though these experiences to date have been limited to well-defined cognitive domains, such as computer programming, physics, and mathematics [14]. Yet, there is an emerging belief that these AISs could increase their validity as exclusive viable training options if the fundamental challenges to achieving increased and accelerated learning outcomes were identified and solutions were discovered. Within this context falls some more current research that is focused on accurately modeling the learner and the educational experiences [27].

4 GIFT: The Generalized Intelligent Framework for Tutoring

In addition to devising AISs that can support increased learning in science and math, there is also work emerging to devise pedagogical templates that address creative and ethical thinking. GIFT is emerging as a leader of these kinds of platforms [21]. Specifically, GIFT can make instructional decisions to adapt content and sequencing of content to support expert problem solving, as well as make adaptive selection based on learner traits, needs, and preferences. Further, it can host a range of constructivist learning objects to support meaningful learning in educational experiences, e.g., game-based learning, virtual tutors, and virtual human agents.

As a content delivery platform, learning object materials can be presented to the learner for opportunities to experiment with content and construct their own knowledge through simulated yet authentic learning scenarios. GIFT's adaptive functionality also allows participants to come back to their learning courses populated with prior engagement data to feed forward the adaptive elements. In this way, GIFT functions as a cognitive tool. As a cognitive tool, GIFT serves as an extension and repository of prior experiences of the learner that not only feeds forward the content and sequencing of material but can also remind the learner about their prior work, adapting assessments and simulations based on prior demonstrated competency. The challenge in this is devising and validating individual student models, devising trait and behavioral markers by which to structure an adaptive model. This learner modeling is recognized as a persistent, difficult task. The solution to this lies in part in merging innovative technologies with new pedagogical theories based on the science of learning and conducting empirical investigations to validate the models [28]. One current research effort to address this challenge is an investigation into understanding the effect of the relationship between learner traits and the sequencing of increasing complex content as it contributes to accelerated learning mediated by GIFT.

4.1 Devising a Learner Model for Accelerated Learning Mediated by GIFT

An inter-institutional study is currently underway between Columbia University and the CCDC Soldier Center - STTC using GIFT as an experimental test bed and delivery platform to investigate traits and cognitive abilities that will be used to devise a pedagogical template to support expert decision making for medical personnel training in critical care education. After correlational analyses and experimentation, it is the intention of the investigators to come to a better understanding of the salient traits that are relevant to abstract/creative reasoning in expert decision making, using GIFT can to deliver materials and monitor outcomes to support accelerated critical care learning.

Two pilot studies were recently conducted at the United States Military Academy to examine the initial effects of priming of analogical and spatial reasoning in verbal and mathematical learning outcomes. This initial look at the priming of these tasks is part of a larger effort to determine whether there would be an effect on learning if participants were primed with these tasks delivered through GIFT prior to engagement with medical content. This is an important effect to study as it speaks directly to the pedagogical template that can be authored within GIFT or any other AIS in the efforts to effectively employ these systems as hybrid cognitive tools and tutors.

In the first pilot test, mental rotation problems were used to prime participants to solve mathematical reasoning problems. When participants were primed with mental rotation tasks, there was a trend that these participants outperformed those who did not receive the mental rotation task on a mathematical reasoning test. In a second informal pilot test, mental rotation problems were also used to prime participants to solve problems, this time solving for verbal analogies. The results indicated that those who solved mental rotation tasks prior to solving for verbal analogies had an overall increased success rate than those who had not been primed with the mental rotation tasks. While no conclusive, statistically significant claims can be made from this informal examination, there is enough anecdotal evidence to support a broader, more comprehensive experimental study examining the effect of spatial reasoning tasks on learning outcomes mediated by an AIS.

Accordingly, the authors of this paper are in the process of launching two experimental studies that will provide data on how the sequencing of content in a pedagogical design within GIFT can provide further evidence on the efficacy of this AIS as an effective hybrid cognitive tool and tutor. As a framework, GIFT's robust efficacy ultimately lies in its structural flexibility to author courses that sequence learning objects that are not merely static but dynamic, meaningful, and authentic.

5 Conclusion

This paper has advocated for a re-examination of Dewey's call to support intelligent learning where technology-based learning platforms are designed as constructivist, educational experiences to support the skills necessary to develop discriminate intelligence – a trait necessary as the driving force that sustains a Democratic society. This call becomes increasingly possible to realize given the progress on technological affordances available for integration in CAI educational experiences driven by informed research by educational psychologists.

Essentially, AISs are uniquely positioned to function both as a computer cognitive tool and a tutor, providing opportunities for meaningful engagement in authentic experiences to represent and construct knowledge as well as assist in complex decision making. In this way, AISs are already moving far beyond mere cognitive tools or the limited experiences afforded by even a human tutor. Rather, AISs are creating novel, engaging, liminal spaces where learners can more fully engage in a constructivist approach to learning, allowing for distributed cognition for problem solving to support discriminate intelligence.

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